Cvictus VSP

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ABSTRACT

CREWES participated in the acquisition of walk-away baseline and monitor crosswell and vertical seismic profile (VSP) surveys at a Cvictus combined hydrogen production and carbon dioxide sequestration site in central Alberta in early 2022. Fifteen hundred tons of CO_2 were injected between the baseline and monitor surveys. Distributed acoustic sensing (DAS) data were acquired for downhole sparker data over a 150 m depth interval for the cross-well baseline survey and a 38 m interval for the cross-well monitor survey with a nominal twelve shots per depth level. Vibe Points (VP) on four different azimuths centered on the observation well were acquired with eight sweeps per VP for the baseline VSP and sixteen sweeps per VP for the monitor survey. Initial time-lapse zero-offset VSP processing of a single VP shows no obvious post-injection amplitude or time-delay anomaly at reservoir depth. More work, including modelling and full processing of the 2D walkaway VSP source lines is in progress.

INTRODUCTION

Cvictus Inc. has a combined hydrogen production and CO_2 sequestration project underway in central Alberta called the Mannville Project. In early 2022, the site consisted of an injection well and an observation well that intersect a coal seam located at approximately 1500 m depth. Both wells are vertical and are spaced 50 m apart. The observation well has single mode engineered fiber that was provided by Baker Hughes. The fiber is installed from surface to the bottom of the well and is terminated at the bottom of the well.

CREWES was approached to provide a DAS interrogator and an operator to record seismic data for a cross-well survey that was to be conducted using a small electrical sparker source operated by Avalon Sciences Ltd. (eg. Wills et al., 2014) on a cost recovery basis. The initial plan was to fire the sparker source in the coal seam only. This plan evolved into an attempt to acquire a full cross-well survey using the sparker. In addition, we suggested transporting the University of Calgary's IVI EnviroVibe to the site in order to acquire a walk-away VSP survey on the fiber.

Cross-well and VSP baseline DAS surveys were acquired in February of 2022 and monitor cross-well and VSP DAS surveys were acquired in March of 2022 after injection of 1500 tons of CO_2 into the coal seam. Data were recorded on the University of Calgary's OptaSense ODH4 and simultaneously on a Baker Hughes SureView. Baker Hughes measured 140 m of surface fiber between the interrogators and the well head using an OTDR. The baseline VSP was only recorded on the OptaSense interrogator. Both interrogators were run with a 7 m gauge length and 1 m trace spacing. The Baker Hughes interrogator remained on site and recorded data for the duration of CO_2 injection. In total, the two interrogators generated about 22 Tb of continuous field data.

CROSS-WELL SURVEY

The sparker was fired twelve times per source point from 1515 m to 1365 m at a 2 m depth interval for the baseline survey on February 21, 2022. Acquisition took about 7 hours, not including tool deployment, troubleshooting, and retrieval from the well. GPS time of shot was provided by Avalon Sciences, who also operated the sparker tool.

The monitor survey was acquired from 1513-1475 at a 2 m depth interval, and from 1475-1401 m at a 6 m depth interval on March 7, 2022 with cold temperatures and high winds. A boiler truck was parked close to the observation well head on the upwind side, with plywood and tarps to attempt to mitigate wind noise at the observation well head. The source was fired 12 times per depth level except for 1513 m (100 shots), 1493 m (100 shots), 1473 m (100 shots), and 1401 m (54 shots).

The increased source effort at some depth levels in the monitor survey was because we were not certain we could see any energy from the sparker on the OptaSense Interrogator's live display in the field during the baseline survey. The change from 2 m depth intervals to 6 m intervals and acquisition of 54 shots at 1401 m instead of 100 are because we were shooting to a time limit. Total acquisition time for the monitor survey was about 5.5 hours, not including tool deployment, troubleshooting, and removal from the well.

Sparker data source gather extraction and stacking is in progress. Initial impressions are that we were either unable to record the sparker source with the OptaSense interrogator, or we have issues with the GPS time of shot. We need to confirm time-zones and determine if GPS leap-seconds are a factor. In addition, we are planning to run the continuous DAS data through event detection software in hopes of locating sparker events at the expected depths for each shot.

VSP SURVEY

The VSP survey was initially designed based on the walk-away walk-around surveys that we have conducted at Carbon Management Canada's Newell County Facility (eg. Hall et al, 2018, Innanen et al., 2022), centered on the Cvictus observation well. The design quickly collided with reality in the form of topography, land ownership, and infrastructure on the well lease, resulting in the Vibe Point (VP) locations shown in Figure 1. The far offset VP to the southeast and south of the observation well were not re-acquired during the monitor survey. VP line numbers are the bearing relative to grid north, and station numbers are meters from the well. For example, VP 47040 is located approximately 40 m from the well to the northeast. There was some concern about our ability to generate enough energy to image the 1500 m reservoir depth with a small Vibe. We have previously been able to image reflectors at approximately this depth with two EnviroVibes running two sweeps per VP in a high-fold surface 3D survey (eg. Figure 3; Isaac and Lawton, 2014), so we arbitrarily decided to increase the source effort by running our single EnviroVibe with eight sweeps per VP for the baseline VSP survey, and VP 2010 with sixteen sweeps.

The sweep used was a 10-100 Hz linear sweep over 16 s. We acquired data for 49 VP in about 4 hours of production shooting. The ground was frozen for this survey, but surface temperatures were slightly above 0 ºC, leading to snowmelt and surface mud on the well lease over the course of the day. Figure 2 shows signal-to-noise improvements with increased vertical fold at VP 2101 from the baseline survey as recorded on the OptaSense ODH4. These data are plotted with no scaling or filtering. Horizontal bands of noise that can be observed on the data are primarily due to a nearby diesel generator, door slams and footsteps inside the trailer that was housing the interrogator.

The monitor survey was acquired on March 8. Temperatures were close to -30 ºC and the ground was well frozen. VP were acquired with 16 sweeps per VP, based on the VP 2101 baseline results (Figure 1), with the exception of VP 272010, which was acquired with 24 sweeps. A total of 43 VP were re-acquired over the course of 5 hours.

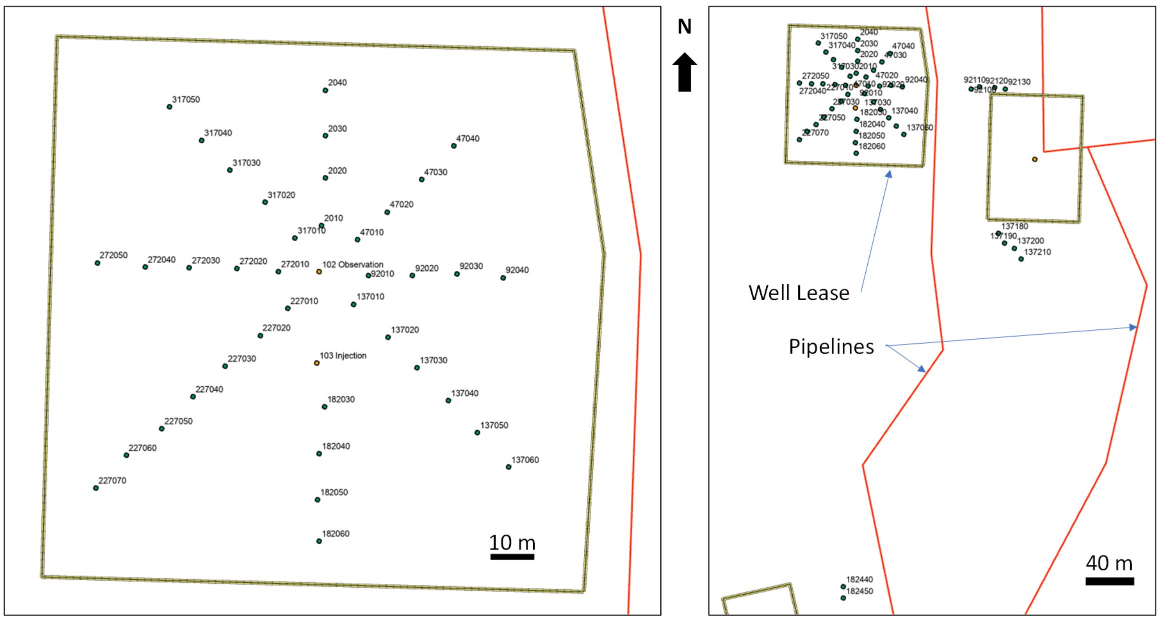

FIG. 1. Map of VP on well lease (left), repeated at a larger scale (right) to show three patches of far-offset VP, located to the E, SE, and S of the observation well.

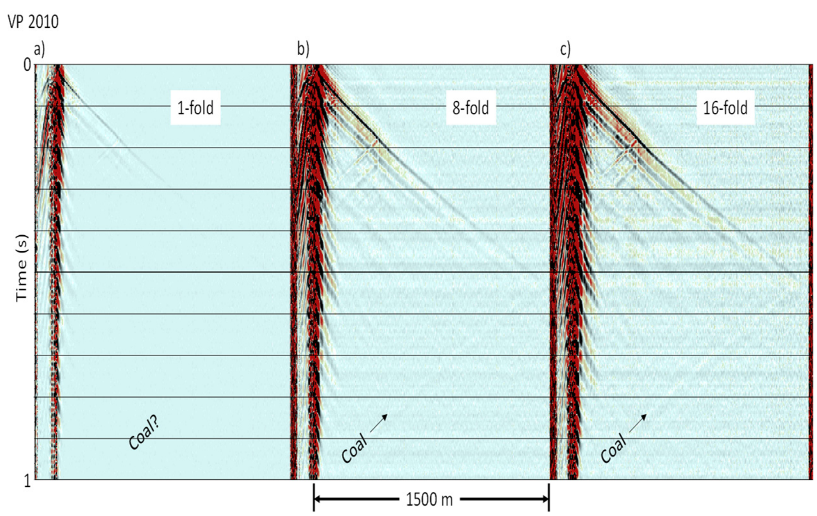

FIG. 2. February VP 2010 data with vertical fold equal to one (a), eight (b) and sixteen (c) showing signal to noise improvement with increased source effort. Data are displayed with no scaling of filtering.

RESULTS

We have begun zero-offset VSP processing for the OptaSense data. Figure 3 shows sixteen vertical fold data for VP 2010 from the monitor survey with AGC for display, beginning with stacked and correlated field data on the left (Figure 3a). Strong horizontal bands of noise seen on this source gather are due to noise source at or near the interrogator location in a trailer on the wellsite, including a diesel generator, door slams, and footsteps. Figure 3b shows the same data after application of a *f-k* pie-filter filtered to exclude velocities greater than 8000 m/s. Figures 3c and 3d display the down-going and up-going wavefields after wavefield separation by *f-k* filtering, again with 8000 m/s velocity limits.

First-break picking was conducted by picking the peak of the direct arrivals on the sixteen-fold March monitor survey down-going wavefield data (blue line; Figure 3c) because it has a better signal-to-noise ratio than the eight-fold data. Unfortunately, data quality is still poor from above the reservoir to the bottom of the well, and picks at these depth levels were hand drawn rather than being data driven. First-break picks were then copied to the February baseline data and the March up-going wavefield data (blue line; Figure 3d).

Figure 4a show the up-going wavefield from Figure 3 after flattening and applying a top mute based on the first-break picks, and Figure 4b shows the stacked result. Figure 4c shows Figure 4a after applying a bottom mute based on bulk-shifted first-break picks to exclude multiples, and Figure 4d shows the resulting corridor stack. The single stacked output trace for this VP trace has been duplicated ten times to aid visibility in Figures 4b and 4d.

We generated a synthetic seismogram in Synth (available to CREWES sponsors in the CREWES Matlab toolbox) using a P-wave slowness log (DTP log) from the observation well and the 10-100 Hz Vibe sweep that was used in the field. Dominant frequencies at the reservoir depth are observed to be in the 20-30 Hz range (not shown). Figure 5 shows a comparison between the synthetic and the monitor survey corridor stack after bandpass filtering with an Ormsby 5-10-30-35 Hz filter. The trough in the synthetic that corresponds to the coal reservoir has been bulk shifted to line up with the high amplitude peak-trough-peak in the corridor stack that was interpreted to be the coal prior to creation of the synthetic. As is typical with synthetic data derived from well logs, the shallower reflections will not line up with the seismic data without stretching the synthetic. Overall, there is a good character match, which lends confidence to the initial corridor stack results.

Figure 6a shows a comparison of the February and March stacks for VP 2010, with a shallow trough and the interpreted reservoir trough picked (blue lines). Differences in reflectivity can be seen between these two picks, which appear to be primarily low amplitude noise that has been brought up by the AGC that was applied for display. Figures 6b and 6c show zoomed in displays of Figure 6a. The coal picks are at the same time, and there are no apparent amplitude anomalies post-injection that are visible at this stage in the processing. Figure 7 show the same comparison, but for the February and March corridor stacks. In this case, the shallow event time is comparable between the baseline and monitor surveys, but the March coal pick is 4 ms later than the February pick. We do not believe

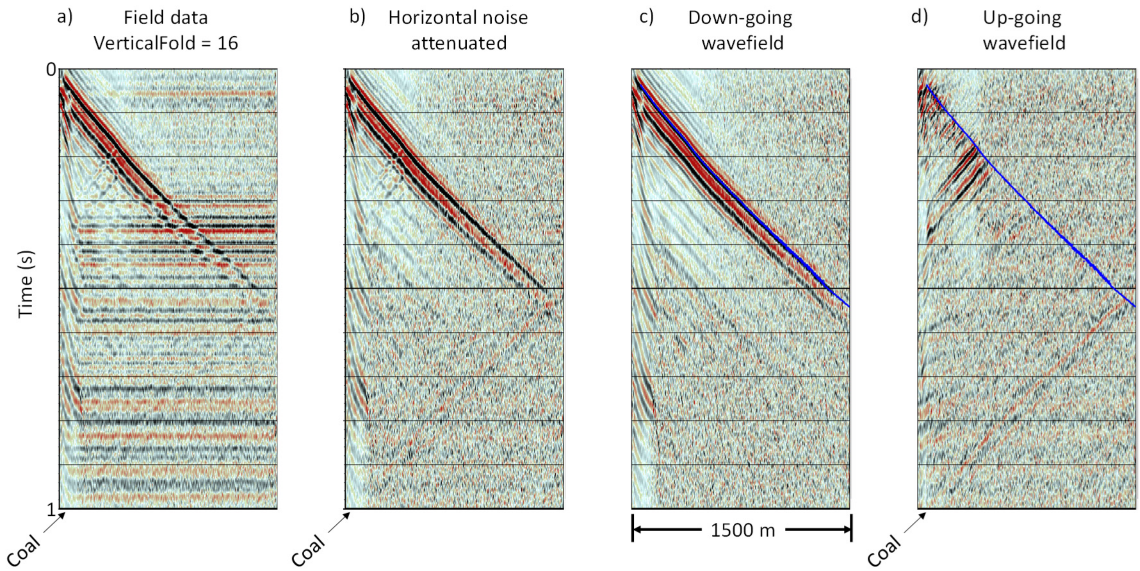

FIG. 3. March VP 2010 field data with vertical fold equal to sixteen (a), after removing horizontal noise bands using a *f-k* filter with 8 km/s cut-offs (b), and the down-going (c) and up-going (d) wavefields separated using *f-k* filters. Data are displayed with a 500 ms window AGC.

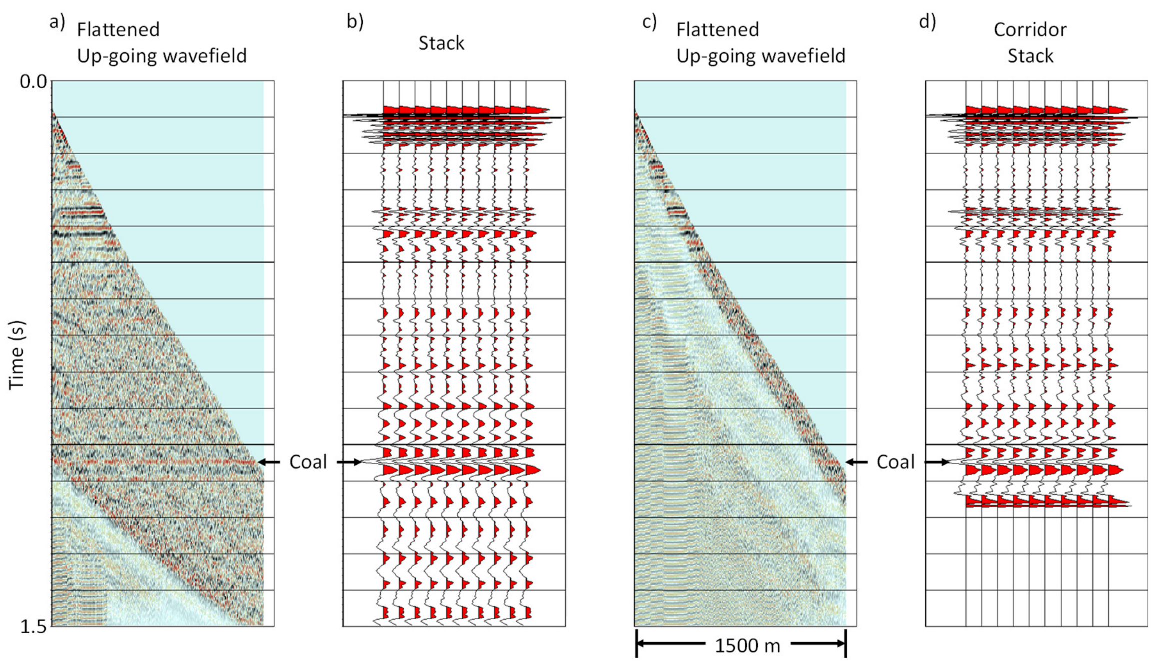

FIG. 4. March VP 2010 field data with vertical fold equal to sixteen after flattening on first-break picks (a) and stacking (b), and after applying a bottom mute (c) and corridor stacking (d). Data are displayed with a 500 ms window AGC. The stacked trace(s) have been repeated ten times for visibility (b and d).

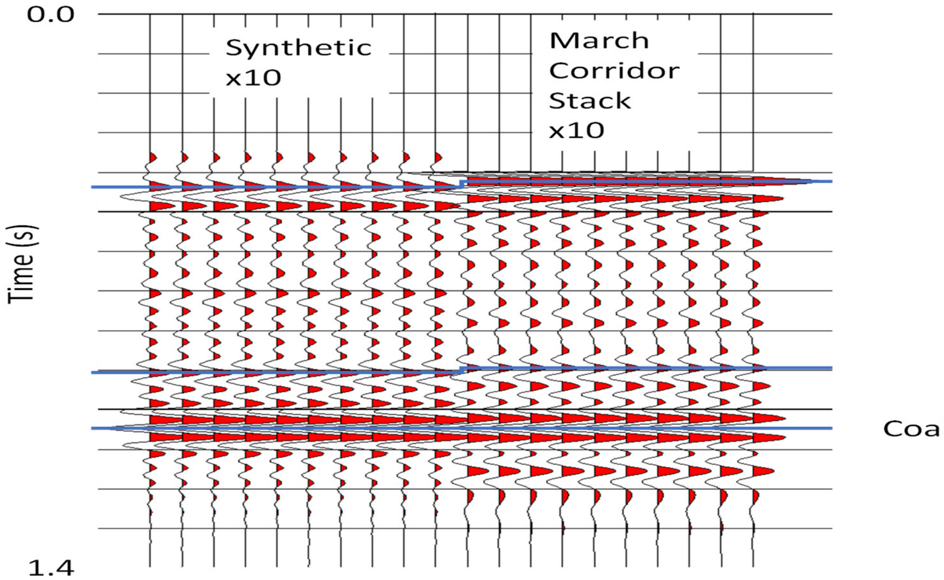

FIG. 5. Initial comparison of a synthetic seismogram (left) to the March VP 2010 corridor stack (right; Figure 4d). Data are displayed with an Ormsby 5-10-30-35 Hz filter and a 500 ms window AGC. The synthetic has been shifted to line up the trough associated with the coal but has not been stretched to better match shallower reflections. The synthetic and stacked trace(s) have been repeated ten times for visibility.

this time-delay is related to CO_2 injection but is rather due to incorrect-flattening of the reflection close to the direct arrivals prior to stacking due the poor quality of the first break picks at reservoir depth. This should be addressed by further attempts at noise reduction to facilitate first break picking at reservoir depths, and possibly by running residual statics after noise attenuation and flattening the up-going wavefield

DISCUSSION AND FUTURE WORK

CREWES participated in Cvictus cross-well and VSP surveys in early 2022, where 1500 tons of CO_2 was injected into a coal reservoir at approximately 1500 m depth between the baseline and monitor seismic surveys. The cross-well survey was conducted with an electrical sparker source from Avalon Sciences, and the surface VSP surveys used the University of Calgary's IVI EnviroVibe with a nominal 8 sweeps per VP for the baseline survey and 16 sweeps per VP for the montor survey. DAS data were recorded on single-mode fiber in an observation well with two different interrogators, one OptaSense ODH$ from the University of Calgary and one SureView from Baker Hughes. the baseline VSP was only recorded on the OptaSense interrogator. The SureView interrogator was run in continuous acquisition mode over the course of injection.

A first pass of source gather extraction from the continuous DAS data has been completed for all four surveys. We have thus far not seen any signs of the sparker source on the OptaSense data. We need to confirm time-zones and determine if GPS leap seconds are a factor for time-of-shot. Additionally, we intend to run event detection software on the continuous DAS data to look for sparker events in the data independent of the GSP timing. It would also be interesting to run event detection on the Baker Hughes data to look for microseismic events that may have occurred during injection.

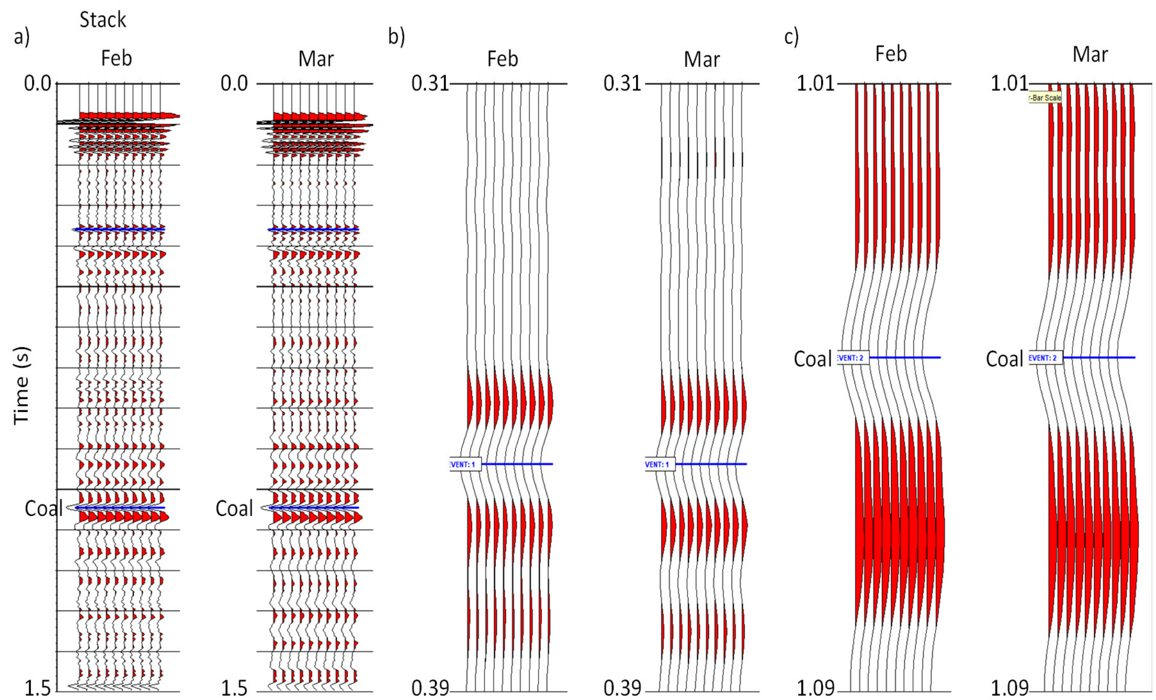

FIG. 6. February (vertical fold = 8) and March (vertical fold = 16) stack comparison (a) 0-1.5 s, (b) (0.31-0.39 s, (c) 1.01-1.09 s. The stacked trace(s) have been repeated ten times for visibility and with a 500 ms AGC.

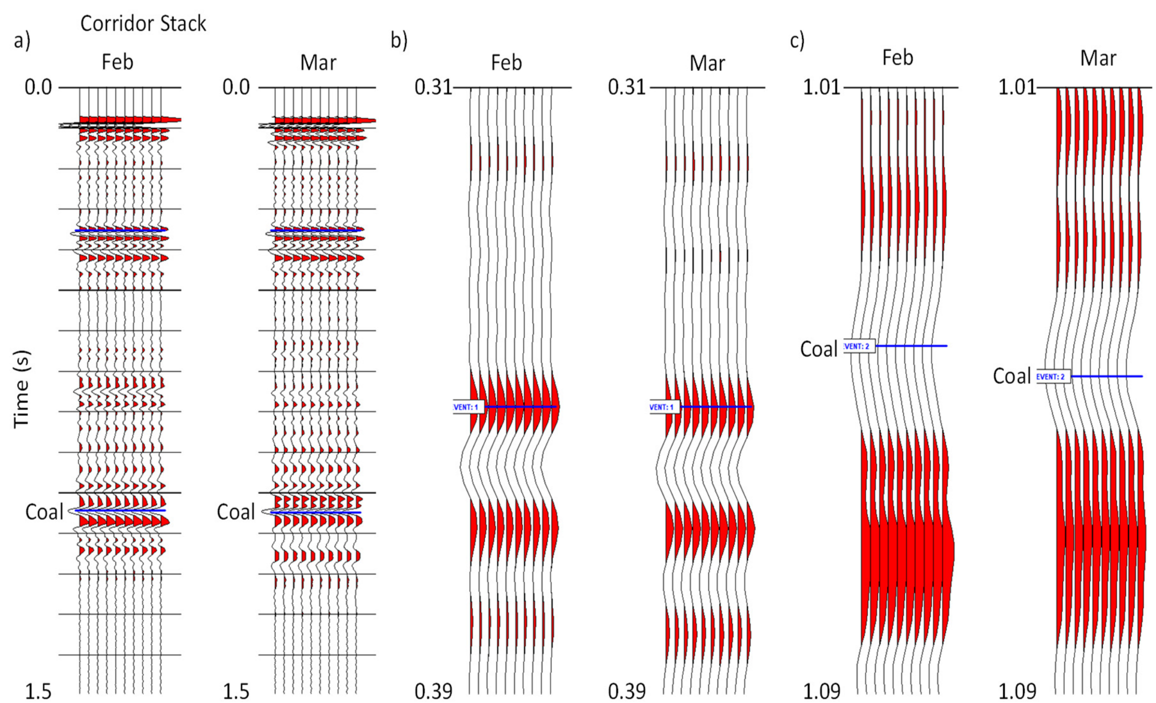

FIG. 7. February (vertical fold = 8) and March (vertical fold = 16) stack comparison (a) 0-1.5 s, (b) (0.31-0.39 s, (c) 1.01-1.09 s. The stacked trace(s) have been repeated ten times for visibility visibility and with a 500 ms AGC.

We did not know prior to this project if we would be able to put enough energy in to the ground with our EnviroVibe to be able to image a reflector at 1500 m depth, although results from prior high-fold surface 3D surveys at other sites suggested that it would be possible. We have shown that we can see reflections from the coal on our VSP data, even at the farther source offset (not shown), but the signal-to-noise ratio at reservoir depth is poor even with sixteen sweeps per VP. For future work at this site, we would suggest increasing the source effort by using more sweeps per VP with a small vibe, or by using a larger Vibe.

Initial VSP processing to stacked traces show a good character match to synthetic seismic data calculated from well logs. There is a good match between baseline and monitor survey stacks, with no time-delay or amplitude anomalies due to CO_2 injection being found at this stage of the VSP processing. A comparison of baseline and monitor survey corridor stacks does show character changes and 4 ms time delay for the reservoir pick. This is likely due to the coal reflection not being flattened correctly due to poor quality first break picks resulting from the poor signal-to-noise ratio for direct arrivals at depth.

Further VSP processing is underway. We need to improve the quality of our first break picks at depth in some way that is yet to be determined. We could also try running residual statics on the flattened up-going wavefield, the success of which will also depend on signal-to-noise. Final processing steps will include the generation of interval velocities, deconvolution and VSP-CDP transform or migration and stacking to simulate surface seismic for the walk-away source lines. Further inspection for possible CO_2 anomalies can then be performed on those results. We perform some modelling to simulate seismic response to future reservoir states.

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