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Oil Sands Reservoir Characterization in Athabasca, Canada

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Abstract

Reservoir characterization was conducted by combining geological and geophysical methods in the oil sands area, Athabasca, Canada. For the production of bitumen from the reservoir 200 to 500 meters in depth, the Steam Assisted Gravity Drainage (SAGD) method (Steam Injection EOR) has been adopted as bitumen is not movable at the original temperature. It is essential to understanding the detailed reservoir distribution as bitumen is produced just from the vicinity of the producing wells by the SAGD method.

A conceptual geological model was constructed from well analyses and their correlation based on a sequence stratigraphic framework. Depositional environment of the target zone was interpreted as fluvial to upper-estuarine channel fill deposits, and oil sands reservoirs were formed as the vertically stacked incised valley fill sands. Conducting acoustic impedance inversion to improve resolution and subsequent multi-attribute analysis integrating seismic data with well data facilitated an understanding of the detailed reservoir distribution. These results were converted to depth domain by geostatistical methods, then structural and property models were constructed using visualization software.

By using multi-attribute analysis and acoustic impedance inversion with constructed conceptual geological models, both efficient well deployment design and better estimation of reserves distribution became possible. Top and bottom depths of the reservoir were estimated in the range of 2.0 meters near the existing wells even in such a complex channel sands environment which often changes its sedimentary facies abruptly. Multi-attribute analysis also enables the basement shale to be imaged and identification to a certain degree of thin shale within the reservoir.

This paper proposes a new workflow for the oil sands reservoir characterization, which improves the resolution of geological models significantly.

Introduction

A vast amount of oil sands has accumulated in the Athabasca area, Alberta, Canada. These oil sands consist of bitumen and unconsolidated sand distributed from surface down to 750 meters. The proved remaining reserves of bitumen from oil sands in Canada are estimated as about 170 billion barrels (Alberta Energy and Utilities Board, 2007).

Japan Canada Oil Sands Ltd. (JACOS), a subsidiary of JAPEX, has been operating the production of bitumen in the Hangingstone west area approximately 50 kilometer southwest of Fort McMurray using an in-situ Steam-Assisted Gravity Drainage (SAGD) method since 1997. In this area, the oil sands reservoirs exist at a depth of around 300 meters.

For the purpose of reservoir characterization, considerable amount of core and well logs have been acquired and a complex depositional system which consists of several incised valley fill sandstone units has been analyzed. In 2002, a 3-D seismic survey was conducted and 3-D geological models were constructed by integrating core, log, and seismic data.

In this paper, we will explain our work flow for the oilsands reservoir characterization and some actual example for the optimization of the field development.

Geological Settings

The McMurray Formation (lower Cretaceous) ,which comprises the main layer of oil sands, is composed of channel-type sedimentary facies such as the massive sandstone (Channel Sand-bar Facies: CS), sandstone with muddy rip-up clasts (Channel Sand-bar with Rip-up Clasts Facies: Clasts), sandstone/mudstone alternation (Lower & Upper Point-bar Facies: LPB and UPB), and mudstone（Abandon Channel Fill - Tidal Flat Facies: TF). Figure 1 shows example of cores representing each sedimentary facies. CS, Clasts, LPB are considered as the reservoir facies for the SAGD method, while UPB and TF are not. Sedimentary environments of the McMurray formation are considered to be fluvial-to-upper- estuarine channel fill deposits around the mouth of a river where tidal influence is dominant.

Vertical Resolution of Data

Comparison of scales in outcrops, cores, logs, and seismic data are shown in Figure 2. When integrating these data and construct geological models, it is important to recognize the limit of resolution, to make an effort to improve the resolution of each data, and to obtain the best mix of these data.

Vertical resolution of logging data depends on target properties and the way of observation. For seismic-related properties, vertical resolution of sonic log is around 30 centimeters and that of density log around 50 centimeters.

Predominant frequency of the seismic data in the McMurray interval is around 100 Hz, which suggests vertical resolution to be around 6.5 meters according to the one-quarter wavelength criterion of Rayleigh. Interval velocity in the McMurray formation is around 2,600 m/s. If we consider that 6.5 meters is the limit of detectability, it is hard to get detailed facies distribution in the oil sands layer as it is sometimes as thick as 15 meters. But it is not constrained by this separability when we conduct amplitude analysis. Brown (2004) defined visibility which is different from separability which corresponds to the conventional definition of Rayleigh's vertical resolution. In terms of visibility, it is possible to detect a thin layer by analyzing amplitude as far as signal to noise (S/N) ratio allows (Brown, 2004). In the case of extremely high S/N ratio, visibility can be in the range of 1/30 wavelength, which corresponds to about 1.0 meters in the present case.

Work Flow

Figure 3 shows the flow diagram of the analysis.

Initially the sedimentary facies of every ten centimeters is determined from existing core data and the relationships between core facies and well log responses are examined. Next, sedimentary facies of the wells without core data are estimated from the well log data.

Sequence stratigraphic correlation is then conducted by using well log data, and a framework of the stacked incised valley system is established (Takahashi et al, 2006-1) . Schematic diagram of the well correlation based on the sequence stratigraphic framework in the McMurray formation is shown in Figure 4. Gamma-ray log curves are indicated for each well. This example consists of three sequence boundaries (SB) and corresponding three sequences (SQ). In order to restore the paleo-topography in the McMurray period, all the well data are adjusted and flattened at the shale marker on the gamma-ray log near the top of the McMurray Formation. When correlating, sand top levels for each sequence are assumed to be more or less the same as the incised valleys are interconnected as the network of rivers. Further detailed sequence structural models are constructed using seismic data at a later stage. An example of the structural model showing one of the sequence boundaries (bottom of the incised valley) based on the log and seismic data is shown in Figure 5.

Model-based inversion of acoustic impedance (AI inversion) is conducted to achieve higher resolution and suppress the amplitudes of sidelobes. In general, model-based inversion results are highly dependent on the initial model. In the McMurray formation, as the sand and shale distribution is not simply stratified, it is considered that the initial model constructed by the interpolation among well-logs (filter-out model) is not adequate. It is then decided to adopt a simple three-layer model with constant velocities, and leave all the higher frequency determination to seismic trace itself.

Multi-attribute analysis (Hampson et al., 2001) integrating well and seismic data is then applied. As the purpose of this analysis is to distinguish between reservoir/ non-reservoir facies, sedimentary facies index logs are adopted as the target logs. Sedimentary facies logs are simplified to two categories, reservoir and non-reservoir facies, to stabilize the result of multi-attribute analysis. On the selection of seismic attributes, two attributes such as AI inversion results and instantaneous frequency values are a priori selected because of good correlation, and the others such as integrated seismic trace, second derivative of instantaneous amplitude and amplitude weighted cosine of instantaneous phase are selected based on the stepwise regression described in Hampson et al. (2001). Full automatic stepwise regression did not give satisfactory results in this case. Details of the analysis was described in Takahashi et al. (2006-2).

Based on the core and log observation at the wells and depth-converted 3-D seismic data, physical property models showing sedimentary facies are constructed as shown in Figure 6.

Optimization of Field Development

Procedures described above contribute both to reserves estimation and the well deployment optimization. For the detailed well planning, multi-attribute analysis plays an important role as the vertical and horizontal resolutions are superior when compared with seismic and acoustic impedance sections. Multi-attribute analysis enables basal shale (base of reservoir) imaging and the identification to a certain degree of thin shales within the reservoir. Top and bottom depths of the reservoir are estimated in the range of 2.0 meters even in such a complex channel sands environment.

An example of the reservoir prediction and well planning based on the multi-attribute analysis is shown in Figure 7. Colors on the multi-attribute analysis section indicate probability of being reservoir. Prediction is more confident for reservoir facies if values approach 1.0, and for non-reservoir facies if values approach 0.0. In Figure 7, some well pair was planned to drill and multi-attribute analysis was examined along the planned horizontal well section. Mud plug with limited lateral extent in the middle of the planned pair was predicted as shown in Figure 7. Offset wells, P1 and P2, were already drilled and reservoir distribution along the pair was predicted based on acoustic impedance, multi-attribute analysis, and existing wells. Well O1 was drilled based on this multi-attribute analysis and existence of this mud plug was successfully proved. As the extent of the mud plug has rather limted judging from the multi-attribute volume, the horizontal well pair was drilled across the mud plug.

Conclusions

This paper proposes a new workflow for the oil sands reservoir characterization, which improves the resolution of geological models significantly. Based on the three-dimensional geological models, detailed reserves estimation and optimization of development plan were cariied out. Among the series of analysis, multi-attribue analysis plays an important role due to its high resolution and predictability of reservoir facies. These procedures should be applicable to areas with the complex geological setting other than oil sands fields.

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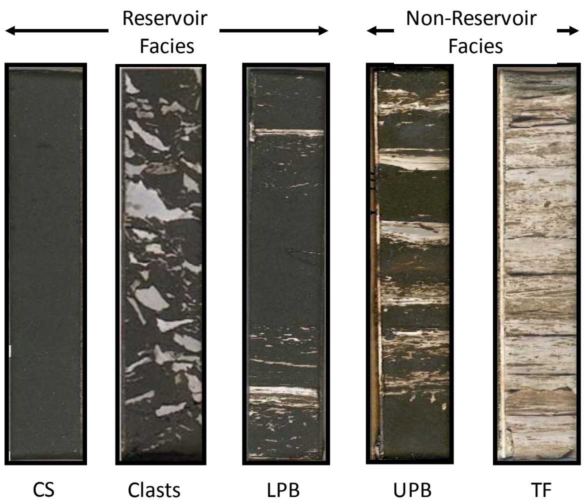

Figure 1 Example of cores representing each sedimentary facies.

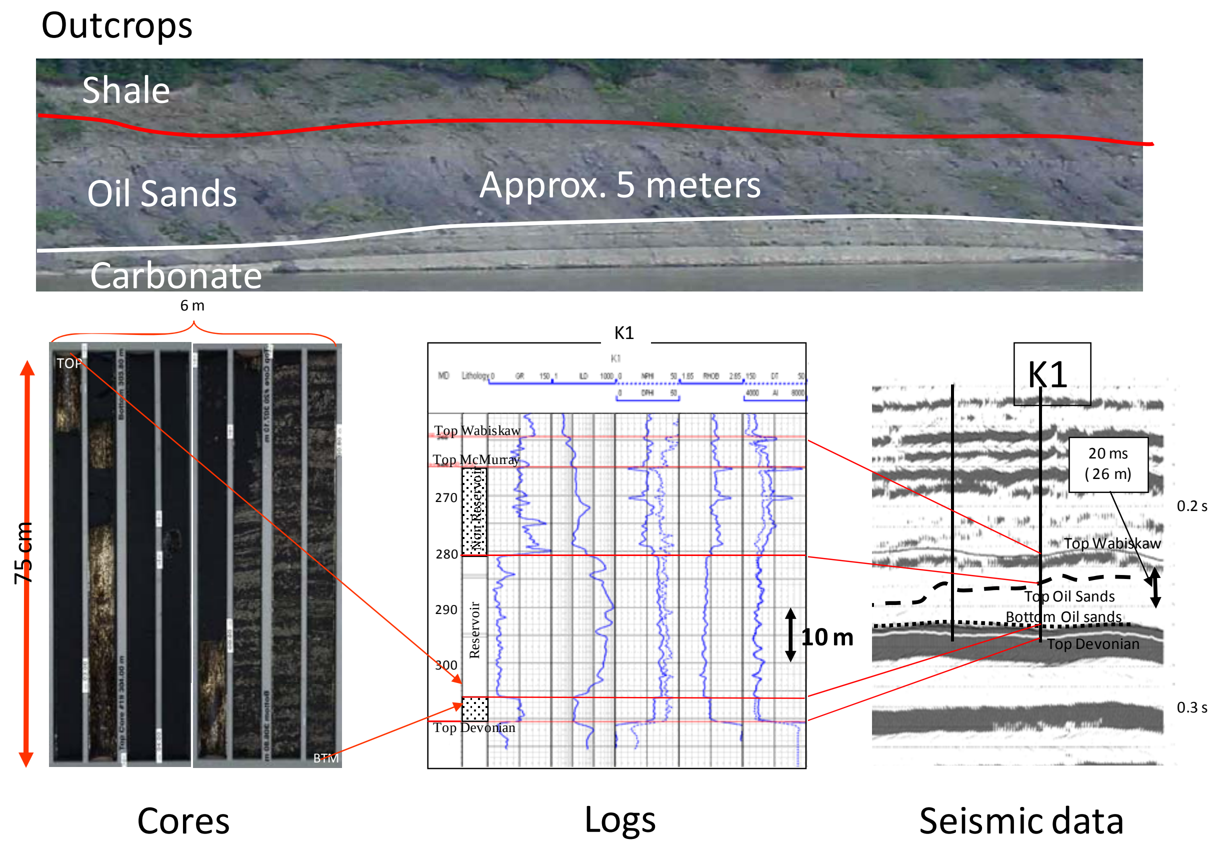

Figure 2 Comparison of scales in outcrops, cores, logs, and seismic data.

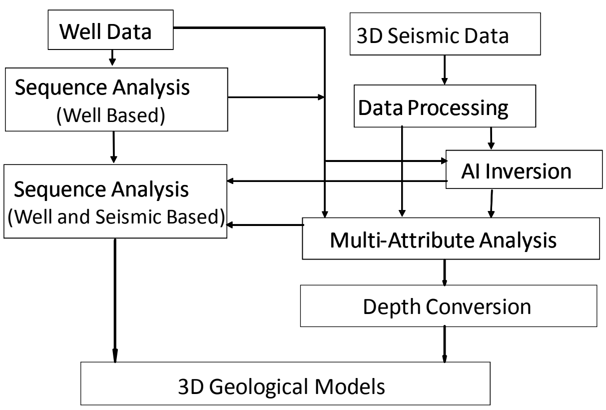

Figure 3 Flow diagram of the analysis.

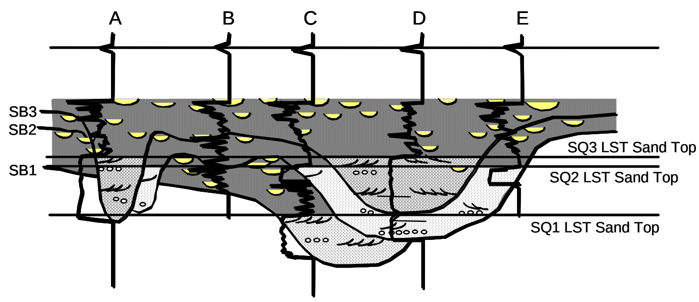

Figure 4 Figure 4 Schematic diagram of the well correlation based on the sequence stratigraphic framework in the McMurray

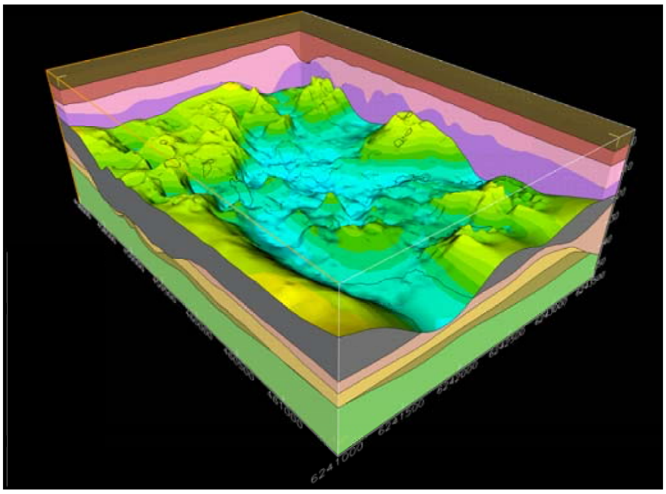

Figure 5 An example of structural models showing one of the sequence boundaries based on the log and seismic data.

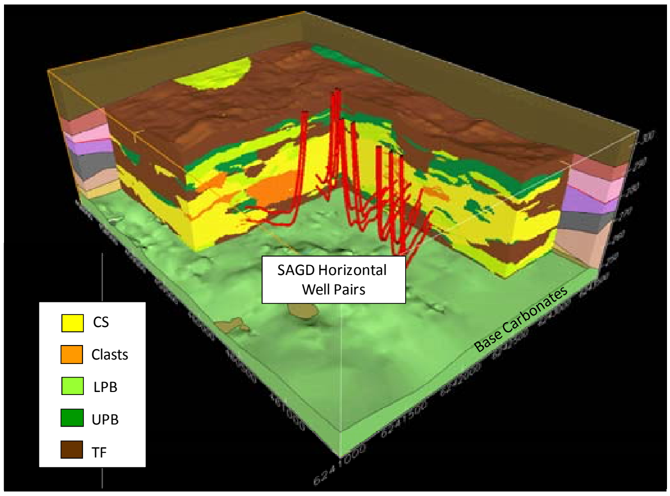

Figure 6 An example of property models showing the distribution of the sedimentary facies.

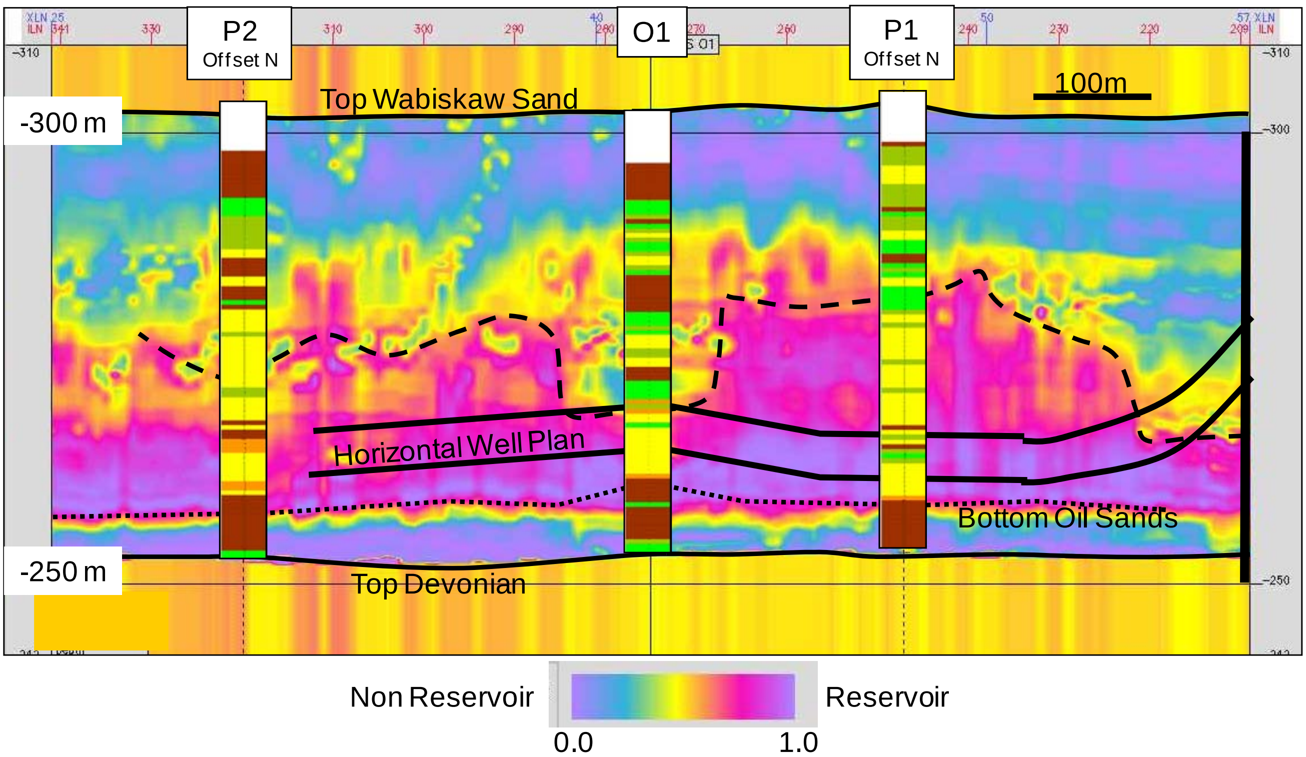

Figure 7 An example of well planning on the depth-converted multi-attribute analysis section.