Using buried receivers for multicomponent, time-lapse heavy oil imaging

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Summary

In 2015 a time-lapse buried receiver 3C/2D seismic experiment was performed in the heavy oil area of NE Alberta, Canada. The purpose was to determine if on-going reservoir monitoring was feasible beneath a thick layer of muskeg. 3C analog geophones and digital sensors were installed at surface, 3m and 9m along with dynamite sources at 9m. Shot points were doubled at each source location in order to acquire data during winter conditions and also during the following summer.

The test was in response to poorly imaged seismic stacks and inversions from previously acquired 3C/3D surface seismic data. High quality time-lapse PP and PS images were produced from the 2D data when both the dynamite sources and receivers were buried to 9m depths. Recording PP and PS reflections that bypass the absorptive near-surface muskeg layer with buried receivers and sources facilitates time-lapse multicomponent seismic monitoring in this area.

Introduction

The study area, located near Fort McMurray, Alberta, overlies a portion of McMurray oil sands that will be developed using Steam Assisted Gravity Drainage (SAGD) techniques. Steam injection into the reservoir will be periodically monitored using time-lapse 3C/3D seismic data to understand why, where and how the heat moves.

Near-surface, low-velocity, heterogeneous layers can pose significant detrimental impacts on the quality of land seismic data. In some parts of Northern Canada a type of bog consisting of water and partly decomposed organic material, called muskeg, occurs at the surface. This muskeg can become thick enough to attenuate some PP and most PS seismic waves.

In this study area the muskeg has been measured up to 8m thick and was detrimental to an existing PP and PS 3C/3D surface seismic dataset. Figure 1 shows an example of PS converted-wave data from the 3C/3D dynamite surface seismic survey. The center part of the line, where the thick muskeg exists, demonstrates the severe absorptive effect on the shear-waves being recorded at the surface. The P-waves were also affected but to a lesser degree than the S-waves.

Time-lapse joint PP/PS pre-stack inversion has demonstrated its value in locating steam chambers and mobile bitumen within heavy oil reservoirs surrounding this study area (Gray et al., 2016; Zhang and Larson, 2016). Therefore, 4D joint inversion techniques are expected to form an integral part of the reservoir management for this SAGD project. These expectations led to the decision to investigate whether the quality of the seismic data could be substantially improved by planting dynamite sources and permanent buried receivers below the thick muskeg layer. In the winter and summer of 2015 a 3C/2D seismic line was acquired with buried receivers with the purpose of testing whether future high-quality 3C/3D time-lapse seismic monitoring was a possibility.

Design and Acquisition

The 2D seismic program was designed to answer not only the data quality issue (Pullin et al., 1987) but also address 3C processing and operational concerns related to sensor tilt and horizontal orientation.

The 2D test line was composed of six different sensors and two source configurations:

Sensor

1. 78 surface deployed 3C analog geophones every 10m
2. 78 surface deployed 3C digital MEMS accelerometers every 10m
3. 39 3m buried 3C analog geophones every 20m on the even stations
4. 39 3m buried digital MEMS accelerometers every 20m on the even stations
5. 39 9m buried 3C analog geophones every 20m on the odd stations
6. 39 9m buried 3C digital MEMS accelerometers every 20m on the odd stations

Source

1. 22 lines orthogonal to the receiver lines with two buried sources (0.125 kg dynamite @ 9m) every 20m
2. 1 line parallel to the receiver lines with two buried sources (0.125 kg dynamite @ 9m) every 20m

Figure 2 shows a map view of the layout of the central 2D line with receiver stations in red along with inline source stations and the source stations along orthogonal lines shown in green.

Front end preparations included widening an existing 3D receiver line to accommodate a Low Impact Seismic (LIS) drill for geophone installation. The LIS drill assisted with installing 0.125kg dynamite sources on both the grid and the 2D line. The duplicate source points employed 4” PVC pipes as both a monument and to protect the leads against curious wildlife.

A few analog and digital receiver planting poles were manufactured from three meter sections of steel pipe and fastened together with pinned steel couplers. An orientation tool was attached at the top and custom fitted cups attached to the bottom. The planting pole design proved cumbersome for the 3m and 9m buried receivers but was manageable in weather down to -10ºC. When temperatures plunged to -25ºC significant challenges were encountered with wet muskeg quickly freezing to the loading pole cups and couplers.

Sand points were attached to the sensors before installation to increase the coupling success rate and to aid in decoupling the tool from the sensor (Figure 3). 4” PVC pipe and colored caps were used at the surface as both a monument and to protect the cable and connectors against the elements and curious wildlife.

Wireless recording equipment was deployed and the sensors went through a series of QC’s to ensure they were operating correctly before acquisition. The recording equipment was collected in a methodical manner as to not confuse data from different sensors at different depths. The crew returned in the summer, using Argos in the extreme wet terrain (Figure 4), to re-deploy the recording equipment and re-acquire the data from the buried geophones.

Processing

Figure 5 shows a comparison of a dynamite shot gather being recorded into the vertical component of analog receivers at the surface, 3m depth and 9m depth. In several ways, Figure 5 illustrates the successful outcome of the buried-receiver experiment since the data recorded by the 9m receiver data is obviously far superior to the surface receivers and the 3m deep receivers. Not only are there much larger static delays present on the surface and 3m receivers than on the 9m receivers, but also there is much more variation in frequency content from trace to trace on the surface and 3m receivers. From Figure 5 it is evident that a good deal of the reflected energy returning to the surface is being absorbed by the muskeg layer. After observing the pre-stack gathers, it was decided not to process the 3m receivers since the 9m receivers were much better quality.

The first acquisition of the 3C/2D line took place in January, 2015, and the second took place in June, 2015. Figure 6 shows a comparison of the PS radial-component asymptotic-conversion point stacks from the surface receivers versus the 9m deep receivers from the winter acquisition. The zone of interest (the McMurray oil sands) is approximately at 400ms PS time on the 9m deep receiver section. The PS stack from the 9m deep receivers shows good quality, but it is impossible to interpret the surface-receiver PS section due to its poor quality.

One concern during acquisition was that the 3C down-hole receivers might move or twist in position over time. Analysis of the orientation of the 3C receivers between winter and summer indicated that the receivers had stayed in place in the 9m deep holes. It was unexpectedly discovered that several of the 9m deep receivers had inadvertently been placed down the hole in reverse-polarity orientation. This was an important finding for improving future acquisitions.

Based on comparisons such as those in Figure 6, it was decided to perform time-lapse processing of winter and summer datasets using only the 9m deep receivers, not the surface or 3m deep receivers. Although no production took place between winter and summer acquisitions, it was considered important to test the repeatability of the buried receivers and to test whether the processing flow could compensate for any changes in the seismic response between winter and summer. The decrease in NRMS from raw data through post-stack migration during the AVO-compliant processing steps of the PP 9m deep receiver data was from 130% to 20%. The decrease in NRMS to 20% after post-stack migration indicates that the non-repeatable factors were reduced to a level where time-lapse differences could be reliably detected, if SAGD production had occurred. Figure 7 shows the winter, summer and difference sections for the 9m deep receiver dynamite PP data.

The decrease in NRMS of the radial converted-wave PS data through the major AVO-compliant processing steps was from 130% to 40%. The decrease in NRMS down to 40% (compared to 20% for the PP data) is to be expected for the noisier, narrow-band PS data. Figure 8 shows the winter, summer and difference sections for the 9m deep receiver, dynamite PS data.

Conclusions

The acquisition and processing of the 3C/2D test line successfully demonstrates that high-quality 3C images can be obtained if both the sources and receivers are buried beneath an extremely absorptive muskeg layer.

Acknowledgements

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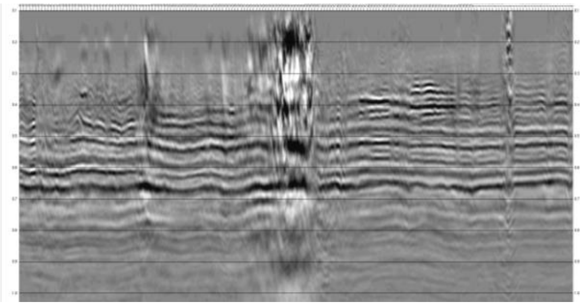

Figure 1: A PS converted-wave section from a 3C/3D seismic survey acquired with receivers at the surface. The location of thick muskeg at the surface is evident from the absorption of the shear waves (particularly visible in the central portion of this section). The location of the 2D test line with buried receivers is at the center of this crossline from the 3C/3D survey.

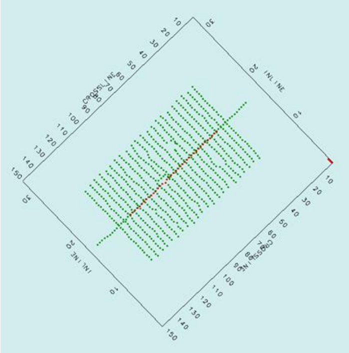

Figure 2: Map view of the acquisition location of the 3m and 9m buried receivers (in red) along the 2D line and the dynamite sources (in green) along the 2D line as well as along lines orthogonal to the central 2D line.

Figure 3: Custom sensor cup at end of loading pole with 3C analog geophone and sandpoint. Orientation tool.Recording equipment connected and QC'd. Planting tool in action.

Figure 4: Summer operations using Argos in the extremely wet conditions

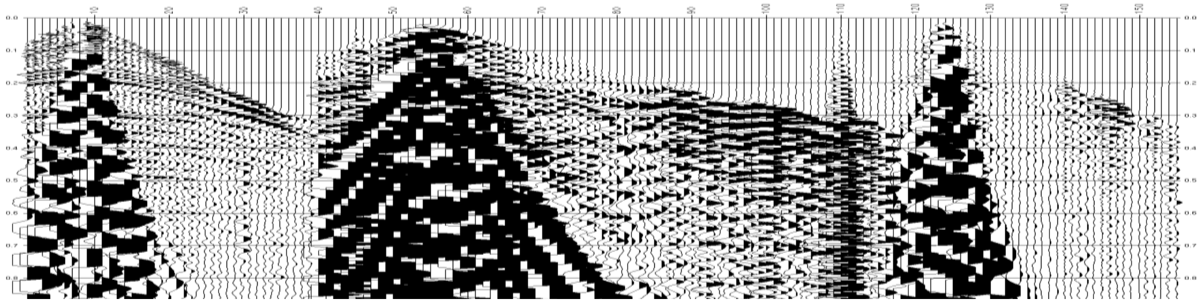

Figure 5: The vertical component of a dynamite shot gather recorded by 9m deep receivers (left), receivers at the surface (center) and 3m deep receivers (right). The highest quality, most coherent, broadest bandwidth reflections were recorded on the 9m deep receivers since the down and upgoing raypaths do not pass through the absorptive muskeg layer at the surface.

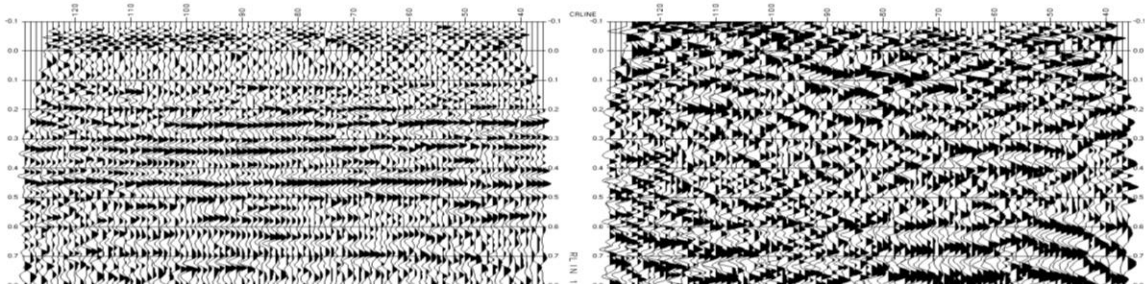

Figure 6: Radial PS converted-wave stacks recorded by 9m deep receivers (left) and by receivers at the surface (right).

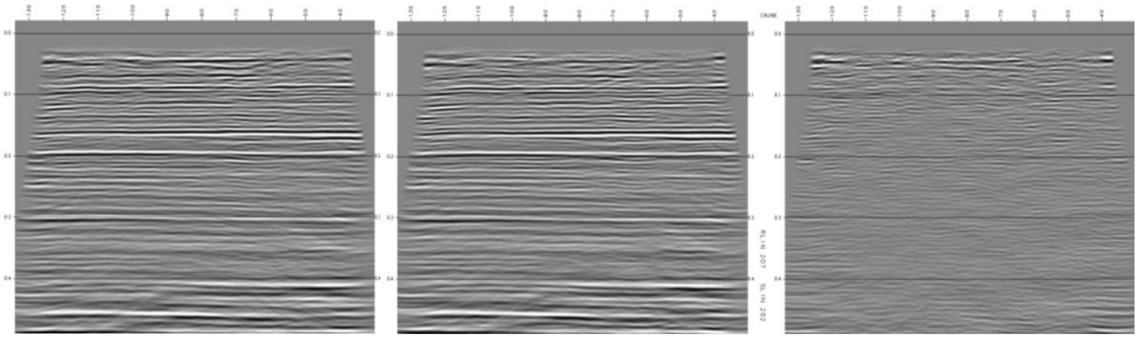

Figure 7: Final migrated PP stacks recorded with 9m deep receivers from the winter (left), summer (center) and difference (right).

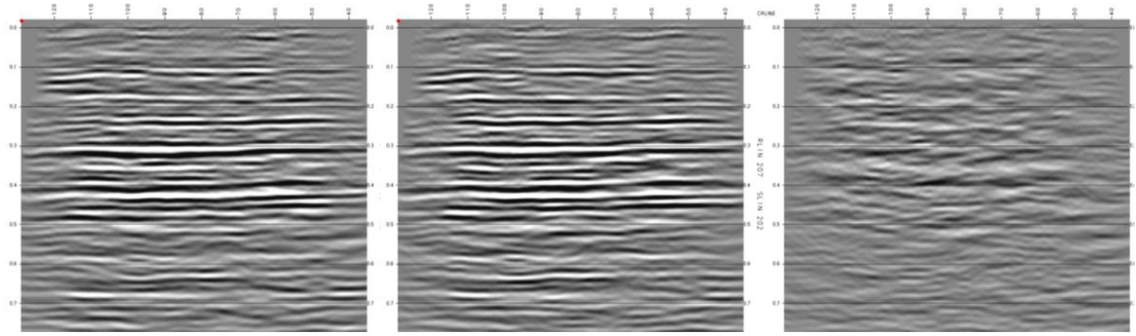

Figure 8: Final migrated PS stacks recorded with 9m deep receivers from the winter (left), summer (center) and difference (right).

EDITED REFERENCES

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