GC Seismic Aids Heterogeneity Hunt*

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General Statement

Canada's Athabasca oil sands represent the biggest petroleum accumulation in the world and presently produce more than one million barrels of oil per day. These are the Lower Cretaceous bitumen sand reservoirs comprising the McMurray Formation that varies in thickness from 10 to 90 meters and occurs at depths of 0 to 400 meters. While the shallow oil sands are exploited by open-pit mining, the deeper reservoirs are produced through some type of insitu bitumen production like SAGD (Steam-Assisted Gravity Drainage).

SAGD operations require extensive, bitumen-saturated, homogeneous formations for optimum production. The McMurray Formation, however, is heterogeneous in terms of reservoir continuity, mineralogy, sedimentary facies and water-saturation, and is too complex to be fully understood from the sparse available core database. Surface seismic data are one option for characterizing this reservoir heterogeneity, with a common approach being to use neural networks or statistical analysis at well locations to deduce relationships between seismic attributes and lithology. These relationships are then used to determine lateral lithology variations between wells.

Methodology

We describe here a two-step approach to understand the heterogeneity of Athabasca oil-sand reservoirs. The first step involves a rock physics study to understand relationships between lithology and petrophysical parameters. From this effort, lithology-sensitive rock parameters are selected that can be detected seismically. The second step is to derive these lithology parameters from seismic data.

The first step – rock physics analysis – is carried out for various rock physics parameters across the zone of interest. Parameters that exhibit the best sensitivity to lithology are selected. For example, on Figure 1 we show P-impedance, Vp/Vs velocity ratio and density cross-plotted against gamma ray using log samples from the study area. For these study wells, P-impedance shows a limited ability to distinguish lithology; Vp/Vs ratio shows a gentle variation with lithology; and density appears to be the best indicator of clay content.

Now that the desired rock parameter – density – has been determined, step two is to do AVO analyses of prestack seismic data to estimate rock density along seismic profiles. Normally, density determination is done using a three-term AVO analysis that requires prestack seismic data with long offsets. In our study we improved this conventional approach by adopting innovative ideas like using a windowed approach instead of a sample-by-sample computation for deriving AVO attributes, reducing distortion due to NMO stretch and offset-dependent tuning, using error-based weights and accounting for the strong reflections from the McMurray Devonian interface.

On Figure 2 we show a density section derived from seismic data. The lateral variation in seismic-based density shows the richest sand areas (in green color) within the mid-McMurray are around wells 5 and 6, with good shaly cap rocks in the upper-McMurray. These predictions are verified by gamma ray logs acquired in both wells. Recently drilled wells 3 and 7 served as blind well tests. Well 3 found mainly a shaly facies within the McMurray, and the seismic inversion for density agrees with these log calibration data. Well 7 was drilled at the edge of the richest sand zone, and its reservoir also matches the seismic-based density results. In addition, the sandy cap rock within the upper-McMurray in well 7 is predicted by the seismic inversion.

Conclusions

This study demonstrates the application of rock physics analysis and the determination of rock density from seismic data can be used to characterize heterogeneity with the McMurray Formation portion of the Athabasca oil sands. While other rock physics parameters can be used, density seems to be a good indicator of lithology at this study site. This same methodology can be applied to other areas where the objective is to determine heterogeneity within any formation of interest.

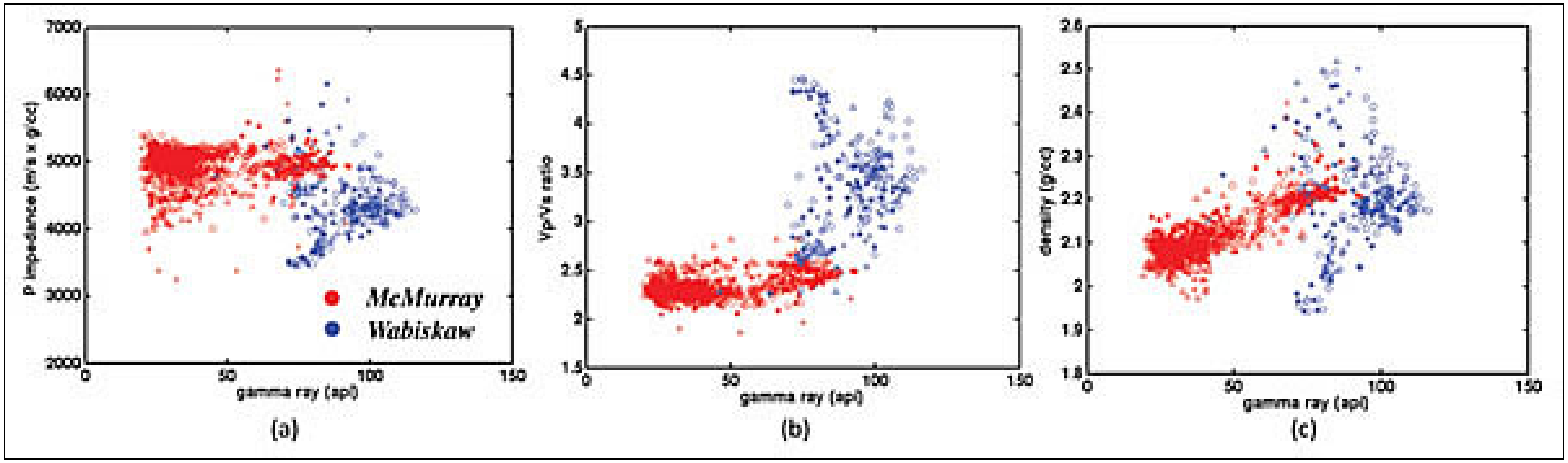

Figure 1. Cross-plots of gamma-ray versus (a) P-impedance, (b) Vp/Vs velocity ratios and (c) density. Red samples are from the McMurray Formation and blue samples are from theWabiskaw Formation. Note that bulk density and gamma-ray responses (c) increase in a quasi-linear manner.

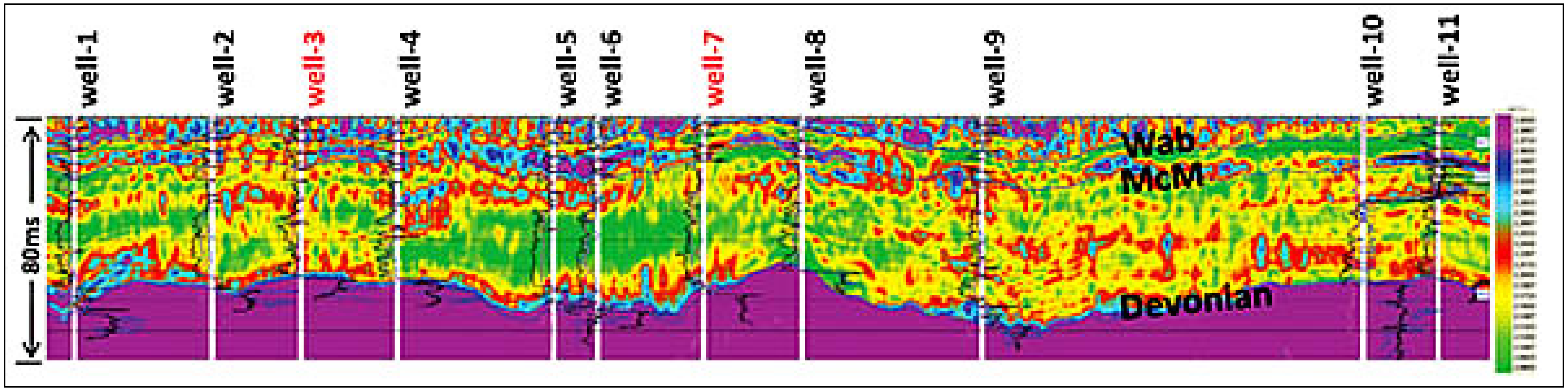

Figure 2. Density section derived from seismic data. Overlain on the section are density logs (black curves), gamma ray logs (purple) and impedance logs (blue). Wab is the Wabiskaw Formation; McM is the McMurray Formation.