Petrophysical and Seismic Signature of a Heavy Oil Sand Reservoir: Manitou Lake, Saskatchewan

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Summary

We analyse a suite of well logs from the Manitou Lake heavy oil field in Saskatchewan. In particular, elastic measurements from logs were used to study the effect of lithology and saturating fluid on density and P- and S-wave velocities in the sand reservoirs. The density and Vp values do not change significantly from shale to sand, but the shear-wave velocity increases significantly from 800 to 1300 m/s. Changes in density appear to be related to fluid content and porosity. A Vp/Vs value lower than 2.15 indicate sand reservoirs. PP and PS synthetics show variations in the seismic response at the top of the reservoir, with bright spots expected on the PS section where sand is present.

Introduction

The bulk density of a rock is a function of mineral composition, porosity, water saturation and hydrocarbon fluid type. In the case of oil sands or heavy oil developments, accurate estimates of density are necessary to determine the location of shales in the reservoirs, which may interfere with the steaming or recovery process (Gray et al., 2006). The Vp/Vs value has also been successfully used to differentiate lithologies and could be used to identify reservoir changes (Lines et al., 2005, Watson et al., 2002).

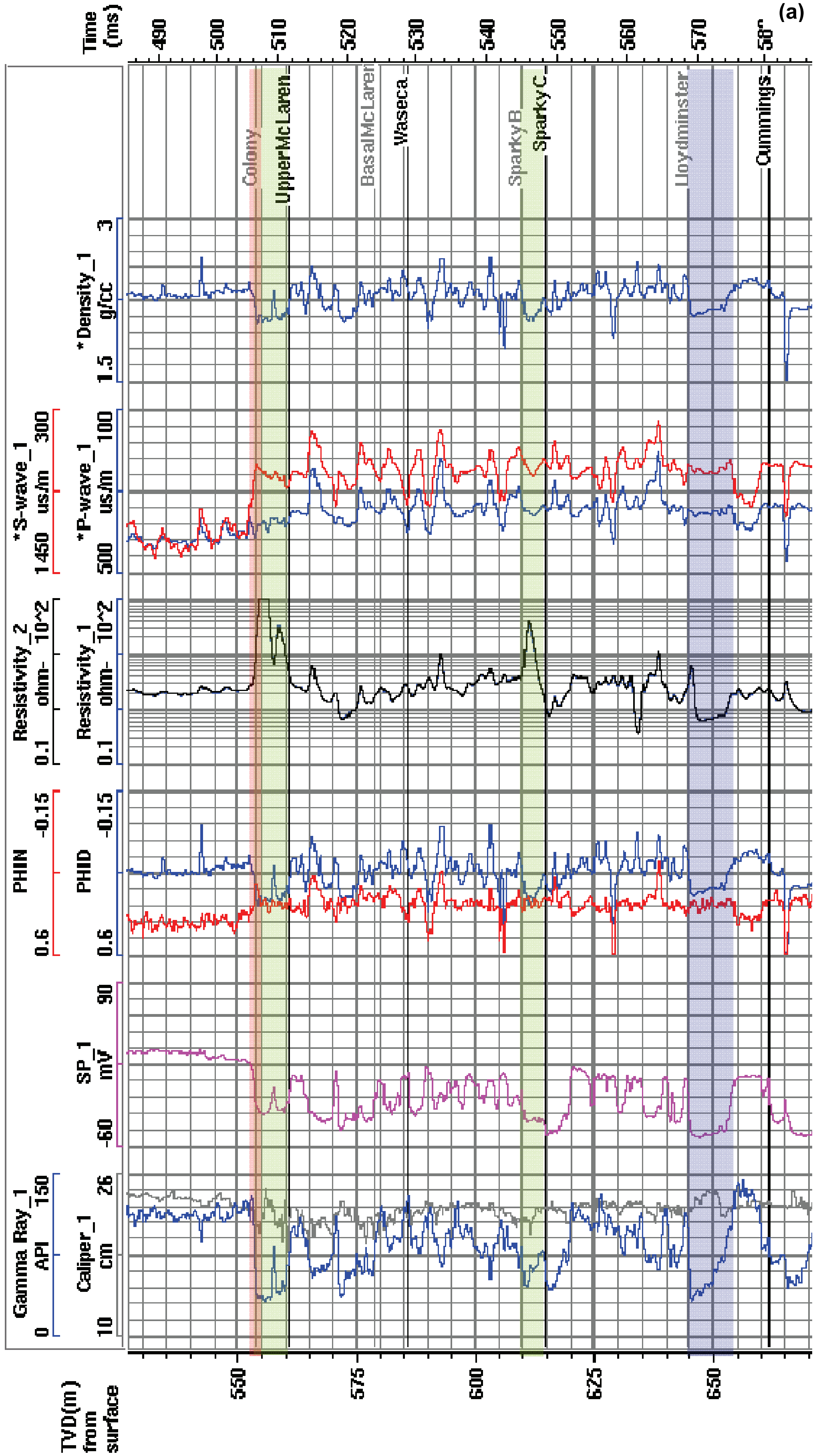
In this study, two wells (A11-17 and C07-16) from Manitou Lake, Saskatchewan were used to evaluate the relations between different rock properties and the elastic parameters derived from the well logs. The logs used included gamma ray (GR), spontaneous potential (SP), density, neutron and density porosity, caliper, and resistivity, among others. P-wave and S-wave sonic logs were available for well A11-17.

The exploration targets in the area include the Colony and Sparky members of the Mannville Group. The Colony sand member consists of shales, siltstones, coals and sandstones. Deposition of this member occurred in an extensive complex of anastomosing channels sandstones, encased within siltstones, shales, coals and thin sheet sandstones (Putnam and Oliver, 1980). It is overlain by the marine shales of the Colorado and Belly River Groups. The Sparky member is informally grouped into the middle Mannville, which is dominated by sheet sandstone development, with narrow, channel sandstones and shales also present (Putnam, 1982). These units have been interpreted as a delta-front facies with associated tidal-flat, tidal-channel, and beach environments (Vigrass, 1977).

Rock Properties

Figure 1 shows the logs from wells A11-17 and C07-16. Note the sharp increase in the GR, SP at the top of the Colony sands, which is expected as we pass from the shales of the Colorado Group to the sands of the Mannville Group. At this interface the density log decreases, the P-wave shows almost no change and the S-wave velocity shows a very significant increase from 800 m/s in the shales to 1300 m/s in the sands. High resistivity values in the Colony and Sparky members indicate hydrocarbons, while the cross-over between the density and neutron porosity logs in the Colony sands suggests gas. Several coal beds can be interpreted in the area, based on the lower density values, between 1.6 and 1.7 g/cm^3.

Figure 2 shows crossplots between different elastic properties, with the GR value expressed on the color bar. Note that two clusters separate on the P-wave vs. density crossplot, showing overlap on the density values for shales and sands. The mudrock line that relates P- and S-wave velocities fits very closely to the least-squares fit from the data. Note that the Vp/Vs value appears to give the best differentiation with regard to lithology, with Vp/Vs values lower than 2.15 corresponding to sands, and higher values to shales. The sand reservoirs map within a very narrow range of shear wave velocity, between 1300 and 1500 m/s; however, it is not useful in differentiating water and hydrocarbon bearing sands.


(a)
Time (ms)
TVD(m) from surface
Gamma Ray_1 API 0 150
Caliper_1 cm 10 26
SP_1 mV -60 90
PHIN 0.6 -0.15
PHID 0.6 -0.15
Resistivity_2 ohm- 0.1 10^2
Resistivity_1 ohm- 0.1 10^2
*S-wave_1 us/m 1450 300
*P-wave_1 us/m 500 100
*Density_1 g/cc 1.5 3
Colony
UpperMcLaren
BasalMcLaren
Waseca
Sparky B
Sparky C
Lloydminster
Cummings

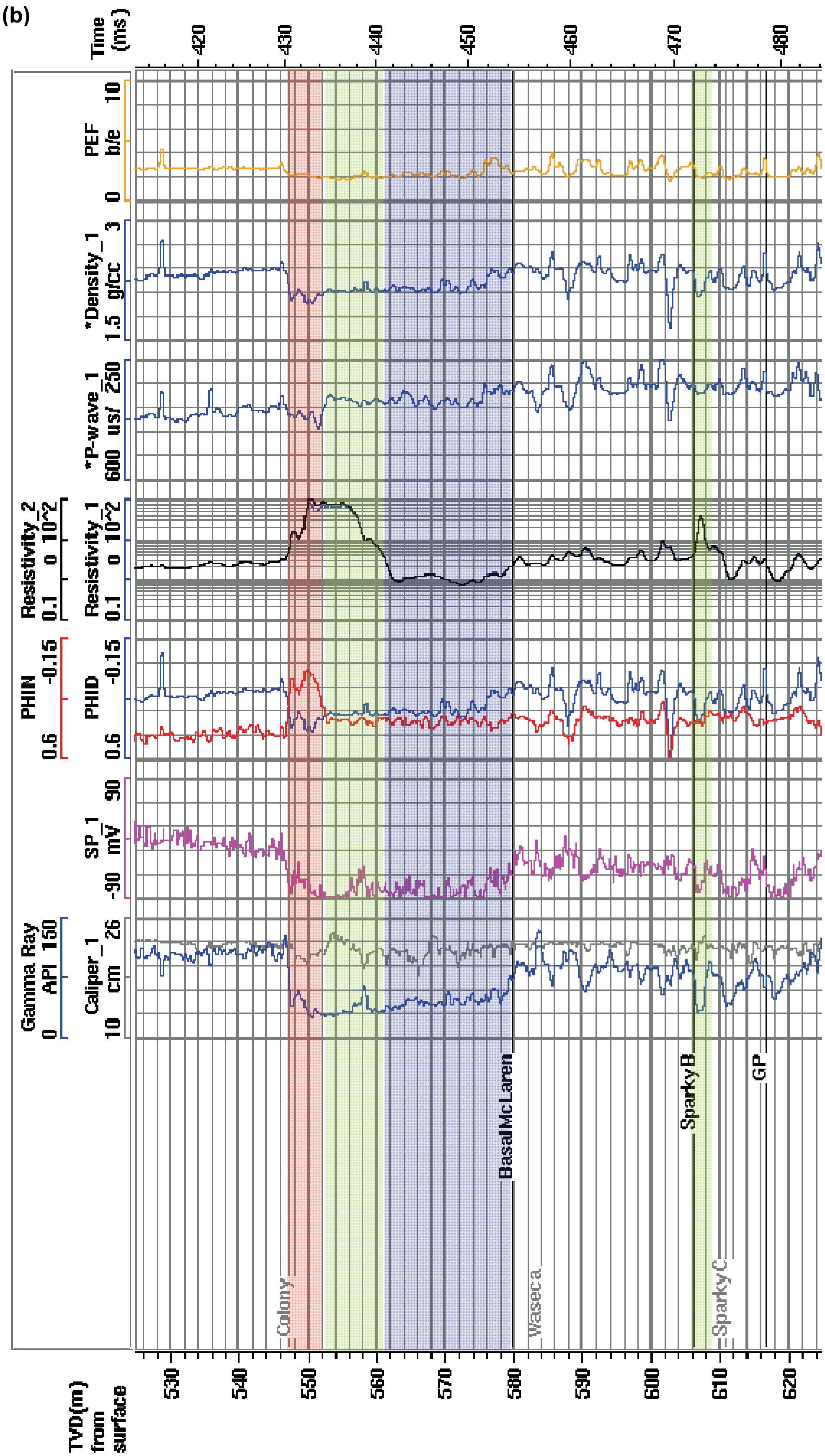


Figure 1: Suite of logs for well (a) A11-17 and (b)C07-16. Gas is indicated by red highlight, oil by green, and water by blue.

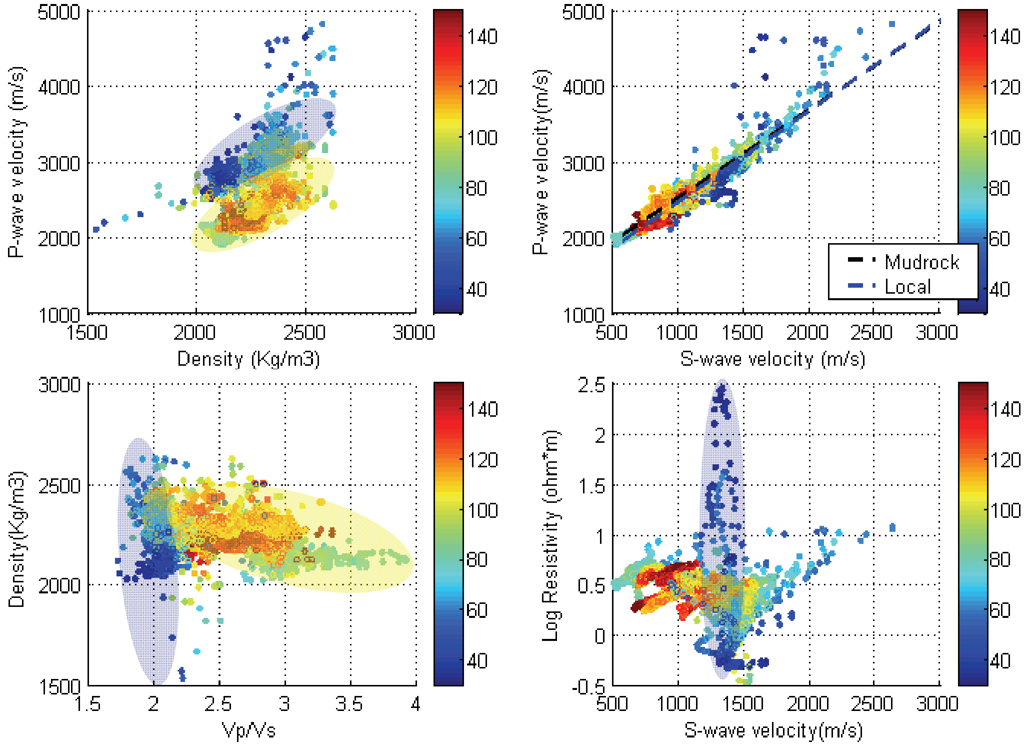


Figure 2: Crossplots (a) P-wave velocity vs. density; (b) S-wave velocity vs. P-wave velocity; (c) Density vs. Vp/Vs, and (d) P-Impedance vs. P-wave velocity for well A11-17. Yellow ellipses indicate high GR values, while blue ellipses represent low GR values. Colorbar indicates GR values

Figure 3 shows the variation in density, P-wave and S-wave velocity with respect to the saturating fluid. The gravity of oil in this area is around 12 °API, which corresponds to a density of 0.9861 g/cm^3. For this reason, the presence of oil or water in the formation is not going to change the density log significantly. The values for P-wave velocity also overlap for water and oil-saturated rocks. However, gas results in a lower density and decreased P-wave velocity, as expected. Well A11-17 shows less differentiation with respect to density, but the gas cap in this well is very thin. However, it is interesting to note that shear-wave velocity increases for water and gas, while it shows lower values where oil is present.

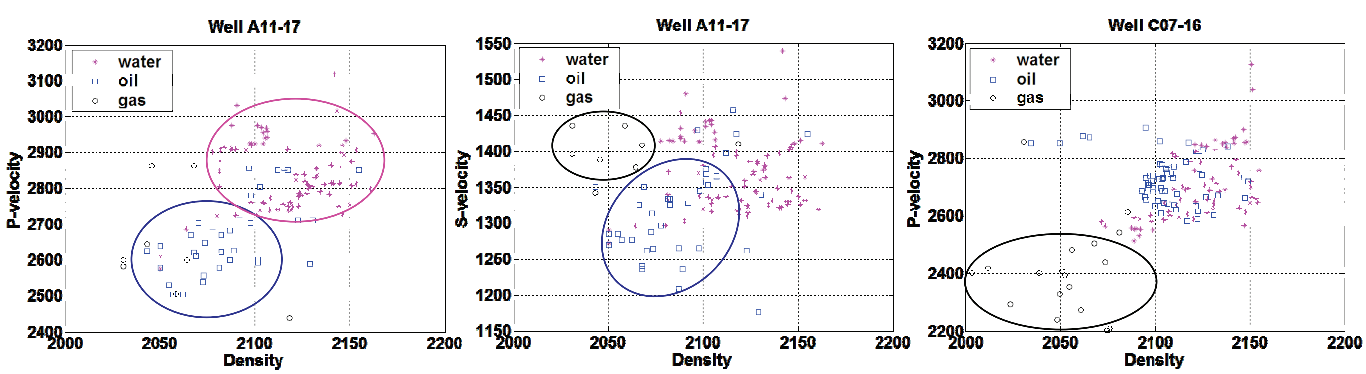


Figure 3: Density, P-wave and S-wave velocity variations with saturating fluid for clean sands with porosities higher than 30 %. Black circles correspond to gas, blue squares to oil and magenta stars to water.

Synthetic Seismograms

PP and PS synthetic seismograms were generated for well A11-17 (Figure 4). The PP synthetic was generated using a Ricker wavelet with a dominant frequency of 60 Hz, while the PS synthetic used a 40 Hz Ricker wavelet, to account for the lower bandwidth of PS data. The PP signature at the top of the Colony corresponds to a zero-crossing, while on the PS section it corresponds to a peak. The Sparky B shows the same signature, with the top being a trough on the PP section and a peak on the PS section. This change in character can significantly affect the registration process during interpretation. Given the significant change on the S-wave velocity seen at the top of the Colony, we can expect to find bright spots in the PS section associated with sand intervals.

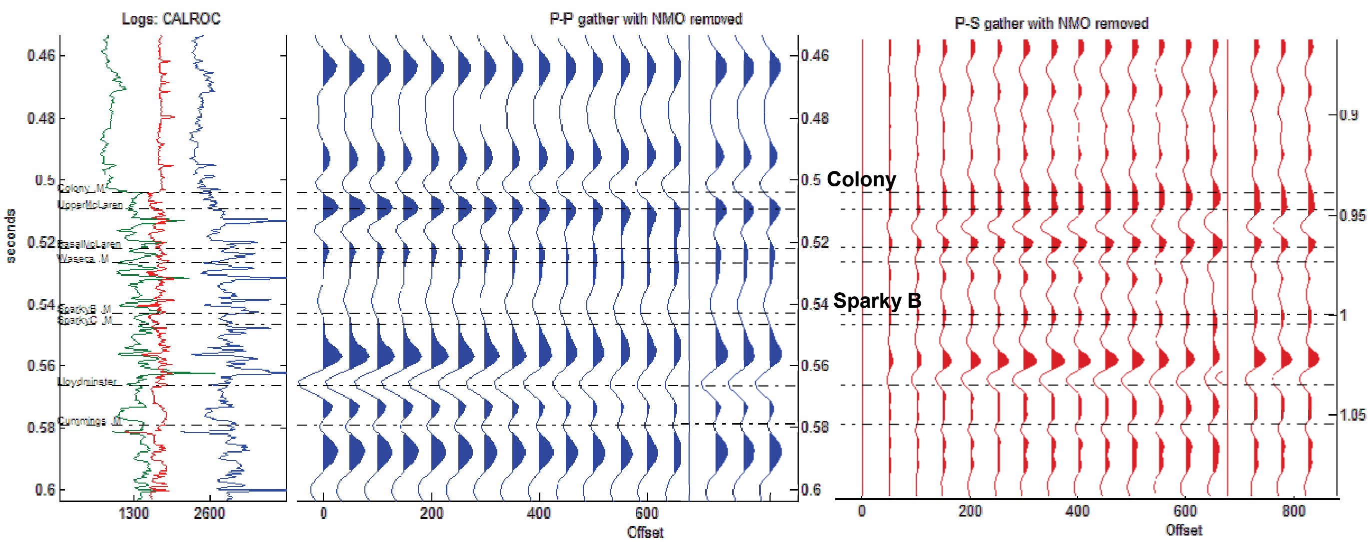


Figure 4: PP and PS synthetic seismograms for well A11-17. Final three traces correspond to the stacked traces.

Conclusions

Shear-wave velocity is a very good lithological indicator in the area, showing a change of 500 m/s at the sand/shale interface, which results in significant changes in the PS section. Variations in density are more complex, with no direct relation to lithology, but showing some effect from the fluid content. Further work using fluid substitution will give more insight to the effect of fluids in the area.

Acknowledgements

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References

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