Predicting oil sands viscosity from well logs, NMR logs, and calculated seismic properties

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Summary

Viscosity is a critical parameter in determining how to optimally produce a heavy oil or oil sands reservoir. While oil viscosities can be measured in the lab from well samples, it would be very useful to have a method to reliably estimate oil sands viscosity from well logs. Donor Company has generously provided laboratory viscosity measurements from one of their major oil sands projects, with multiple measurements per well.

Multi-attribute analysis enables a target attribute (viscosity) to be predicted using other known attributes (the well logs). The top well logs for predicting viscosity in this study were: *resistivity, gamma ray, NMR Total - NMR Free Porosity separation, SP, P-wave sonic, and S-wave sonic.* They successfully predicted viscosity with an average validation error of 69,000cP (or 0.69 of one standard deviation). The top seismic properties for predicting viscosity were: *P-wave velocity* and *P-Impedance*. They predicted viscosity with an average validation error of 94,000cP (or 0.94 of one standard deviation). The well logs detected more viscosity variations than the calculated seismic properties did.

Introduction

The fluid property with the greatest impact on oil sands recovery is viscosity (Batzle et al 2006). The more viscous the oil, more steam needs to be injected into the reservoir to reduce the viscosity to allow it to flow. The most viscous hydrocarbon, bitumen, is a solid at reservoir conditions and softens readily when heated. Viscosity of bitumen can range from 10,000 cP [10 Pa*s] to more than 1,000,000 cP [1,000 Pa*s] (Alboudwarej et al 2006). As the bitumen is heated, the viscosity is reduced from something resembling asphalt to something resembling coffee cream.

Donor Company has generously provided viscosity measurements for one of their major oil sands projects, with three measurements per well. Figure 1 shows the distribution of the base reservoir

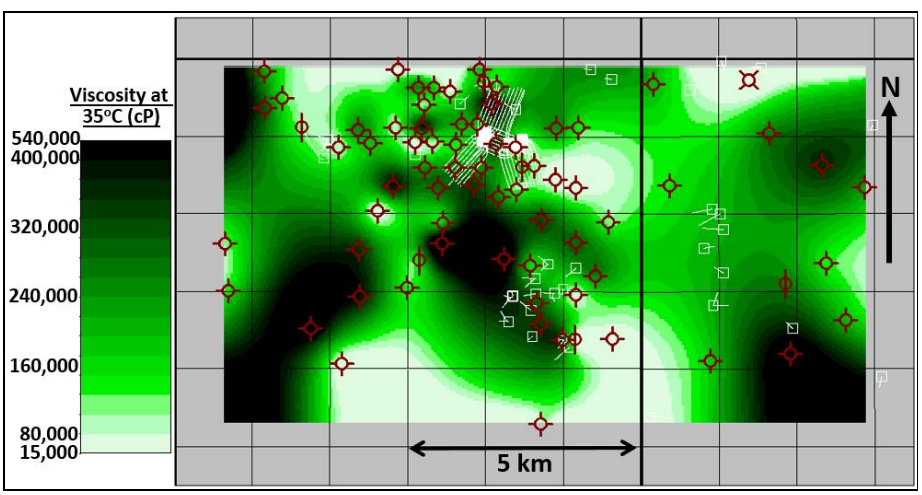

Figure 1: Distribution of the base reservoir viscosity measurements. All the data wells are shown in red. There are significant lateral viscosity variations throughout this reservoir.

viscosity measurements, with significant lateral variations evident from the data. The goal of this study is to establish a correlation between the measured viscosity values, and *all* of the available well log curves (including calculated seismic properties) to allow us to predict viscosity in wells that do not have lab viscosity measurements.

Theory of Multi-Attribute Analysis

Figure 2 illustrates the basic multi-attribute problem, showing the target log and, in this case, three attribute logs to be used to predict the target attribute (Hampson-Russell 2013).

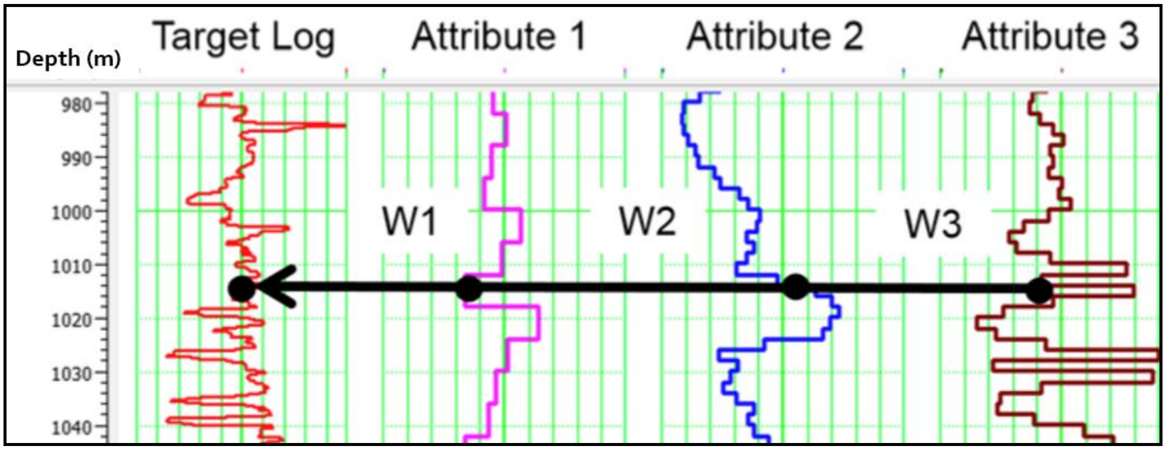

Figure 2: The basic multi-attribute regression problem showing the target log and, in this case, three attribute logs used to predict the target attribute (Hampson-Russell 2013).

To illustrate the concept, suppose that viscosity is being predicted using only bulk density, gamma-ray, and resistivity logs. The fundamental equation of linear prediction can be written as:

$$V(z) = w_0 + w_1 D(z) + w_2 G(z) + w_3 R(z) \tag{1}$$

where $V(z)$ is viscosity in centipoise (cP), $D(z)$ is bulk density in kg/m^3, $G(z)$ is gamma-ray in API units, and $R(z)$ is resistivity in ohm*m. This can be written in matrix form where each row represents a single depth sample:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} 1 & D_1 & G_1 & R_1 \\ 1 & D_2 & G_2 & R_2 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & D_N & G_N & R_N \end{bmatrix} \begin{bmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \end{bmatrix} \tag{2}$$

or more compactly as: $\boldsymbol{V} = A\boldsymbol{W}$. The regression coefficients, *w,* can be solved for using least-squares:

$$\boldsymbol{W} = [A^T A]^{-1} A^T \boldsymbol{V} \tag{3}$$

By using the statistical techniques of Step-Wise Regression and Cross-Validation, the best predicting attributes can be determined, as well as the optimal amount of attributes to use (Russell 2004).

Data and Prediction Results

In the oil sands study area, there are 78 total wells with viscosity measurements, but only 40 of those wells have *all* of the well log attributes available. The viscosities (measured at 35°C) range from 9,000 cP to 541,000 cP, with an average value of 121,000 cP and standard deviation of 100,000 cP.

Multi-attribute analysis determined that the best well logs for predicting viscosity were: *resistivity, gamma ray, NMR Total - NMR Free Porosity separation, SP, P-wave sonic, and S-wave sonic.* They successfully predicted viscosity with an average validation error of 69,000cP (or 0.69 of one standard deviation). The top seismic properties for predicting viscosity were: *P-wave velocity* and *P-Impedance*. They predicted viscosity with an average validation error of 94,000cP (or 0.94 of one standard deviation).

Figure 3 and Figure 4 show the new viscosity prediction results in two examples wells. The left side of the figures show the predictions from well logs, and the right side shows the predictions from calculated seismic properties. The gold zones represent the bitumen (reservoir) intervals. The spikes in the predicted viscosity logs occur in non-reservoir intervals (shale barriers), which makes sense because the prediction is calibrated at the measurement points, which are all in reservoir intervals.

The well from Figure 3 shows dynamic variations in the predicted viscosity. On the left side, the new prediction using well logs shows a shallow decreasing viscosity profile from 410m to 420m, and two separate profiles of increasing viscosity in two reservoir intervals separated by a more shaley zone (440m to 460m). The predicted viscosity closely matches the true viscosity at each of the three measurement depths. On the right side, the viscosity prediction from calculated seismic properties detects less variations than the well logs see, and does not match the base viscosity measurement as closely.

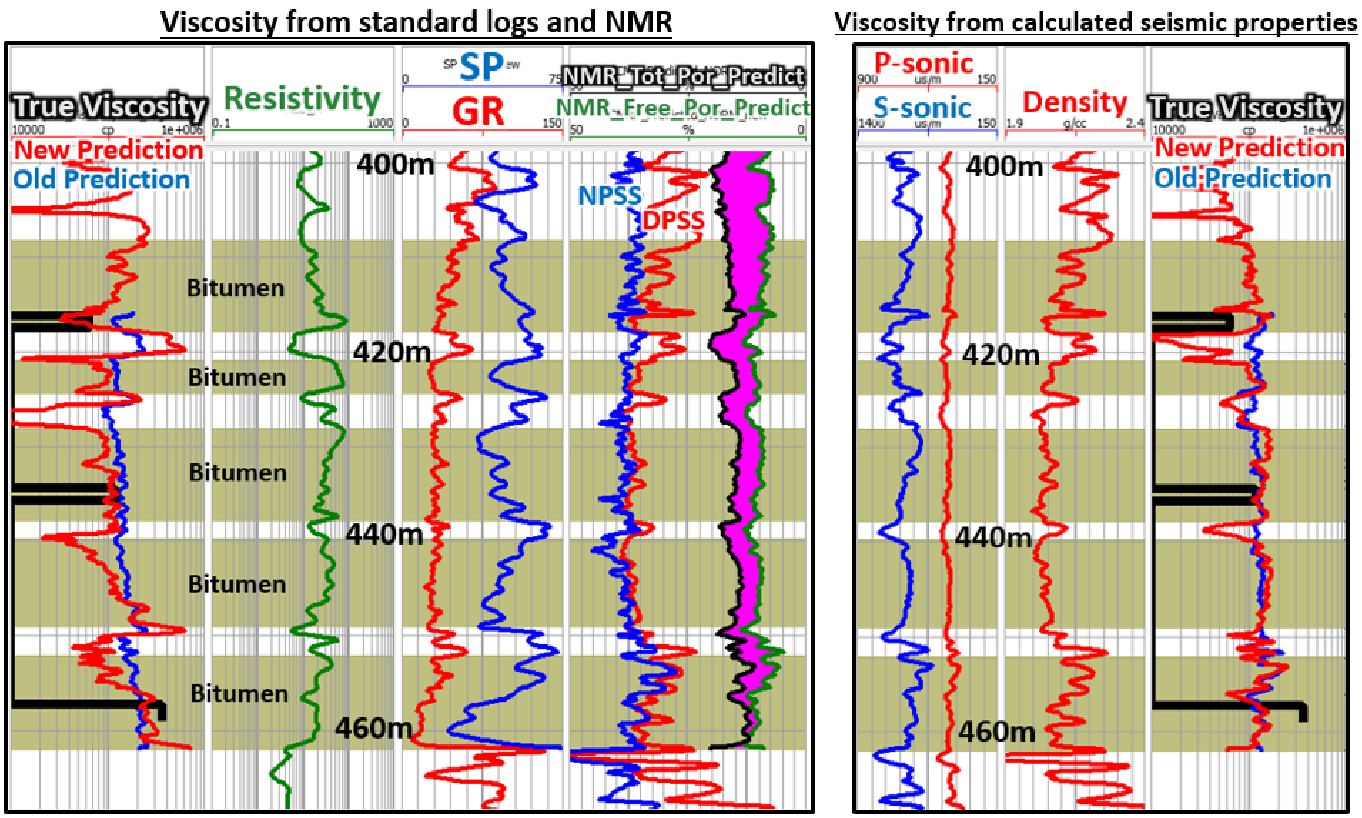

Figure 3: Predicting viscosity from standard logs and NMR (left side), and calculated seismic properties (right side). Validation results for an example well are shown. The two outermost tracks show the true viscosity measurements (35^{0}C) in black, with the new prediction in red overtop the old prediction in blue. The viscosity tracks are presented on logarithmic scales from 10,000cP to 1,000,000cP. The gold zones highlight the bitumen intervals. The magenta colored area is the separation between the predicted NMR Total and NMR Free porosity logs, which represents hydrocarbon contained in small pores and capillaries with poor mobility. Credit: Hampson-Russell Emerge™

The well from Figure 4 shows two modeled viscosity gradients predicted from well logs (left side), One from 215m to 233m, and the other from 235m to 245m. The predicted viscosity closely matches the true viscosity at each of the three measurement depths. On the right side, the viscosity prediction from calculated seismic properties detects less variation than the well logs see, but still matches the true viscosities within reason.

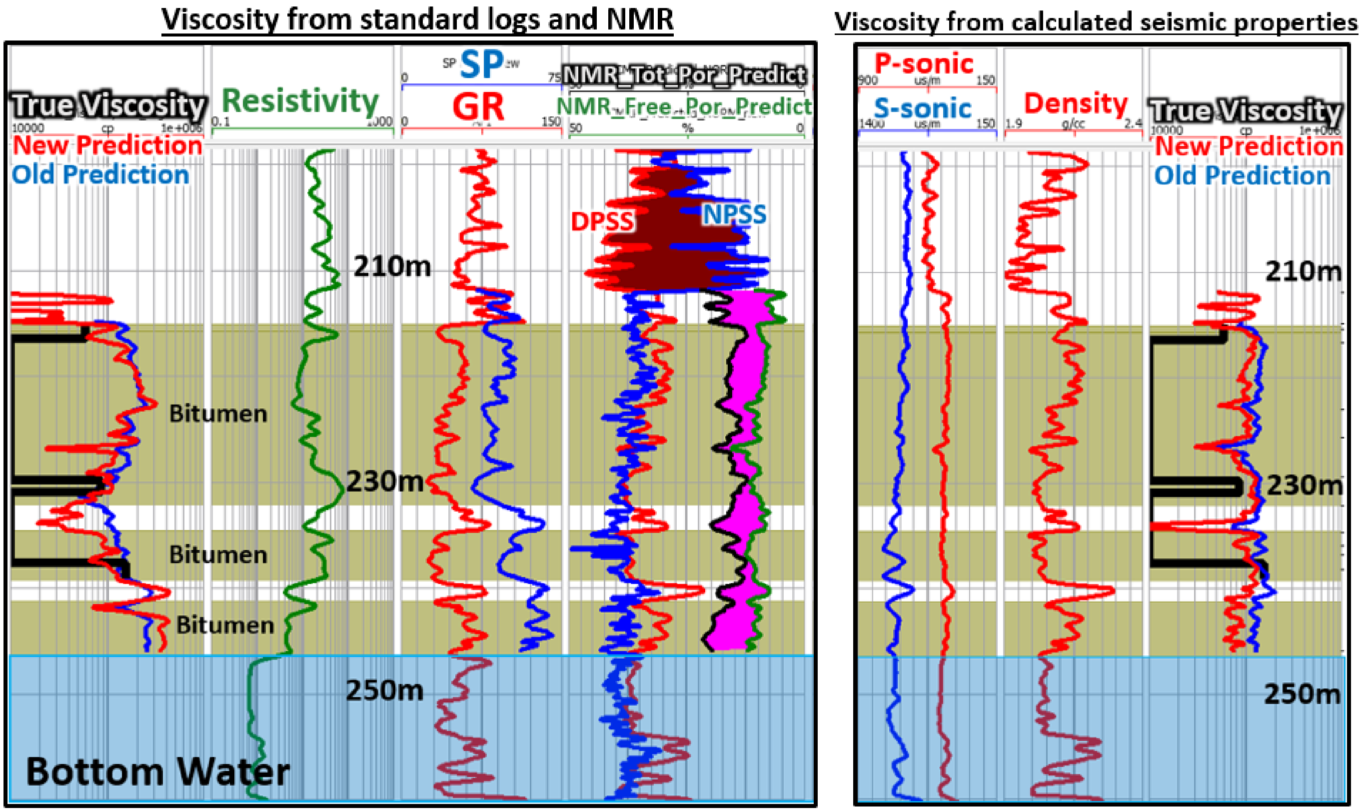

Figure 4: Predicting viscosity from standard logs and NMR (left side), and calculated seismic properties (right side). Validation results for an example well are shown. The two outermost tracks show the true viscosity measurements (35^{0}C) in black, with the new prediction in red overtop the old prediction in blue. The viscosity tracks are presented on logarithmic scales from 10,000cP to 1,000,000cP. The gold zones highlight the bitumen intervals. The magenta colored area is the separation between the predicted NMR Total and NMR Free porosity logs, which represents hydrocarbon contained in small pores and capillaries with poor mobility. Credit: Hampson-Russell Emerge™

Conclusions

This study demonstrated that multi-attribute analysis of well logs can successfully be used to predict viscosity, given sufficient lab viscosity measurements to train the model. Viscosity estimates within about 70,000cP can be made on any well in the area assuming it has a reliable standard suite of well logs. Note that this model predicts a lab measured viscosity at 35°C, whereas virgin reservoir viscosities are on the order of millions of cP, at around 10°C.

Calculated seismic properties were less accurate and less dynamic viscosity predictors than the well logs were. However, they were still within 100,000cP most of the time. With improved shear sonic logs in the study area, the seismic properties likely would have been more accurate. To extend viscosity prediction into the seismic world, a thick reservoir would be needed for resolution, and high frequency, prestack seismic data to extract the required elastic properties which would hopefully detect the large viscosity variations throughout the reservoir.

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