Lithology Differentiation and Bitumen/Water Separation in Athabasca Oil Sands: Rock Physics Study

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Summary

This paper presents the study on lithology differentiation and bitumen/water separation in Athabasca oil sand reservoirs especially in McMurray formation. Using wireline logs, we analyze rock physics parameters, comparing those that are seismically derivable and are sensitive to lithology variation. A real data example is used to show the applicability of this analysis for extraction of lithology from seismic data. Our study on the reservoir zone from the chosen area also shows that clean sandstone in the McMurray formation does bring out the difference in elastic properties between highly water saturated and highly bitumen saturated clean sands. This difference can be attributed to the semi-solid nature of bitumen at low temperatures. Cold bitumen with high viscosity increases the rock's resistance to elastic stresses. The elastic property difference between water and bitumen saturated rocks encourages the application of seismic data in mapping thief zone and bottom water in Athabasca oil sands. Uncertainty in using elastic parameters to map lithology and bitumen saturation is also stated.

Introduction

Reservoir heterogeneity in Athabasca oil sands is a big challenge for in-situ bitumen production. A successful SAGD project requires homogeneous, extensive and highly bitumen saturated sand reservoirs. High degree of geological heterogeneity causes unreliable interpolation of the lithology from available well control. Good quality seismic data has good lateral and vertical coverage and helps understand oil sands reservoir heterogeneity. To honor the advantage of seismic data in mapping reservoir heterogeneity for Athabasca oil sands, the relationships between reservoir lithology and rock physics parameters need to be determined, especially those that can be derived from seismic data. Rock physics and petrophysics are studied for specific purposes: (1) understanding the relationships between rock physics parameters and lithology, (2) looking for limited number of rock physics parameters that are sensitive to lithology and can be derived from seismic data with enough reliability, and (3) providing physical foundation for choosing attributes used in multi-variate statistical analysis or neural network prediction. The thief zone (gas or water above bitumen) or bottom water constitutes another aspect of the reservoir heterogeneity in Athabasca oil sands. In SAGD operations for example, the water thief zone prevents the steam to come into contact with bitumen; a depleted gas cap thief zone will allow the steam to come into contact with the low-pressure zone. In both cases reduced production rates can result. In the second part of the paper we focus on water/bitumen separation. After detailed comparisons of the rock physics parameters response to bitumen saturation, a couple of parameters with good sensitivity to fluid type changes are chosen and analyzed.

Lithology differentiation for Athabasca oil sands

P impedance, S impedance, and density are a set of basic rock physics parameters that can be derived from surface seismic data, although different practitioners can define a different set of basic parameters based on their understanding of AVO. Surface seismic data is usually generated by P wave sources, and records P impedance contrast primarily. Therefore P impedance can be determined more reliably than the other two parameters. S impedance and density contribute to the seismic amplitude variation at non-normal incidence reflections, and theoretically can be determined from offset-dependence in seismic data. Commonly-used AVO inversion can solve S impedance contrast in addition to P impedance contrast. As is generally perceived, it is difficult to determine density reliably from AVO inversion. However, we show with the help of examples, that density can be determined from surface seismic data with similar reliability as S impedance. Once the basic rock physics parameters are determined, it is possible to derive other parameters like Vp/Vs, Poisson's ratio and Lambda-Mu-Rho, which are diagnostic of lithology. Gamma ray (GR) log curve is usually a good indicator of clay content that affects lithology in oil sand reservoirs. It is therefore beneficial to understand relationships between rock physics and lithology using gamma ray. Crossplotting is used as the tool to understand the relationships between rock physics parameters and lithology. In Figure 1, P impedance, Vp/Vs ratio and density are cross-plotted against gamma ray using log samples from one studied area. Here, P impedance shows limited ability to separate lithology, and density is one of the best indicators of clay content among various rock physics parameters. These and other rock physics parameters from different areas are also studied and the results will be shown in the presentation.

Figure 2 shows an example in which density is reliably derived from seismic data and successfully used to map reservoir heterogeneity (Xu and Chopra, 2008). The middle McMurray is usually the reservoir while the upper McMurray and Wabiskaw are the cap rocks. The richest sand areas (seen in dark green color) within mid-McMurray are around wells 5 and 6 with good shaley cap rocks in upper-McMurray and these are verified by gamma ray logs of both wells. Recently drilled well 3 and well 7 served as blind well tests. Well 3 is mainly shaley within McMurray and the density inversion result verifies this. Well 7 is drilled at the edge of the richest sand zone and its reservoir also matches with the inversion results. In addition, the sandy cap rock within upper-McMurray in well 7 is convincingly predicted by the inversion.

Bitumen/water separation in McMurray formation

Heterogeneity of bitumen distribution is another factor impacting successful in-situ bitumen production using SAGD technology. Highly water-saturated sand becomes a thief zone, which significantly impact the efficiency of steam. In addition to differentiating lithology, it is important to separate water saturated and bitumen separated sands. Water and bitumen saturated sands have significantly different response on some petrophysical log curves, such as resistivity logs, but high reservoir heterogeneity prevents reliably extrapolating reservoir properties at the borehole to areas far away from the borehole. To utilize the good lateral resolution of seismic data, the relationship between rock physics parameters and saturation of bitumen. For conventional oil reservoirs, the difference of the effects of oil saturation and water saturation is usually small, but when oil is light and with enough gas dissolved, effect of the oil saturation will show obvious differences from that of water saturation. In Athabasca oil sands, density of the bitumen is higher than water at low temperature. According to Mochinaga et al (2006), density of bitumen in their experiment is about 1.01 g/cc at the temperature of 20 degree Celsius, the density difference between bitumen and water in low temperature is so small that it is not possible to separate them reliably. Bitumen at low temperature behaves like a semi-solid. One can assume that the bitumen filling the rock pores has the effect of cementation, which makes the rock have stronger resistance to compressional and shear stress. Based on the study by Kato et al (2008), bitumen saturated rock has higher P and S velocity at low temperature (<20 degree Celsius) than at high temperature (> 20 degree Celsius).

In Figure 3, Poisson ratio is cross-plotted against gamma ray and color coded by bitumen saturation (as colorbar) in the left panel, and in the meantime density is cross-plotted against gamma ray and color coded by bitumen saturation (as colorbar) in the right panel. In the right panel, samples with the bright red color (high bitumen saturation) and those with dark blue color (high water saturation) overlay together and indicate they are clean sandstone with similar porosity. In left panel, the highly water saturated clean sand samples (in dark blue) locate in higher Poisson's ratio zone, away from highly bitumen saturated clean sand samples (in bright red). Based on above observation, it is possible to use the Poisson's ratio or Vp/Vs ratio to separate water from bitumen in cold reservoirs. But ambiguity exists when porosity varies largely in the clean sands. Reliable estimation of the porosity helps reduce the ambiguity. The porosity can be derived from density if the bulk density can be determined reliably.

Because of the complex viscoelastic nature of bitumen, rock physics parameters of bitumen are highly dependent on dispersion and temperature. The observation of the change of Vp/Vs ratio due to bitumen is based on the wireline logs from chosen area only. The physical mechanism of the difference needs to be studied further. And the wireline logs from other areas in Athabasca oil sands will be investigated.

Conclusions

This study presents the results on lithology differentiation and water/bitumen separation using rock physics parameters that are seismically derivable. The analysis is based on wireline logs mainly and can be summarized as:

- Density is one of the best indicators of clay content among various rock physics parameters
- Under low temperature, semi-solid bitumen has effect of cementation, which makes bitumen-saturated sands increase the resistance to compressional and shear stresses. The wireline log study shows that the highly bitumen saturated sands have smaller Poisson's ratio or Vp/Vs ratio than highly water saturated sands with similar porosity.

The study in the paper provides the physical basis for deterministic and conventional interpretation of reservoir heterogeneity of Athabasca oil sands, and shows the sensitivity of rock physics parameters to lithology and fluid variation. But due to the complicated nature of reservoirs, such as the combination of shale volume and porosity changing, uncertainty exists in using a limited number of parameters to describe reservoir heterogeneity. If a number of rock physics variables are needed to determine reservoir properties, a more sophisticated method might be considered. Certainly, the deterministic and conventional interpretation provides initial solutions and control of quality.

References

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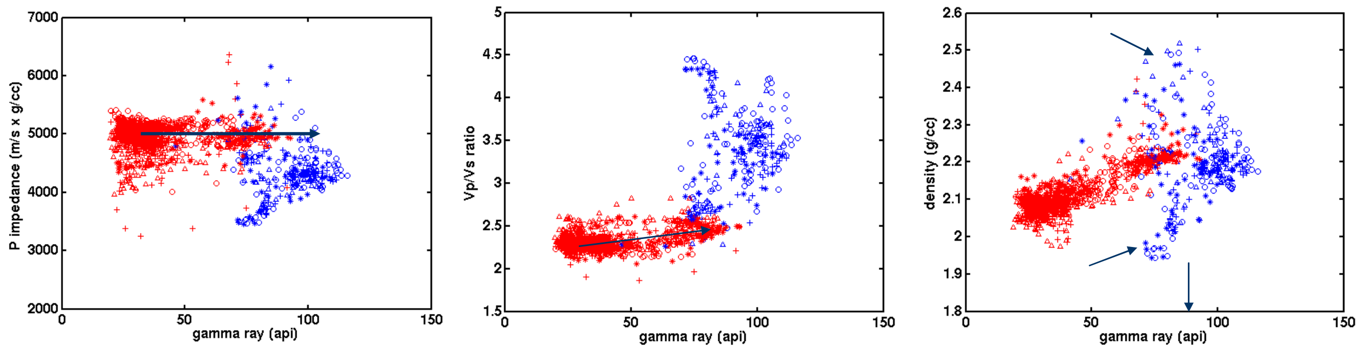

Figure 1. Cross-plotting of P impedance, Vp/Vs ratio, and density against gamma ray. Log samples from well logs from studied areas are used. Samples from McMurray formation are in red and those from Wabiskaw are in blue.

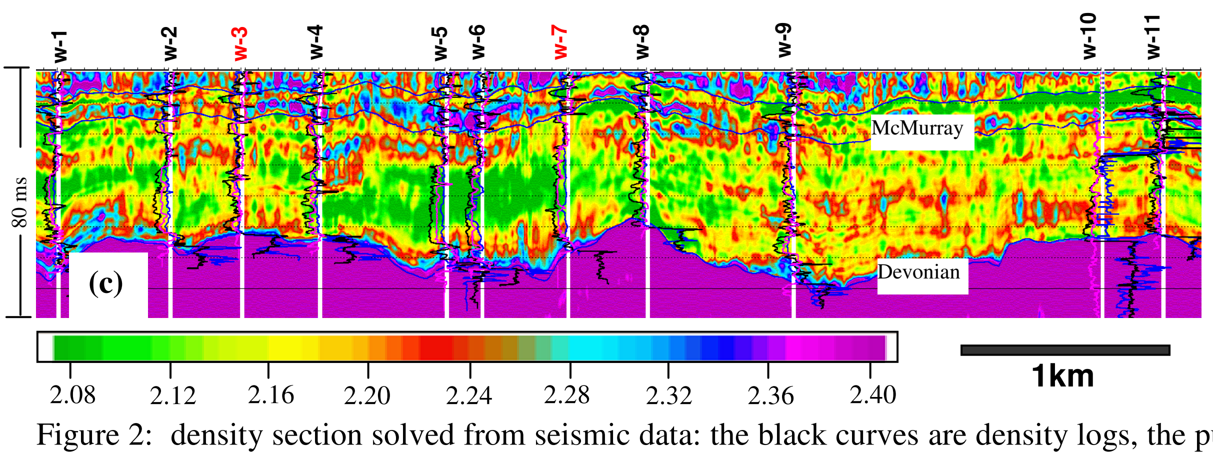

Figure 2: density section solved from seismic data: the black curves are density logs, the purple are gamma ray logs, and the blue are impedance logs.

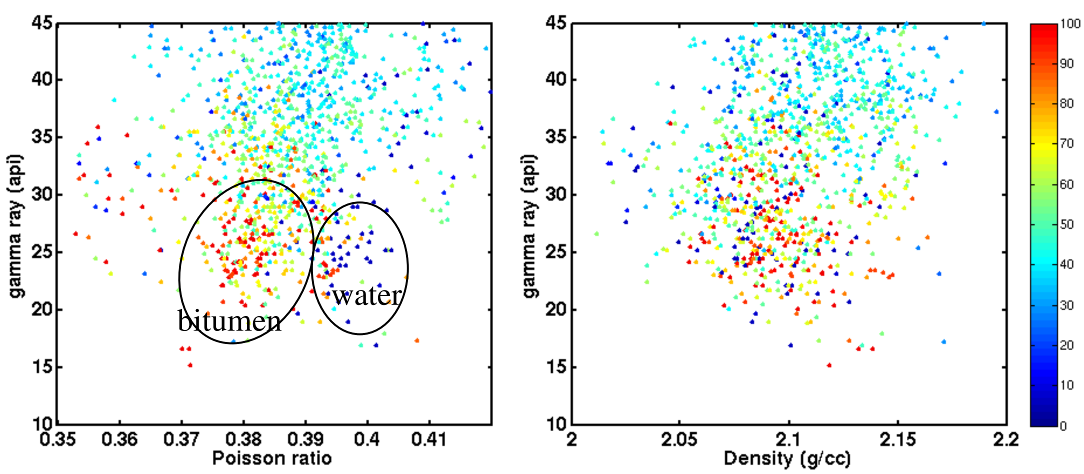

Figure 3. Left: Poisson ratio is cross-plotted against gamma ray with color coded by bitumen saturation (as colorbar); right: density is cross-plotted against gamma ray with color coded by bitumen saturation (as colorbar). Usually Poisson's ratio shows change when the porosity of clean sandstone changes. In right panel, samples with the bright red color (high bitumen saturation) and those with dark blue color (high water saturation) overlay together and indicate they are clean sandstone with similar porosity. In left panel, the highly water saturated samples are located to higher Poisson's ratio zone, away from highly bitumen saturated samples.