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A High Resolution VSP in the Oil Sands for Improved Reservoir Characterization

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SUMMARY

This is a case study that looks at the application of a high resolution multi-component VSP acquired in the Athabasca Oil Sands Region of Canada. The 2D Walkaway VSP was the first to be acquired using a new type of downhole array capable of over 2,000 channels of 3-component data per borehole. The HDVSP™ array is based on the VectorSeis® MEMS sensors, which are deployed at either 1 or 2-metre intervals from the surface to the bottom of the well. For this case study, 141 3C sensors were deployed in the well at 2m intervals.

The Athabasca oil sands region is an area with complex reservoirs, complex fluid distributions and unconventional rock property behavior. High quality shallow multi-component seismic data contributes to the conditions required for unprecedented detail in reservoir characterization, enabling accurate predictions of both lithology and fluids. The incorporation of converted-wave data shows how an under-utilized dimension of seismic data can increase the quality of the solution. The VSP data was used to improve the seismic reservoir characterization by enabling high-quality calibration and integration of the converted shear (PS) data with the conventional P-wave (PP) data obtained from the multi-component 3D surface seismic.

Introduction

This is a case study that looks at the acquisition and application of a high resolution multi-component walkaway Vertical Seismic Profile (VSP) recorded in 2010 in the Athabasca oil sands region of Canada. This is an area with complex reservoirs, complex fluid distributions and unconventional rock property behavior. The target in the oil sands is typically less than 400m deep; in this study, the top of the zone of interest is at approximately 200m. In addition to the complexities mentioned above, shallow targets complicate conventional seismic methods (both surface and downhole) and they can be difficult to image due to variable near surface conditions. High quality, densely sampled 3D multi-component seismic data were acquired and processed with this in mind.

The VSP was the first to be acquired with a new type of downhole array designed specifically for shallow high resolution work. The data were used to improve the seismic reservoir characterization by enabling high-quality calibration and integration of the converted shear (PS) data with the conventional P-wave (PP) data obtained from the surface seismic. The incorporation of converted wave data shows how an under-utilized dimension of seismic data can contribute to unprecedented detail in reservoir characterization, enabling accurate predictions of both lithology and fluids.

Background

Historically (and still ongoing) the typical VSP in the oil sands would be acquired with a limited number of downhole sensors that necessitated moving the downhole tool and reshooting. The tool might have to be moved a number of times to get coverage over the whole well at the desired spatial interval. This method takes time and is less than ideal from a geophysical standpoint, particularly for high resolution work and particularly in the oil sands region (due to large and rapid changes in the near surface). In some cases, clients were left with two or more sparsely sampled VSP datasets (one from each move of the array) that could not be merged together to get the intended spatial sampling.

To address these problems of VSP data in the oil sands, something new was needed. The requirements were:

- Record high quality 3-component (3C) data;
- Have a tight receiver interval to avoid spatial aliasing of the data;
- Have sufficient sensors to cover the whole well in one run; and
- Be cost effective.

Existing downhole equipment was neither suitable nor cost effective, so a new type of array was designed. The HDVSP™ downhole array is based on the VectorSeis® digital MEMS sensors and is capable of over 2,000 channels of 3C data per borehole. The sensors can be deployed at 1m or 2m intervals from the surface down to the bottom of the well.

Method

The VSP was intended to be acquired simultaneously with the 3D surface seismic program, but the seismic crew arrived before the well had been drilled, so a 2D walkaway VSP was acquired a few weeks later. There were 141 3C sensors deployed in the well at 2m intervals, from a depth of 3.2m to 283.8m below ground level. A MiniVib was used as the energy source, sweeping from 10Hz to 300Hz. The data acquired was good quality, though there was often a significant variation in the source signature from VP to VP due to the rough lines and the frozen muskeg. Figure 1 shows some typical hodograms of the first breaks on the horizontal components, which illustrate the high vector fidelity and near perfect coupling achieved with the sensors, both important requirements to obtaining high quality shear wave data. An example of field data after rotation of the horizontal components can be seen in Figure 2. Some of the different types of waves in the data are identified.

Figure 1 Examples of the hodograms used for orientation analysis and for quality control.

The tight receiver interval is used to minimise spatial aliasing of the data since the shear wave velocities in the oil sands can be very low. The recommended receiver depth increment (DI) to avoid aliasing, is half the shortest (apparent) wavelength: $DI = \lambda / 2 = V_{\min} / (2 \times F_{\max})$

Using some values seen from this project:

P waves: $V_{p_{\min}} = 1900 \text{ m/s}$ $F_{p_{\max}} = 300 \text{ Hz}$ $DI = 3.2 \text{ m}$

S waves: $V_{s_{\min}} = 450 \text{ m/s}$ $F_{s_{\max}} = 250 \text{ Hz}$ $DI = 0.9 \text{ m}$

The shear velocity ranged from under 450 m/s in the top part of the well to over 1000 m/s at the bottom. Since the VSP was carried out at 2m intervals, there was some aliasing of the shorter wavelength data. These high frequency short wavelength converted waves are potentially very useful for imaging thin beds that cannot be resolved with the P wave data.

Figure 2 A near offset VP. Field data after rotation of the horizontal components, with AGC applied. Examples of downgoing P waves are indicated in blue; upgoing P waves in green; downgoing transmitted PS waves are indicated in orange and upgoing reflected PS waves in yellow.

Higher frequency shear waves are severely attenuated in the near surface, so downgoing direct shear waves tend to have poor frequency content. Shear waves generated below the weathering layer by PS mode conversion, have not suffered this attenuation and have higher frequency content. In Figure 3, the area marked as S_{up} has good frequency content, though it is spread over a range of velocities.

Figure 3 FK analysis of the window on the left, from a mid offset VP.

Seismic velocities derived from sonic logs are not always reliable, particularly in areas of heavy oil. Schmitt (1999) documented a noticeable difference between logs and VSP velocities in a heated heavy oil reservoir. Batzle et al. (2006) elaborates on how velocities and moduli of heavy oils are strongly temperature and frequency dependent. He points out how properties of heavy oils measured in the ultrasonic (10^5 – 10^6 Hz), sonic logging (10^4 Hz), and seismic (10–100Hz) frequency bands can have completely different values. Sonic velocities in the heavy oil zone are much higher than seismic frequency velocities collected by VSP and disagreements of more than 20% between seismic and logging frequencies can be expected. Batzle also notes that in any synthetic modeling of these reservoirs, the reflections of the heavy oil sands based on standard sonic logs would be completely different than those seen in the lower frequency seismic data.

Figure 4 shows the comparison of the VSP corridor stacks with the surface seismic data for the P-wave and PS-wave respectively. While the P-wave VSP compares very well with the seismic without filtering (frequencies up to 250Hz were common to both), the PS VSP was band-pass filtered down to 40Hz to match the PS seismic data.

Figure 4 Seismic to VSP comparisons; left – PP data, right – PS data.

The VSP was useful in confirming the correct phase rotations for both P and PS data, but was critical in depth-registering the two volumes so that seismic attributes from both volumes could be combined quantitatively. Reflections appearing in the PS data may not have a corresponding reflection in the PP data, and vice-versa. Tying the PP data and the PS data to depth before tying them to each other helps avoid erroneous assumptions about how the two should match.

A detailed quantitative interpretation workflow (including AVO, Inversion and multi-attribute analysis) was carried out on the 3D P-wave data for reservoir characterization and re-done for comparison incorporating the depth-registered PS attributes (Weston Bellman, 2012). Deterministic rock physics templates were created from the well logs and core facies to enable classification of the seismic attributes into a comprehensive facies and fluids volume. Figure 5 shows the final volume incorporating the PS data.

Figure 5 Final classified seismic volume incorporating depth-registered PS seismic attributes. Gamma ray logs are shown at the well locations; colour bar legend shown on the right.

Variability of the water thickness at the base of the reservoir is a known issue in this field. The water thickness predicted by each classified volume (with and without PS attributes) was compared to the actual thickness encountered in eight blind wells over the 3D seismic area. The plots shown in Figure 6 illustrate the predictive improvement made by incorporating the PS data.

Figure 6 Graphs comparing predicted bottom-water thickness (x-axis) with actual values from 11 wells (8 of them blind tests). The plot on the left is without using PS data and the one on right uses PS data. The red line shows the regression line fit to the data points and the black is the ideal 1:1 line.

Conclusion

A new type of down-hole seismic array was used to acquire a high resolution VSP, with 141 3C MEMS sensors spaced every 2m covering the full depth of the well. The quality of the data from the HDVSP™ array was remarkable, with low noise and excellent shear wave data. The VSP data was used to calibrate the densely sampled multicomponent 3D surface seismic, which was then put through a quantitative interpretation workflow, allowing detailed and accurate predictions of both lithology and fluids. The critical importance of depth registering the PP and PS data using the VSP data was noted.

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References

- Batzle, M., Hofmann, R. and Han, D. [2006] Heavy oils—seismic properties. *The Leading Edge*, **25**(6), 750-756.
- Schmitt, D.R. [1999] Seismic attributes for monitoring of a shallow heated heavy oil reservoir: A case study. *Geophysics*, **64**, 368-377.
- Weston Bellman, L.M. [2012] Incorporating 3-Component seismic data for enhanced detail in an oil sands reservoir and fluid characterization. *SEG International Exposition and 82nd Annual Meeting*, Las Vegas, Extended Abstracts, 1-5.