Initial 3C-2D surface seismic and walkaway VSP results from the 2015 Brooks SuperCable experiment

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Summary

A 3C walkaway VSP and surface seismic experiment was conducted at the Containment and Monitoring Institute (CaMI) Field Research Station (FRS) in May of 2015. The FRS is located near the town of Brooks in southern Alberta, Canada. Multiple objectives for the program included student training, surface source and receiver comparisons, multi-component walkaway VSP acquisition, and velocity tomography for site characterization.

Two parallel NE-SW receiver lines were laid out with one line centered on a well and the other offset 100 m to the northwest. Both receiver lines had single-component geophones at a 10 m receiver spacing. In addition, the line centered on the well had three-component geophones at a 30 m receiver spacing. A tool with three-component geophones was deployed within the well at three different levels, giving receiver positions from 106 to 496 m depth at a 15 m spacing.

Two source lines centered on the well location, one linear with a vibe point (VP) every 10 m and the other semi-circular with a VP every 5 degrees were acquired three times, once for each tool position in the well. The source was an IVI EnviroVibe using a variety of filtered and unfiltered maximal length sequence pilots (m-sequences) as well as a linear 10-200 Hz sweep. This abstract presents a first look at the data and some early results.

Introduction

A 3C walkaway VSP and surface seismic experiment was conducted at the Containment and Monitoring Institute (CaMI) Field Research Station (FRS) in May of 2015. Two parallel NE-SW receiver lines were laid out with one line (Line 108) centered on well CMCRI COUNTESS 10-22-17-16, and the other (Line 106) offset 100 m to the northwest (Figure 1). Receiver lines 106 and 108 had single-component SM-24 geophones at a 10 m receiver spacing connected to an Inova (ARAM) Aries SPML recorder. In addition, receiver line 108 had three-component SM-7 geophones in nail-type casings at a 30 m receiver spacing recorded by Inova Hawk nodal systems. A three-component ESG SuperCable was deployed in the well at three different levels, giving receiver positions in the well from 106 to 496 meters depth at a 15 m spacing. These data were recorded using ESG Paladin recorders. A Geode recorder was present in the cab of the EnviroVibe in order to record auxiliary traces from the Pelton decoder that was in the Vibe.

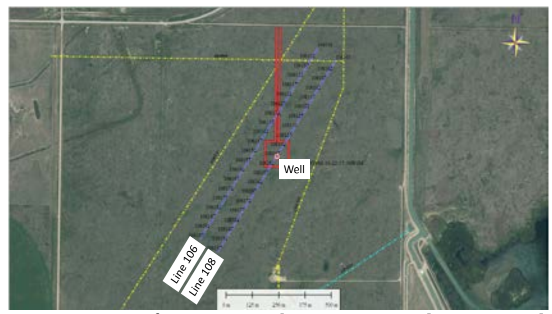

Figure 1: Map of survey area showing receiver lines 106 and 108 (blue dots). Buried pipelines are plotted as yellow/cyan dash-dot lines. The access road and well pad are shown as solid red lines, and the well location is a red bulls-eye. North is up. Background photo courtesy of Newell County, Alberta.

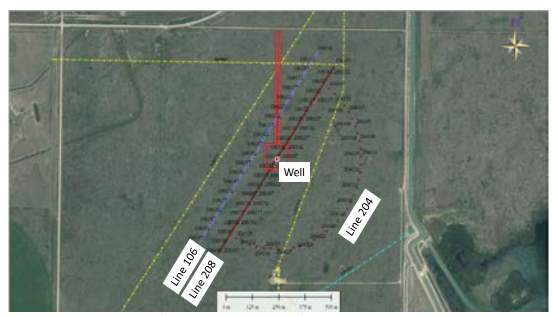

Figure 2: Map of survey area (cf. Figure 1) showing source lines 204 and 208 (red dots).

Two source lines were acquired three times, once for each tool position in the well (Figure 2). The source was an IVI EnviroVibe sweeping from 10-200 Hz linearly over 16 s with an additional 4 s listening time. Source line 208 (NE-SW) had a Vibe Point (VP) every 10 m for surface 2D seismic and walkaway VSP. A semi-circular source line (Line 204) with a radius of 400 m and a VP every five degrees was acquired for a velocity tomography study. Finally, source line 208 was re-acquired using a variety of filtered and unfiltered maximal length sequence pilots (m-sequences) while the SuperCable was removed from the well.

Initial Results

P-P and P-S synthetic offset gathers calculated from well log data show good reflectivity in the zone of interest. Travel-time variations for source line 204 and a receiver at 383.5 m depth (Figure 3) show a several millisecond travel time variation. The fast wave propagation direction (with minimal travel time) coincides with the direction of the NE-SW line and generally follows the orientation of regional maximum horizontal compressional stress. This indicates the existence of weak HTI anisotropy likely due to fractures aligned by the regional maximum horizontal stress field.

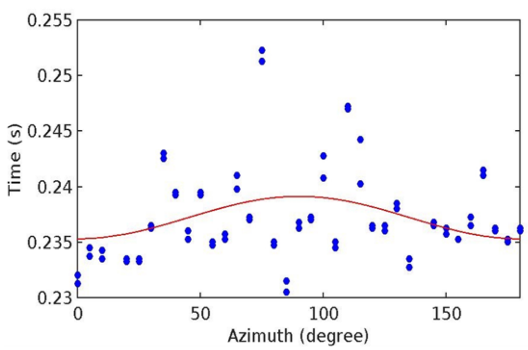

Figure 3: Line 204 travel time variations for receiver at 383.5 m depth

Twenty second uncorrelated VSP source gathers were created from the ESG continuous data, and were then vertically stacked and correlated with TREF. A maximum power two-component rotation was applied to rotate the horizontal components to radial and transverse components. (Figure 4). The P-wave velocity measured for depths 166-496 m (excluding the first four traces) is 2740 m/s. We observe strong down- and up- going events that do not have the same slope as the first breaks. Picking a slope from this up-going wavefield gives a velocity of 1370 m/s which in turn gives a Vp/Vs ratio of 2.0. Average Vp/Vs from the Vp/Vs well log is 2.09. Therefore, we are seeing up-going S-waves for a Vibe point 20 m from the well. Figures 5 and 6 show Figure 4 after attenuation of down-going P-waves and flattening the up-going P- and up-going S-wavefields based on first break pick times.

At selected vibe points on source line 208, we recorded data on receiver lines 106 and 108 for two sets of m-sequence pilots: a pure m-sequence set, and a filtered m-sequence set. Each set has four members. The pure m-sequences are characterized by step-function-like

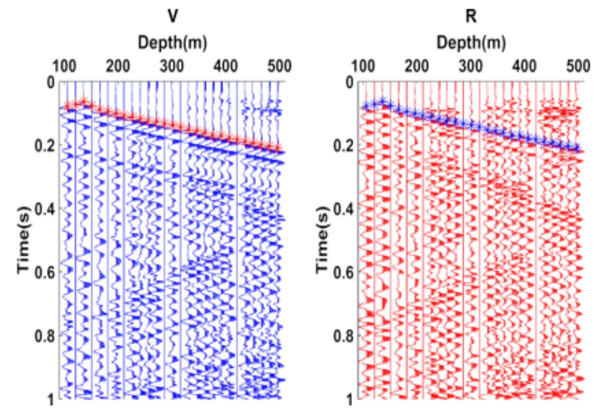

Figure 4: Vertical and radial component unprocessed P-P and P-S correlated source gathers for VP 208149.

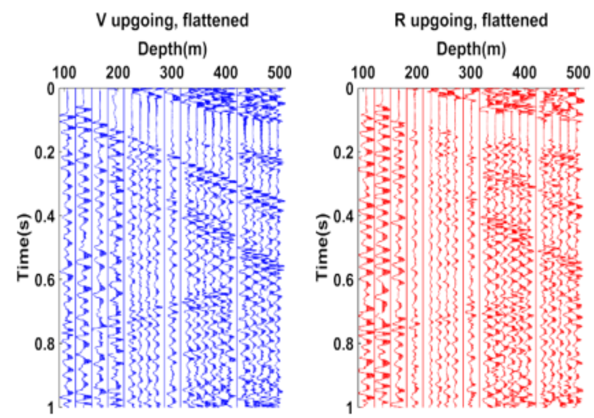

Figure 5: VP 208149 flattened for up-going P-waves after attenuation of down-going P-waves.

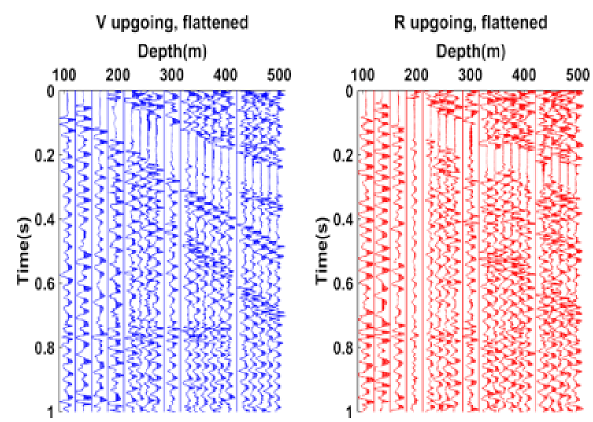

Figure 6: VP 208149 flattened for up-going S-waves after attenuation of down-going P-waves.

transitions between two values -1 and +1. The pure-sequences were modified by an Ormsby bandpass filter with corners at [5-10-200-250] Hz. The m-sequence pilots were all 16.376 seconds long. For comparison purposes, we also recorded data using a standard linear sweep pilot (10 to 120 Hz swept over 16 seconds with 500 ms end tapers). In all cases, listen time was 4 seconds, and in all cases we recorded both correlated and uncorrelated data as well as the signals from accelerometers mounted on the base plate and reaction mass of the vibrator. It is hoped that these accelerometer signals will provide clues as to how the hydraulically-powered vibrator reacts to the sharp/smoother transitions that are characteristic of pure and filtered m-sequences.

Pure m-sequences are used to estimate the impulse response of linear systems (among many other uses). The fact that the EnviroVibe generates multiples (which are considered to be artifacts; Figure 7) in seismograms when driven by pure m-sequences means that the EnviroVibe is not a perfectly linear system, especially at high frequencies since it cannot respond accurately to the step-function-like transitions characteristic of pure m-sequences. Bandpass filtering the m-sequence before using it as a sweep introduces side-lobes in the wavelet, although smaller ones than seen for a linear sweep. It also reduces the prominence of the source-generated multiples in the recorded data (Figure 8). Figure 9 shows the same VP acquired with a linear sweep for comparison. It is difficult to see at this scale, but the amplitude spectra for the m-sequence gather contains more energy above 250 Hz than the amplitude spectra for the filtered m-sequence gather.

Examination of these preliminary results indicates that the pure m-sequences and the particular filtering applied are not well suited for the EnviroVibe and its Pelton controller. It appears that the pure and currently filtered TREF pilots probably should not contain any energy above 125 Hz. In addition, we have not yet succeeded in ascertaining how the many settings available in the Pelton controller should be set in order for the hydraulics and position controls to best allow the ground force signals to closely follow the m-sequence TREF signal (for example: Should the phase lock be disabled? Can we prevent the controller from “learning”, which causes the ground force to grow with repeated sweeps?).

Surface seismic processing included refraction statics, air blast attenuation, spike and noise burst edit, surface wave noise attenuation, and Gabor deconvolution. In order to compare Aries to Hawk data, we post-stack migrated receiver stacks using a finite difference migration and applied a bandpass filter of 10-15-80-90 Hz. The migrated data are shown in Figure 10, which also shows for comparison an arbitrary line extracted from a 2014 3D

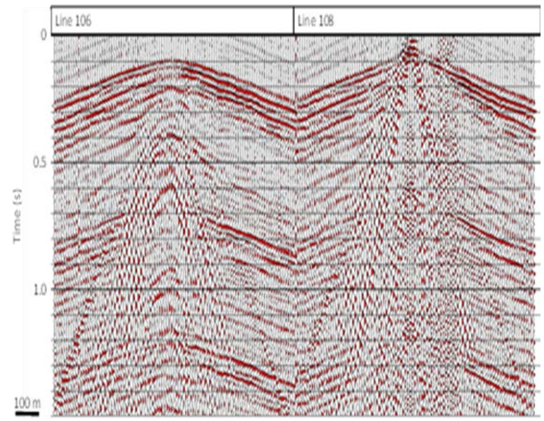

Figure 7: VP 208149 acquired using an m-sequence sweep. Bandpass and AGC for display.

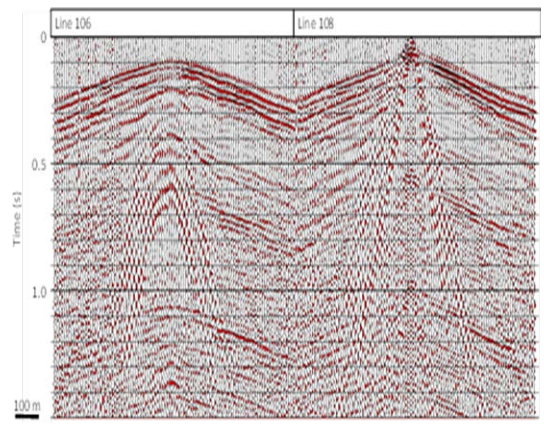

Figure 8: VP 208149 acquired using a 10-200 Hz bandpass filtered m-sequence sweep. Bandpass and AGC for display.

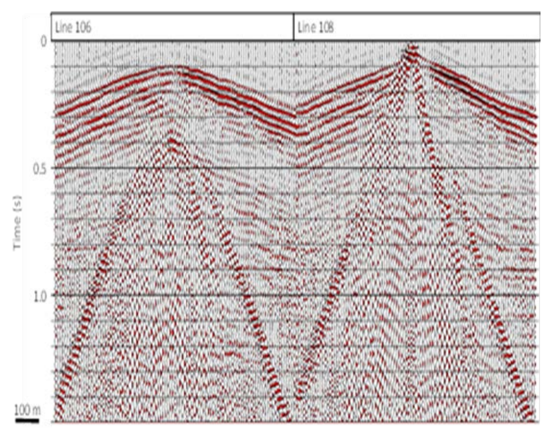

Figure 9: VP 208149 acquired using a linear 10-200 Hz sweep. Bandpass and AGC for display

volume coinciding with the 2015 2D line. The strong event at about 0.25 s corresponds to the Basal Belly River sandstone, which is the primary CO_2 injection target at this site.

While we know from a 2014 3D survey that good quality converted wave data can be obtained at this site at the same time of year and with the same near-surface ground conditions, multi-component surface seismic results from the 2015 data are disappointing. Differences between the 2015 and 2015 include both decreased source and receiver effort as well as restricted azimuthal coverage.

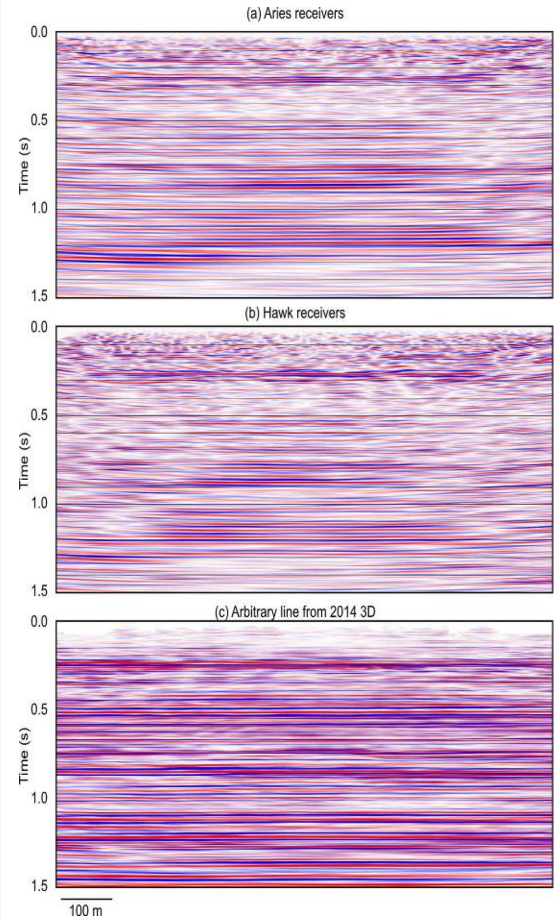

Figure 10: Post-stack migrated receiver lines. (a) and (b) are the Aries and Hawk data, respectively, and (c) is an arbitrary line extracted from a 2014 3D volume corresponding to the location of the 2015 2D line. Data have an AGC applied for display.

Discussion

A variety of seismic work was successfully completed at the Containment and Monitoring Institute (CaMI) Field Research Station (FRS) in May of 2015. Over the course of two days data were acquired for a variety of experiments, including a walk-away 3C VSP, data for a velocity tomography study, 1C-2D and 3C-2D surface seismic, and m-sequence sweep tests. This report has shown examples of field data as well as some preliminary processing results.

Future work

There are a number of projects that will result from these data. We plan to finalize processing of the radial component of the 3C-2D surface data, as well as process the zero-offset VSP to P-P and P-S corridor stacks and process the multicomponent walk-away VSP data. We can simulate multiple Vibes simultaneously running different m-sequence sweeps, and see how successfully the source gathers can be separated and processed to migrated sections. We can study how best to attenuate (or use) source- generated m-sequence multiples. Finally, everything needs to be interpreted and inverted.

Acknowledgements

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