The Challenges of 3D Seismic Application for Athabasca Oil Sands Development*

Takehiko Sato[1] and Leigh Skinner[2]

[1]JAPEX, Tokyo, Japan (takehiko.sato@japex.co.jp)
[2]JACOS, Calgary, Alberta, Canada

Abstract

Commencing in 2002, Japan Canada Oil Sands Limited (JACOS) has acquired several 3D seismic surveys. Field equipment, seismic data processing technology, and the quality of results have evolved and improved recently over the past 5 years. Reviewing the data quality of the 3D surveys, we discuss what factors and how they affect the quality of the seismic data using real examples.

Introduction

Despite its high cost, 3D seismic survey data has routinely been used in oil sands development. Commencing in 2002 with the initial application at our Hangingstone pilot area (3.75 Demo area) JACOS has acquired several 3D seismic surveys. We consider that the application of 3D has shown successful results when incorporated with multi-attribute analysis (MAA) methods. Extending the application of 3D out of the 3.75 Demo area, we became aware of several challenging issues. The first is attenuation by shallow gas where the seismic quality is lowered limiting accurate interpretation. The second is due to multiple noise, which is generally known as a rare problem in land seismic data. The third is the selection of acquisition parameters, particularly the dynamite shot-hole depth. We will show how the final data quality is affected by this parameter. Lastly, vertical resolution of sedimentary facies, which is a key factor in oil sands development.

Attenuation by Shallow Gas

Shallow gas is common in the Athabasca area where thicknesses even less than a few metres, can greatly affect the quality of the seismic data; as we observed in our original data. Shallow gas appears as bright amplitude events on seismic sections. Figure 1 shows on the left a RMS amplitude map of the shallow gas interval in one of our 3D areas. The shallow gas zone exists in the entire area but its amplitude varies locally likely according to the thickness of the gas. Shown on the right of Figure 1, is the RMS amplitude at the top of the Devonian. However, obviously the Devonian RMS amplitude is strongly affected by the shallow gas in accordance with the amplitude – supposed gas thickness. This results in similar looking maps, just with flipped colour scales. Amplitude attenuation is a primary effect by the shallow gas; as such the amplitude is strongly controlled by the presence of the shallow gas sand. Shallow gas also attenuates the high frequency component of seismic

energy then distorts the seismic wavelet locally. Consequently, low amplitude, low frequency shadow zones are created beneath the high attenuation area. Particularly, seismic inversion is badly affected by the attenuation in terms of amplitude and wavelet consistency as well as S/N degradation.

Multiple Noise

We observed that the shallow gas horizon created multiple noise, particularly in the bright areas of the shallow gas zone. Figure 2 shows on the right, results of the initial processing in 2003 and the on the left, results of reprocessing in 2009. Initially, we thought that the dipping events in the McMurray Formation target zone in the 2003 processed data were reflections consistent with a point bar system. However, after detailed study, we concluded that this was multiple noises. As the surface is dipping and the shallow gas multiple generator is near flat, we found the surface related multiple noises appeared as seismic events opposite to the surface dip angle. Special care of multiple noise was taken during the 2009 reprocessing. As well as significant quality improvement, multiple attenuation was also made (Figure 2 – left); this enabled us to clearly identify the top of the oil sand reservoir in the McMurray Formation.

Seismic Source

Currently, dynamite is the only available seismic source in the Athabasca area as the area is swampy and covered in muskeg, preventing vehicle maneuver due to the soft surface. Even in the winter season, a heavy, non-explosive source such as vibroseis is unavailable. One of the key parameters of a dynamite survey is shot hole depth. In the 2003 survey, we chose a 15 m shot hole depth with the aim to set the source below the muskeg and obtain higher frequencies. In the 2007 survey, we chose 5 m for a shot hole depth. Figure 3 shows the time slice at 248 ms of an overlapping area between the 2003 and 2007 surveys. On the 2007 time slice, the point bar system of the McMurray Formation reservoir is well imaged. In contrast, the point bar system is poorly imaged on the 2003 time slice. We consider the cause of the difference is made by the shot hole depth. In the 15 m hole depth shooting, assuming that the muskeg layer is completely filled by water, the first and second ghost notch frequency becomes 50 Hz and 100 Hz. Measuring the frequency at the target level, the bandwidth of the 2003 and 2007 processed seismic data (at the same contractor) are limited to 80-90 Hz, and 120 Hz respectively. Even though there are many differences in the parameters between the two surveys, we conclude that the shot hole depth is the primary cause of the quality difference.

Vertical Resolution

High vertical resolution is required in oil sands development. The SAGD process requires not only an estimation of the gross oil sand reservoir thickness, but also internal imaging of the reservoir, particularly the distribution of non-reservoir facies. JACOS has been developing a multi-attribute analysis (MAA) approach to predict reservoir presence where the final product is represented as a numerical value between 0 and 1 of the probability of reservoir presence. Figure 4 shows an actual well result and the corresponding MAA prediction. To estimate the vertical resolution of the MAA, we computed a running average of the lithology index, which has no physical meaning but is regarded as a reflection as "reservoir grade". We found that a 5 m running average of the lithology index showed similar response to the MAA. Therefore we consider that the MAA itself has 5 m resolution, which is consistent with seismic tuning thickness, assuming the dominant frequency is 100Hz with the interval velocity approximated at 2000 m/s. MAA values of 0.5 lead to various possibilities in the interpretation; for example, the presence of

low grade reservoir facies, half good reservoir facies / half mud dominated facies or intermediate combinations of the previous. In other words, we are not able to know the details of the reservoir below a resolution of 5 m. We conclude that the final MAA prediction is controlled by the resolution of the original seismic data.

Conclusions

JACOS has shot several 3D seismic surveys that we found beneficial to delineate the reservoir, particularly inter-well reservoir prediction. However, there are challenging issues remaining for the application of 3D seismic data in Athabasca oil sands development. The presence of shallow gas lowers the seismic quality below, attenuates the signal, lowers the S/N ration and shallow gas horizons can generate surface related multiple noise. These can influence the quantitative interpretation, particularly the accuracy of seismic inversion. A shallow dynamite source is preferable to improve the vertical resolution as shown above in this abstract. We found also that the low frequency component was important to image the top of the oil sands reservoir. As the McMurray sand reservoir is known as a bottom-loaded type, then the image of the top reservoir is expected to show low frequency. Additionally, we expect that the low frequency component mitigates the side lobe effect due to the dense Devonian carbonates beneath the reservoir. Some broadband type source is expected in the future.

The seismic data has 5 m vertical resolution, which is quite high for conventional exploration, but much higher resolution is required for reservoir engineering in the SAGD process as mud facies of sub-3 m thicknesses impede the development of the steam chamber. The cost for 3D data acquisition is still an issue from a business point of view. Comparing to the 3D seismic surveys for conventional oil and gas exploration and exploitation, higher density shot and receiver intervals are required for oil sands development resulting in relative higher costs. As cost reductions are made, in addition to exploration, we will be able to apply repeat 3D surveys to monitor the bitumen recovery process and improve recovery rate.

Acknowledgements

Figure 1. RMS amplitude maps of shallow gas interval (left), Devonian interval (right).
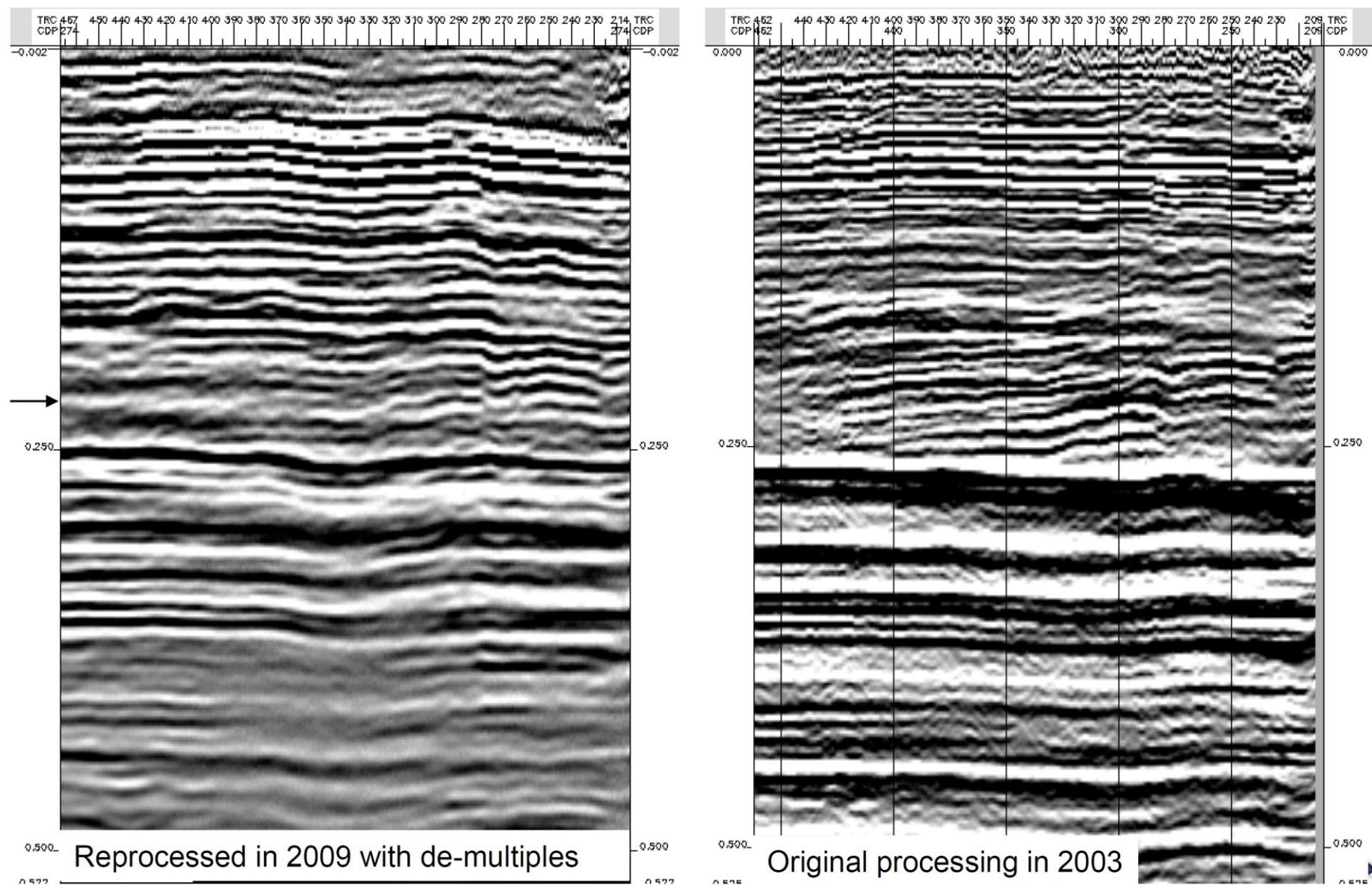
Figure 2. Sections reprocessed in 2009 with de-multiples (left) and original processed in 2003 (right), note: left-dipping events in 2003 section are attenuated in 2009 section.
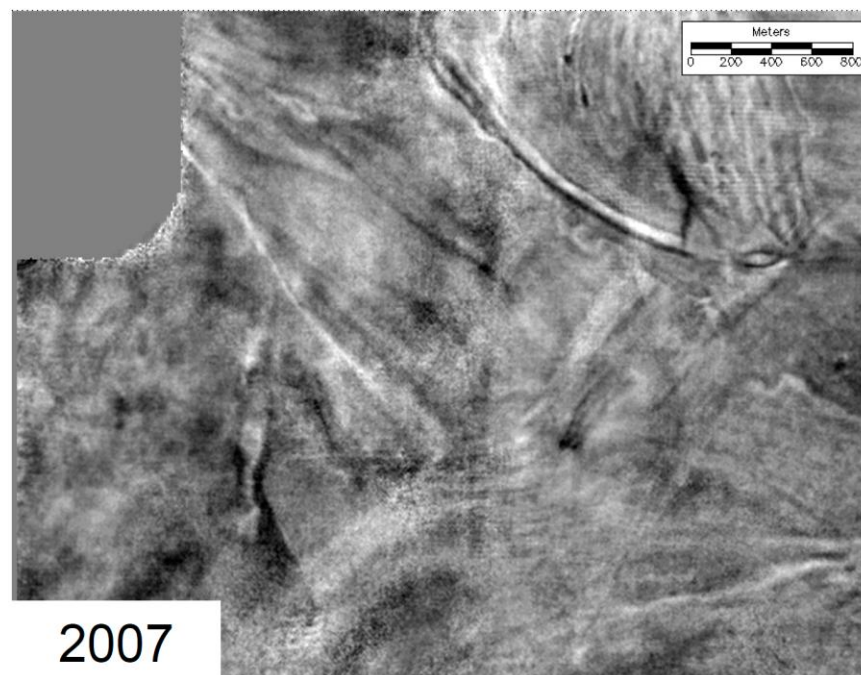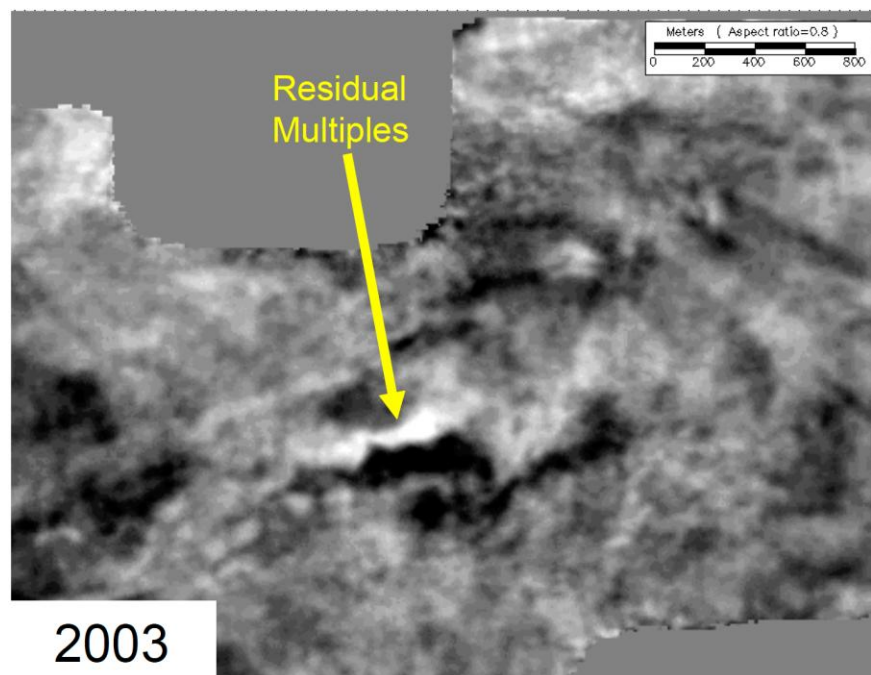
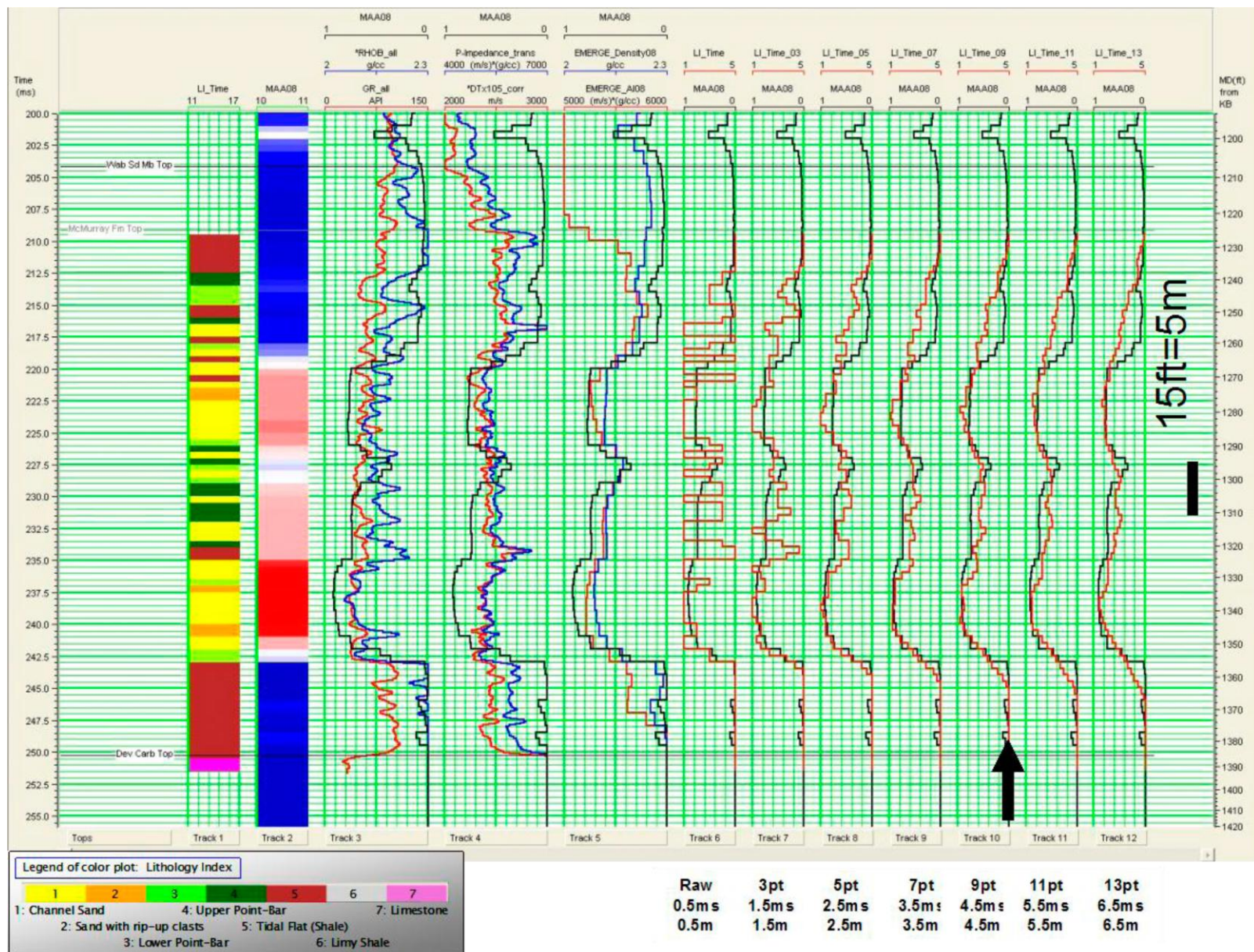Figure 3. Representative time slices at 248ms of 2003 survey and 2007 survey.

Figure 4. MAA prediction and actual well result. Left most: Lithology index (LI) represented in color, next, probability of reservoir predicted by MAA represented in color: Blue: probability 0: white: 0.5, red 1. Right 7 curves are MAA curve (black), moving averaged LI logs (red) with no smoothing, 1.5m smoothing, 2.5m, 3.5m, 4.5m, 5.5m, and 6.5 from left to right respectively.