The initial appraisal of buried DAS system in CO2CRC Otway Project: The comparison of buried standard fibre-optic and helically wound cables using 2D imaging

Shortened title form: The comparison of buried DAS cables using 2D imaging

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KEYWORDS

Distributed Acoustic Sensor, Helically Wound Cable, Seismic Monitoring

ABSTRACT

This study aims to assess the ability of shallow Distributed Acoustic Sensing (DAS) to serve as a cost-effective seismic sensor array for permanent monitoring applications. To this end, as part of the CO2CRC seismic monitoring program, a fibre-optic DAS array was deployed alongside a permanently buried geophone array at the Otway Project site (Victoria, Australia). The DAS array consisted of a standard commercially available tactical fibre-optic cable, which was deployed in 0.8 m deep trenches. A custom designed helically wound (HW) cable was also deployed into one of the DAS trenches for the comparison of the cable designs. The simultaneous acquisition of the seismic data was carried out using ~3000 vibroseis source points and geophones, DAS standard and the HW cables. In order to have the initial assessment of the seismic images acquired with DAS and to compare different cable designs, preliminary 2D seismic reflection processing is conducted on both DAS cables and geophone data along a single 2D line. The geophone data processing guided the data processing of DAS data. Several shallow structures (100 – 450 ms) and some important reflectors at 450 – 600 ms are observed on the final DAS images. The comparison of two different DAS cable types demonstrated that seismic imaging would benefit DAS technology. However, the benefit of utilising HW cable is modest compared to the standard cable. The workflows and the results of this study paved the way for the processing of the 3D seismic dataset acquired with the DAS array, as well as the further detailed analysis of the DAS cables and the system itself.

INTRODUCTION

Time-lapse (TL) seismic has great potential for monitoring fluid injection and possible leakage for global carbon geosequestration projects (White, 2011; Jenkins *et al*., 2012). The success of TL seismic for CO_2 surveillance depends on overcoming a number of challenges, such as prolonged periods between the baseline and the monitor surveys, possible environmental impact of seismic acquisition and relatively poor repeatability of land surveys. These challenges can have a significant impact on the effectiveness and cost of conventional TL 3D seismic (otherwise known as 4D seismic). One method to reduce the cost and increase the number of the surveys is to utilise permanent seismic receiver arrays.

One promising type of a permanent seismic sensor is Distributed Acoustic Sensor (DAS), which works by emitting a series of laser pulses into an optical fibre. A small amount of the light is backscattered by small-scale heterogeneities of the fibre and returns to the interrogation unit. The interrogation unit in a DAS system processes the backscattered light for every pulse to profile the strain changes within the optical fibre structure. An acoustic field can be measured along the whole fibre by recording the returning signal against time. The advancement in optical interferometric methods allows this technology to employ commercial telecommunication optical fibres. DAS has had numerous field applications over the last decade to utilise it in seismic surveys (Hornman *et al*., 2013; Mateeva *et al*., 2014; Parker *et al*., 2014; Correa *et al*., 2017a; Correa *et al*., 2017b; Hornman, 2017). The theory behind DAS technology is thoroughly discussed in Parker *et al*., 2014, Kuvshinov, 2016 and Hartog, 2018. Key advantages of the DAS compared to geophones include relatively low cost, easy deployment, a relatively long lifetime of the fibre-optic cables, and very high spatial coverage (10s of kilometres of continuous fibre cables). These features could potentially lead to significant improvements in the cost-effectiveness of TL seismic monitoring.

Stage 2C of the CO2CRC Otway Project is focused on conducting a comprehensive seismic monitoring program with various seismic techniques, data analysis and modelling to detect and monitor the evolution of a small (15 ktonnes) supercritical CO_2/CH_4 plume injected into a saline aquifer located at 1500 m depth. The biggest challenge for this experiment is high ambient noise level compared to the strength of the TL signal (Pevzner *et al.,* 2013; Pevzner *et al.*, 2017). One option to reduce the noise level is to use buried geophones. To explore this possibility, a small set of permanent receivers were tested at various depths in 2012 and provided drastically improved results in the repeatability of TL seismic (Shulakova *et al.,* 2015). This experiment became the benchmark of the future experimental designs. Concurrently with this test, Daley *et al.* (2013) tested DAS acquisition and obtained promising results. These tests were followed in 2015 by the installation of a permanent 3D receiver array, a permanent 3D DAS array, and a retrievable borehole geophone array in the monitoring well, as well as a DAS array in the injection well (Correa et al., 2018). The purpose of these installations was to perform numerous experiments to ascertain an optimal TL seismic approach for monitoring the emplaced CO_2 plume. The iDAS system (Silixa Ltd., Elstree, UK) including the 3D buried telecommunication style fibre-optic cable array was utilised to test the feasibility of DAS technology for the TL seismic. A prototype helically wound (HW) cable (Kuvshinov, 2016) was also deployed along with the standard cables to allow the comparison of two different DAS cable designs for optimising the DAS technology.

Collocating the DAS system with conventional geophones gives a rare opportunity to assess its performance quantitatively. Following the installation, a conventional vibroseis baseline 3D surface seismic data were acquired using buried geophones, a 3D standard DAS array and 2D HW cable. To set a benchmark for the 3D DAS processing and imaging, we selected a 2D line of geophones and both DAS datasets that are located in the same trench. Yavuz *et al*. (2016) presented the results of the pilot DAS surface seismic data analysis and the subsurface images processed using the conventional data acquired with the geophone array as a guide. In this study, to optimise the DAS data processing, we perform a direct comparison of standard fibre-optic and HW cables through to seismic imaging. HW cable was specifically produced to avoid the directionality issue of DAS data, as the signal decays as cosine squared of the angles of incidence in DAS data, as opposed to geophones that the signal decays as cosine of the angles of incidence. Due to the strong ground roll on DAS data, the signal levels visually not pronounced low for deep reflections, which are present on geophone sections. Hence, in this study, we focus on developing a processing workflow for imaging a few known near-surface reflections (up to 600 ms). The results of this 2D study can form a basis for the development of the workflow for 3D DAS data processing and analysis.

Field Setup

The Stage 2C experiment involved the deployment of a permanent geophone array, fibre-optic DAS system and related infrastructure and equipment. Quality control (QC) was then conducted on the systems followed by the simultaneous acquisition of 3D seismic data for monitoring the CO_2 plume during the injection tests (**Figure 1**). The Otway site permanent seismic array consists of 11 receiver lines (**Figure 2**) with 908 high-sensitivity SG-5 vertical geophones capable of recording the data down to 5 Hz. These geophones were buried 4 meters deep in PVC cased bores with a receiver spacing of 15 m. Geophone installation depth was derived after the series of tests conducted in 2012 (Shulakova et al., 2015). As a part of these tests, we deployed an array of surface and buried geophones (at different depths) onsite and acquired single cross-spread survey. No evidence of higher attenuation at the near surface was noticed. However, burying the geophones deeper than 3 m drastically reduced the wind noise. The same conclusion could be made from the direct comparison of surface and buried geophones done for the main array and presented in Pevzner *et al.*, 2015. It was also an expectation that 4 m depth would ensure that the geophones would be deployed below the water table. Each receiver line of the buried system extends from 890 m to 1460 m with a receiver line spacing of 100 m. After the deployment of the permanent geophone array, a DAS fibre-optic system including standard fibre-optic and an HW cable were also deployed. As we were also aiming to bury the cables for the geophone system, to avoid having anything left on the surface (to reduce the invasiveness of the survey), we used 0.8 m deep trenches for this. The depth of the trench was selected such that the cables would not be damaged by ploughing. The standard telecom fibre cable has a slight helical winding of loose fibre tube at about 11° angle from the axial centre of the cable consistent with telecommunications cable style construction. The slight winding of 11° allows for the DAS receiver spacing to be almost one meter of fibre per one meter of cable. The HW cable has a steeper fibre winding of 30° from the axial centre. The standard fibre-optic cable was deployed into 80 cm deep trenches along the 11 geophone receiver lines (**Figure 1**). We used the standard loose tube telecom cable designed for the burial. Most of these cables have tubes with fibres wound around the strength member to protect fibre from excessive stretch while being deployed. Our DAS acquisition were made with single mode fiber. The HW cable was experimental and multiple buffer tubes with fibers were installed to keep the structure round as the manufacturer did not have solid plastic rod available. Subsequent constructions reduced the number of fiber tubes to two. For the direct comparison of the fibre responses between the two cable types, the HW cable was deployed in the same trench as the geophone receiver line 5. Both standard and HW cables were installed in a 'U' configuration to acquire the data in both south-to-north and north-to-south directions. The 'U' configuration eliminates the need for end splices in the trenches, reducing potential degradation in the signal at the expense of increased data volume. The Otway experimental site has the DAS array with a total length exceeding 36 km, including the DAS cables installed in the boreholes.

CRC-2 well is the injector well for Stage 2C of Otway project containing a fibre-optic cable attached to the tubing. CRC-2 has a depth of approximately 1.5 km, 300 m less than CRC-1 well, which for the Stage 2C experiment serves as a monitoring well. Both CRC-1 and CRC-2 are vertical wells located 150 m apart. The seismic recording facility (Seismic Lab) is located near the CRC-2 wellhead. Twenty-two fibre cables along the receiver lines and the backbone cables are fed along the backbone trench. These cables extend the control boxes through to the Seismic Lab. **Figure 2** shows the map view of the Otway site for the March 2015 deployments.

To make the processing and visualisation of the data more efficient, the DAS array is split into two manageable lengths on two separate iDAS data acquisition setups. Unit iDAS-1 recorded acoustic data from the CRC-2 wellbore fibre loop and the standard fibre loops in lines 4, 5, 6, and 7. Unit iDAS-2 recorded acoustic data from fibre loops from receiver lines 1, 2, 3, 8, 9, 10, and 11. The standard single mode fibres used in the acquisition are designed for the laser wavelengths of 1300 – 1500 nm. Pulse width of the laser was 50 ns. Intensity of the laser was changed a couple of times during the survey as we were aiming to select the best laser intensity. The maximum pulse frequency for this survey is ~5kHz. However, a smaller pulse repetition frequency of ~2kHz was selected. In order to locate the recording channels along the DAS cable during the seismic survey, we conducted a series of tap tests. During these tests, the DAS data were recorded while having a seismic source (usually just a sledgehammer) activated at a known location above the buried fibre-optic cables. Thus, the position of the seismic source along the cable as seen on the record is related back to the surface coordinate and receiver station number. After the tap tests and final QC on the systems, simultaneous 3D seismic data acquisition was conducted on the geophone array and the DAS system using 3003 vibroseis source points. There are two large areas, which we did not have access during this survey. To account for missing shots in these areas, a narrower source line spacing was chosen next to these areas to increase the fold. Two 26000 lb INOVA Vibrators were utilized with a single 24-second sweep set to a frequency range of 6-150 Hz and 0.5 s taper. The data were recorded with five seconds listening time and 1 ms sampling rate. The receiver spacing of both fibre-optic cables is 1 m so that a total of 26804 channels of data were recorded, with a total data volume of 13.5 TB.

Fast Track Pilot Processing

The main objective of this study is to perform an overall assessment of the DAS data to optimise the data processing of the large 3D DAS dataset. To this end, we perform preliminary 2D data processing of both geophone and DAS datasets along a single 2D line. **Figure 2** shows the selected receiver line 5 consisting of 80 channels with 15 m receiver spacing and almost in parallel with selected shot line 29 consisting of 107 shots with a shot spacing of 15 m. As mentioned previously, looped DAS fibre cables allowed us to acquire the data in two parallel segments. However, for simplicity, we only process one side of each cable. Both standard fibre-optic cable with 1176 channels and HW cable with 760 channels have approximately 1 m receiver spacing. This spatial sampling was preselected in the iDAS unit prior to acquisition as well as the gauge length. Because the both cables are connected to each other, the same spatial sampling applies to both cables. It should be noted that, unlike single geophone sensors, DAS channels are formed by a finite length (gauge) of the fibre-optic cable with temporal variation in scattering from the opposite side of this length. This is used to estimate the acoustic signal by measuring the difference in phase between two positions separated by a distance called the gauge length (Bona *et al.*, 2017). The gauge length employed in this experiment was 10 m, and the measurement was assigned to the centre of the gauge.

First, since receiver line 5 had a 2D crooked-line profile, to improve signal alignment before CMP stacking, a crooked line geometry is applied to both geophone and DAS datasets as displayed in **Figure 3**. A bin size of 10 m is utilized to take into account the gauge length of the DAS data and improve the alignment of reflections. **Figure 3** also shows the CMP fold maps of all data sets. The CMP fold of DAS data is high relative to the geophone data, which is to be expected considering the reduced receiver (sensing) spacing. After the geometry setup, we analyse all raw data sets in terms of acoustic events. A shot location closer to the middle of the shot line is marked with a green star in **Figure 3** and used as the reference shot gather in **Figure 4**. The geophone data raw shot gather (**Figure 4a**) shows clear direct arrivals and a few shallow reflections are prominent and continuous. On the DAS raw shot records (**Figure 4b** and **c**), direct arrivals are visible, but the reflections are not apparent. Furthermore, all the datasets show strong ground roll. The ambient noise level and ground roll intensity are higher in DAS compared to geophone data as observed on the reflection strength section of the same shot gathers in **Figure 5**. Strong surface waves in DAS data suggest that their dispersion can be used for characterisation of near-surface properties (Park *et al.*, 1999).

After thorough QC of the datasets, we produce quick brute stacks for all data sets with a simple processing flow (**Figure 6**). This processing flow includes the application of top and bottom mutes to preserve the data in a window between the direct wave and ground roll, an automatic gain control (AGC) (1 s) and bandpass filter (1-25-50-90 Hz). The two strong reflections located between 450 to 600 ms are imaged on the brute stack of the geophone data (**Figure 6a**). Hence, we then try to stack the DAS data sets in a similar way for direct comparison.

Equivalent reflections are visible on both the geophone and DAS brute stacks (**Figure 6b** and **c**).

Geophone Data Processing

In order to evaluate the DAS data for seismic monitoring surveys and the direct comparison of the two different cable designs, the seismic data processing is further refined. To this end, we first build a processing flow for the geophone data and utilise it to assist the DAS data processing. The processing flow for the geophone data is outlined in **Table 1**. The first key processing step for the geophone data is an assessment of several filters to eliminate surface waves and ambient noise. Amongst all tested filter options, the linear Radon filter provides the best results by suppressing noise associated with ground roll. We apply this filter in a window specifically designed to encompass only the ground roll to avoid any undesired distortion on the shallow reflections. **Figure 7** shows gathers before and after Radon filter. The results suggest that Radon filter successfully attenuates the ground roll.

The next step in the geophone data processing is the interactive velocity analysis (IVA). The guide function for IVA on geophone data is extracted from the known velocity field, which was mapped in the previous seismic surveys at the Otway site (Shulakova *et al*., 2015). We also perform an interactive frequency spectrum analysis. This demonstrates that the frequency range of the geophone data is between 30-90 Hz. We then design our bandpass filter accordingly. After the application of this filter, to further suppress ambient noise we apply a simple Alpha-trimmed mean filter, which enhances the continuity of horizontal events. Finally, to increase the temporal resolution, spectral shaping within the frequency range 1-25-60-90 Hz is applied. Comparison of the final stacked section of geophone data (**Figure 8a**) with its initial brute stack (**Figure 6a**) shows that refined data processing can recover signal up to 800 ms.

The shallow reflections around 100 – 450 ms and two other strong reflections located between 450 to 600 ms are imaged (**Figure 8a**). However, deeper reflections are severely affected by surface waves and ambient noise.

DAS Data Processing

After the geophone data processing, we focus on the DAS data processing. Both datasets (standard fibre-optic and the HW cables) have similar processing streams applied. The full processing flow for both DAS datasets is outlined in **Table 2**. The raw DAS data QC indicate that the ground roll is the dominant noise in the data (**Figure 4 and Figure 5**), and ground roll attenuation would be the most critical component for SNR improvement. In the DAS processing, we perform several key trials specifically designed to reduce the effect of the strong surface waves. These trials are guided by the geophone data processing. Hence, we assess all possible filter types such as fan filter, F-K filter and Radon filter for ground roll removal. However, since the linear Radon filter delivered a good outcome for the geophone data processing, we utilize it in the DAS data processing as well. Similar to geophone data processing, the Radon filter is interactively parameterized for both datasets and applied in a window to preserve the signal. After the removal of ground roll, we observe residual noise of parabolic shape. This event is identified as reflected P-S converted waves as seen on a standard DAS data shot section (**Figure 9**). In order to suppress the converted waves, we interactively test a parabolic Radon filter application. Despite these efforts, the results are still far from satisfactory. Consequently, we decide to proceed with a bottom mute to surgically remove the surface waves from stacking.

The noise associated with the airwave is suppressed with the application of a 2D convolutional filter, followed by a simple Alpha-trimmed mean filter to suppress ambient noise. Then IVA is performed for both DAS datasets using a guide function based on the velocity field obtained from geophone data processing. However, in the DAS data processing, a single velocity function provides the best result and is used in the NMO application. A bandpass filter (5-30-60-120 Hz) followed by an F-X deconvolution is applied to the stacked data. **Figure 8b** and **c** display the final stack sections of DAS datasets. The two strong reflections around 450-600 ms, as well as a few shallower reflections, are visible in the final DAS stacked sections.

In order to evaluate the performance of HW versus standard telecommunication style cable, it is desirable to provide a direct comparison between the two datasets with surveys that have the same fold. To this end, the standard fibre-optic cable is limited to the HW cable length and binned using the same crooked line geometry as in the HW cable. The raw shot gather analysis shows that HW cable provides slightly better images than the standard fibre-optic cable. However, because both cables were buried under unsaturated and unconsolidated backfill, some shot gathers show inconsistent results. The brute stacks, which were previously produced in the pilot processing for all datasets, are also created for the limited standard DAS data. **Figure 10** displays the muted brute stack of the limited standard fibre-optic DAS cable (**Figure 10a**) and the muted brute stack of HW cable data (**Figure 10b**). After the application of the same processing flow (**Table 2**) to the limited standard fibre-optic cable data, the resulting section is compared with the final HW cable data stack section in **Figure 11**. It is clear that the HW cable data section has a significantly better resolution for the reflection at 100 – 150 ms (**Figure 11b**). The noise created by the ground roll and surface waves appears to be less pervasive on the HW cable image compared to the standard DAS image. However, the deeper reflections around 450 – 600 ms are better imaged on the standard fibre-optic cable image (**Figure 11a**).

DISCUSSION AND CONCLUSIONS

The Otway Stage 2C experiment provided an excellent opportunity to test the effectiveness of different forms of seismic acquisition hardware for TL seismic. DAS is a relatively new but extremely promising technology that can potentially provide a cost and time effective solution in surface and borehole seismic monitoring. A surface seismic monitoring system utilising a permanent 3D geophone array was acquired in conjunction with a 3D DAS array. To investigate the performance of DAS compared to a collocated geophone array, we selected a 2D subset comprised of one receiver line instrumented with both standard fibre-optic and an HW cables to record into using a parallel source line. Seismic data processing was employed for the initial assessment DAS datasets as well as the direct comparison of the different cable designs.

DAS measures relative strain changes along the cable. Hence, in a surface seismic survey design like ours, it is sensitive to the seismic events that travel in the horizontal direction, such as ground roll. The changes that occur in the vertical direction caused by events such as reflections arrive perpendicular to the fibre and therefore fall in its almost blind component. This broadside sensitivity issue is obvious on the brute stacked seismic sections. Compared to the strong and continuous direct arrivals and reflections from the geophone data, the raw DAS dataset provided visible direct arrivals and no apparent reflections most likely due to the ambient noise level and strong ground roll and surface wave intensity. A data processing flow is created for both DAS datasets using the geophone data processing as a guide. The main challenge in the processing is to suppress ground roll and surface waves in all datasets. While a linear Radon filter has given good results on geophone data, the DAS datasets had to be simply muted to remove this coherent noise due to a low SNR and broadside sensitivity issue. DAS data was still capable of imaging the known reflections. Better continuity of the shallow reflector around 100-150 ms is observed on HW cable data compared to the standard fibre-optic cable and geophone data (**Figure 8**). However, deeper reflections are better imaged in the standard fibre-optic seismic section. Direct comparison of DAS cables for the improved imaging of the reflectors around 100-150 ms on **Figure 11** shows better resolution and higher SNR for HW compared to standard cable. This is probably because the helical winding increases broadside sensitivity of the DAS cable. However, the shallow reflectors (0-100 ms) on all the datasets look very different. These differences are probably caused by the effect of the differences in elastic properties of, or their coupling to, the unsaturated and unconsolidated backfill at the specific locations of the two DAS cables. Despite the fact that DAS has low SNR, the known reflectors around 450-600 ms are still recovered on both HW cable and standard fibre. The subsequent analyses and 3D data processing of the DAS data highly benefited from the insights achieved from this study (Bona et. al., 2016, Correa *et al*., 2017a and Correa *et al*., 2017b).

ACKNOWLEDGEMENTS

The CO2CRC Otway Stage 2C Project received funding through CO2CRC's industry members and research partners, the Australian Government, the Victorian State Government and the Global CCS Institute. The authors wish to acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D) supported by the Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative. Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management through the NETL. We acknowledge the help of M.

Hehir and D. Popik (Curtin University), T. Roberts (Westlog), I. McLintock and P. Dumesny (Upstream Production Solutions) in conducting the field surveys.

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TABLES AND FIGURES

Figure 1. Experimental setup. Photos show a) the trencher digging the trench, b) boring for the 4 meters deep PVC cased bores to install geophones, c) the installation of a geophone in a bore and the geophone cables and d) blue iDAS fibre-optic cables laying at the bottom of each trench, and e) Helically wound cable burried in Line 5 trench for direct comparison (after Hornman *et al*, 2013)

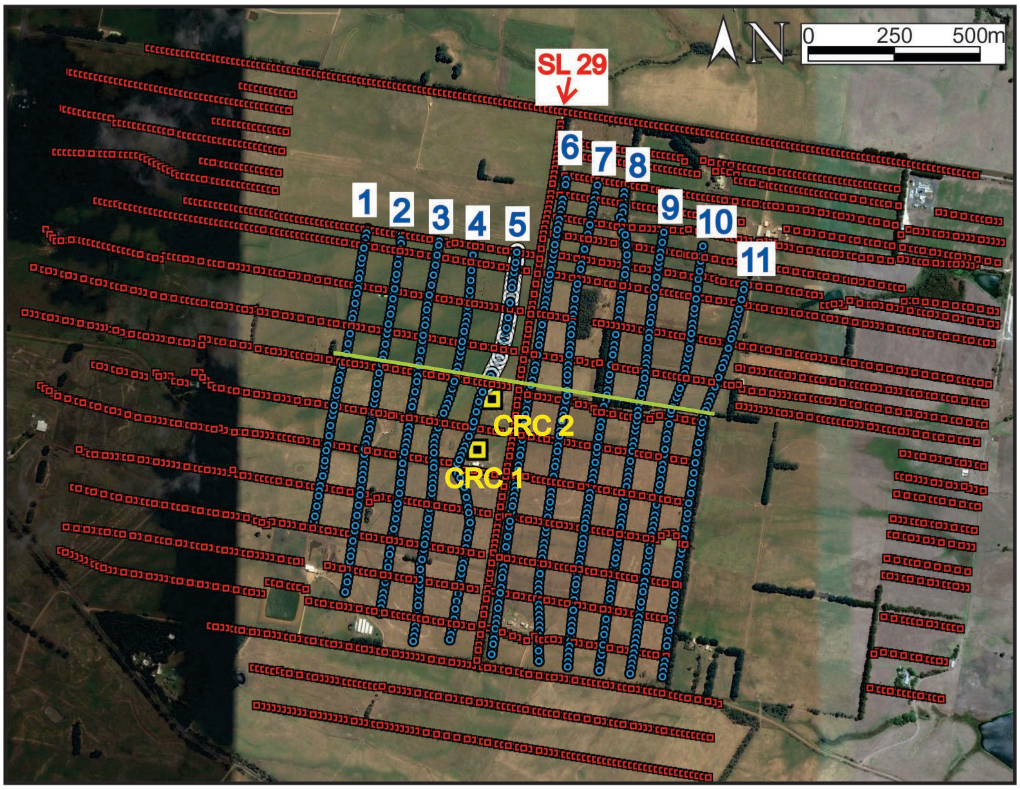

Figure 2. Map view of the Otway site for the CO2CRC Stage 2C seismic survey, March 2015. Eleven lines of surface geophones and baseline survey vibroseis source points are shown in blue dots and red, respectively. The standard fibre-optic DAS cable is collocated along the 11 geophone receiver lines, and HWC is only buried in Line 5 as highlighted with white dots. CRC 1 and CRC 2 wells and the backbone trench (green) are also highlighted (modified from Yavuz et. al, 2016)

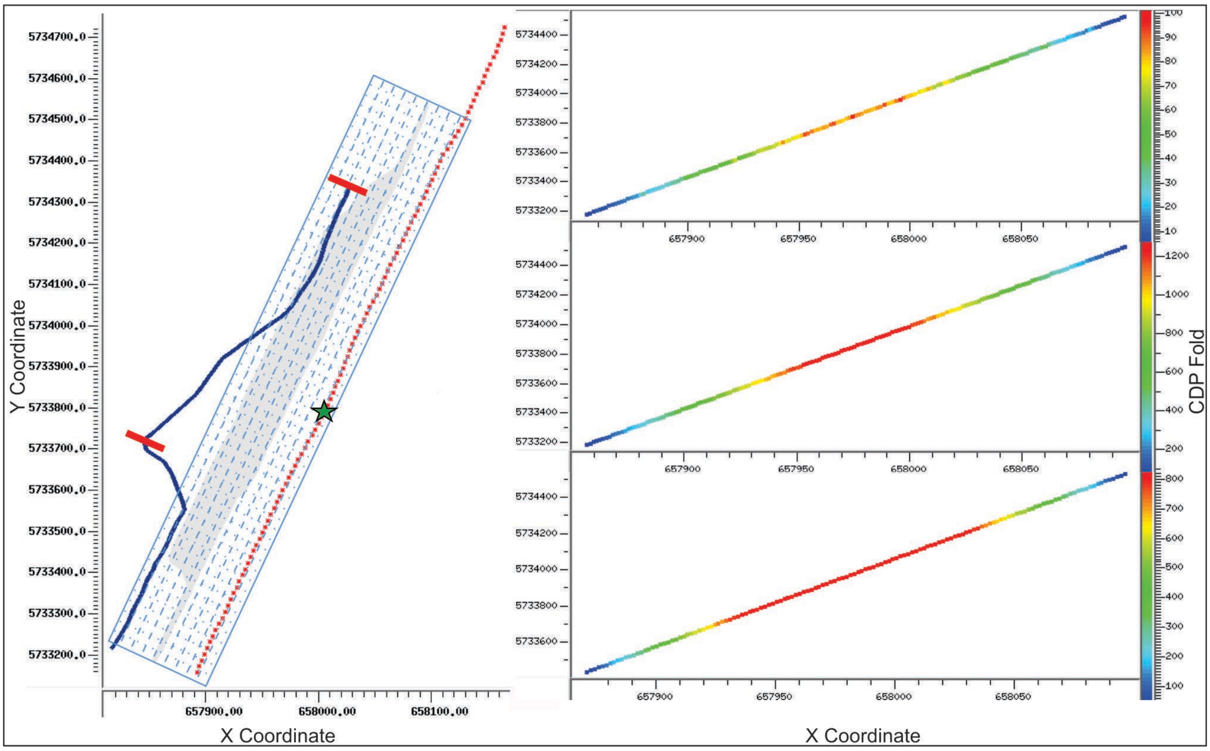

Figure 3. Crooked line binning of both standard fibre-optic DAS and geophone datasets. Red stars and blue crosses show the shot points, and standard fibre-optic DAS cable and the geophones, respectively. Standard fibre-optic DAS and geophone data are binned in green cells and are superimposed on the midpoints. Red lines are showing the start and end of HWC laid in the same trench with the standard fibre-optic DAS. The shot point displayed in Figure 4 is highlighted with a star. CDP Fold maps of the geophone, standard cable and HWC datasets are displayed on the right, respectively from top to bottom.

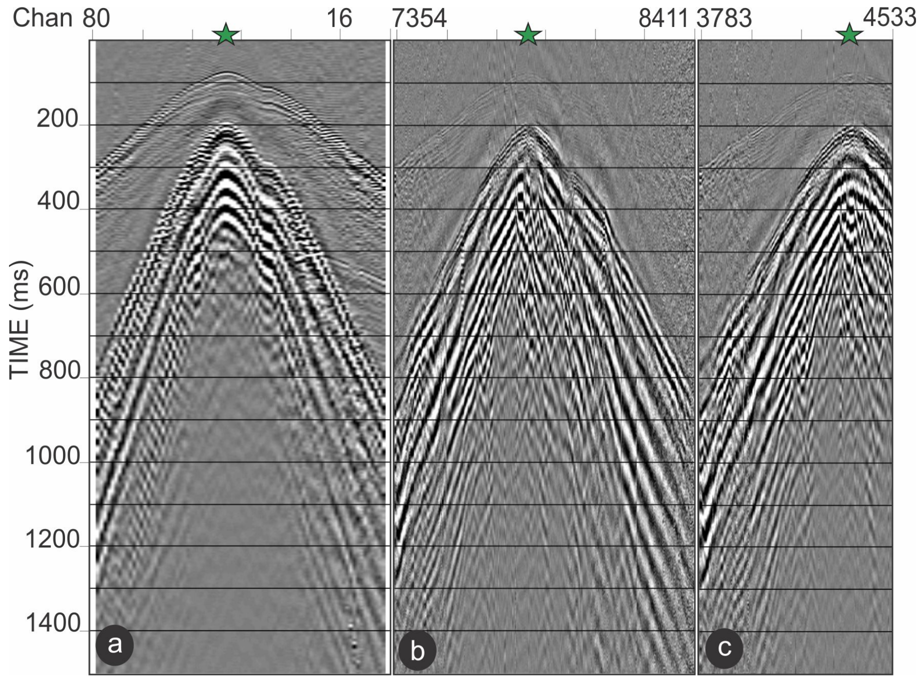

Figure 4. A raw shot gather (see Figure 3 for the location) of a) geophone, b) standard fibre-optic and c) HWC DAS data. The shot point is displayed with a star on each data.

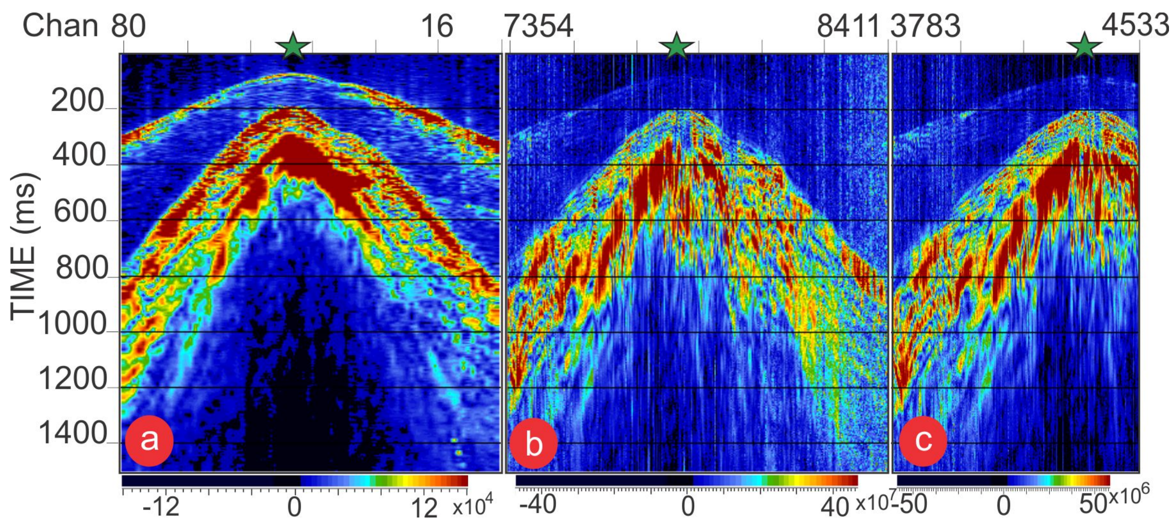

Figure 5. Reflection strength of the raw shot gathers (see Figure 3 for the location) of a) geophone, b) standard fibre-optic and c) HWC DAS data. The shot point is displayed with a star on each data.

Table 1: Geophone data processing flow

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1. Geometry Specification / Binning (10 m)
2. Burst Noise Removal
3. Trace Correlation
4. Interactive Radon / τ-P Analysis
5. Trace shift 500 ms down
6. Window processing (defining a window for Radon filter application)
7. Application of AGC using data window
8. Radon Filter: Linear, Number of P-values 500, P value interest 500-3500 ms, white noise 0.03%
9. AGC removal
10. Trace shift 500 ms down
11. Interactive Velocity analysis (iterative): using the CVS-derived velocities as a guide function: on cdp supergathers created with five inlines and crosslines for every tenth inline and crossline
12. Normal moveout corrections - stretch mute 55
13. Bandpass filter: 2-30-90-140 Hz Ormsby
14. 2D Spatial Filter (Simple Alpha-trimmed Mean)
15. AGC (500 ms, centred)
16. Stack
17. Spectral Shaping (1-25-60-90)

Table 2: Das data processing flow

1. Geometry Specification / Binning (10 m)
2. Burst Noise Removal
3. Trace Correlation
4. Trace mute (Bottom mute for ground roll and below)
5. 2D Spatial Filter (2D Convolutional Filter)
6. Normal moveout corrections (NMO) with a single velocity function
7. Bandpass filter: 15-30-60-120 Hz Ormsby
8. 2D Spatial Filter (Simple Alpha-trimmed Mean)
9. AGC (500 ms, centred)
10. Stack
11. F-X Deconvolution

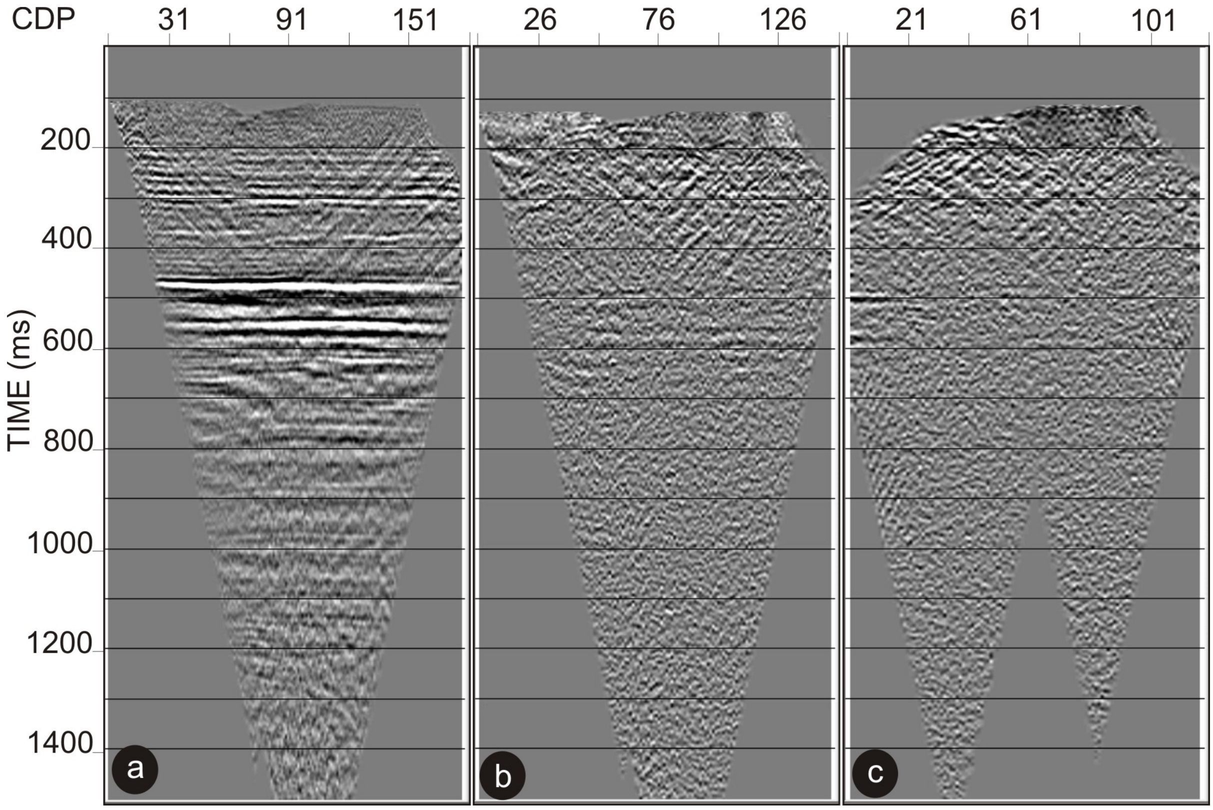

Figure 6. Brute stack sections of a) geophone, b) standard fibre-optic DAS and c) HWC DAS data with a ground roll and direct wave mute.

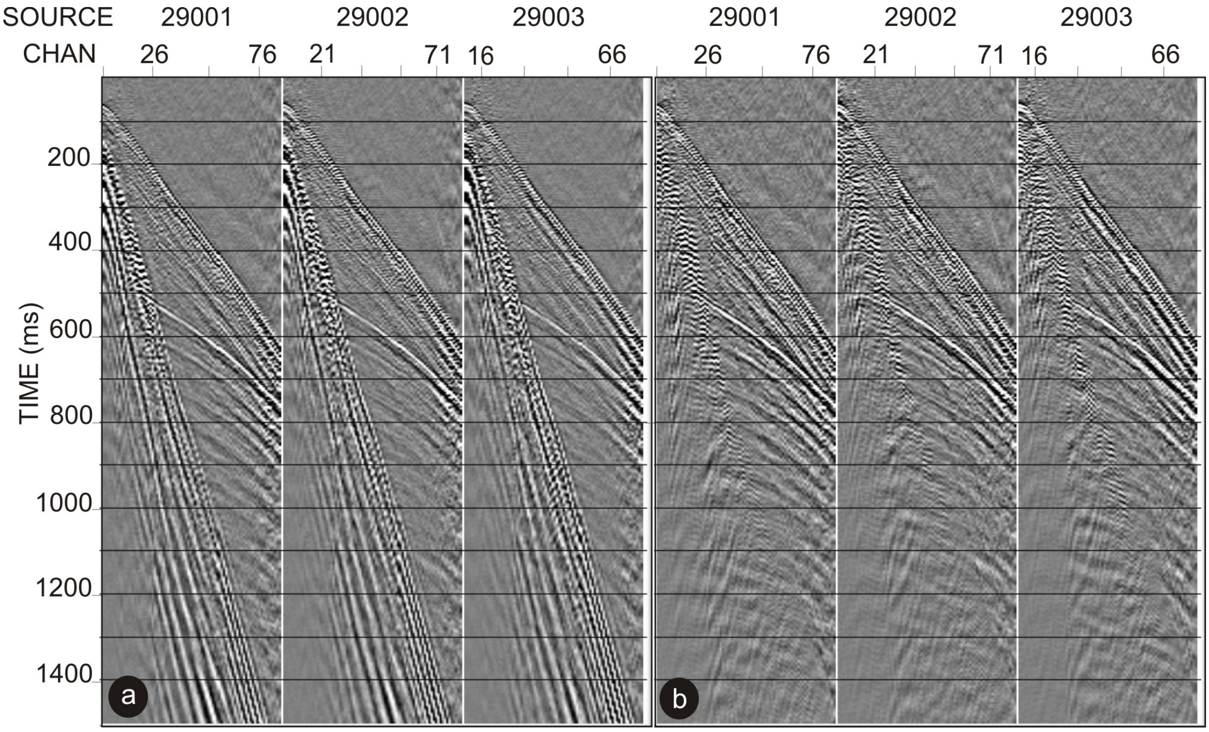

Figure 7. Geophone data shot gathers a) before and b) after the removal of ground roll with a linear Radon filter.

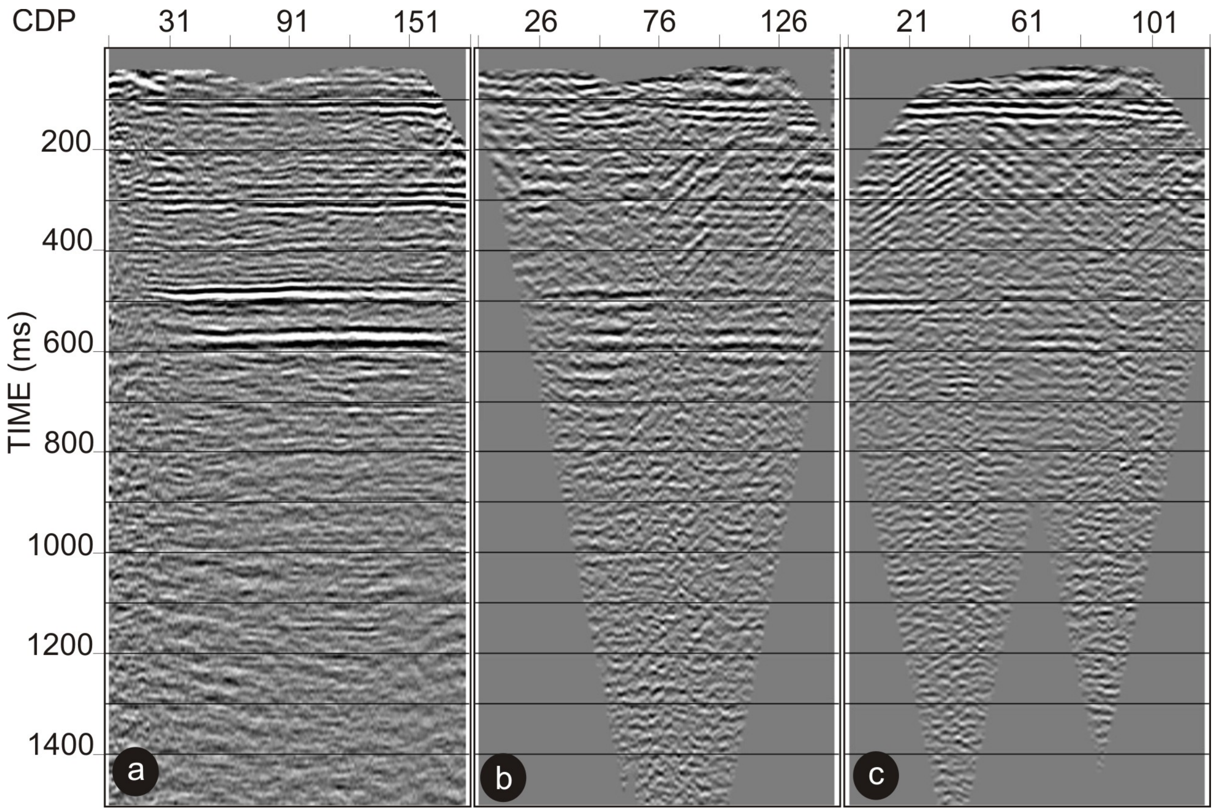

Figure 8. Final stack sections of a) geophone, b) standard fibre-optic DAS and c) HWC DAS data.

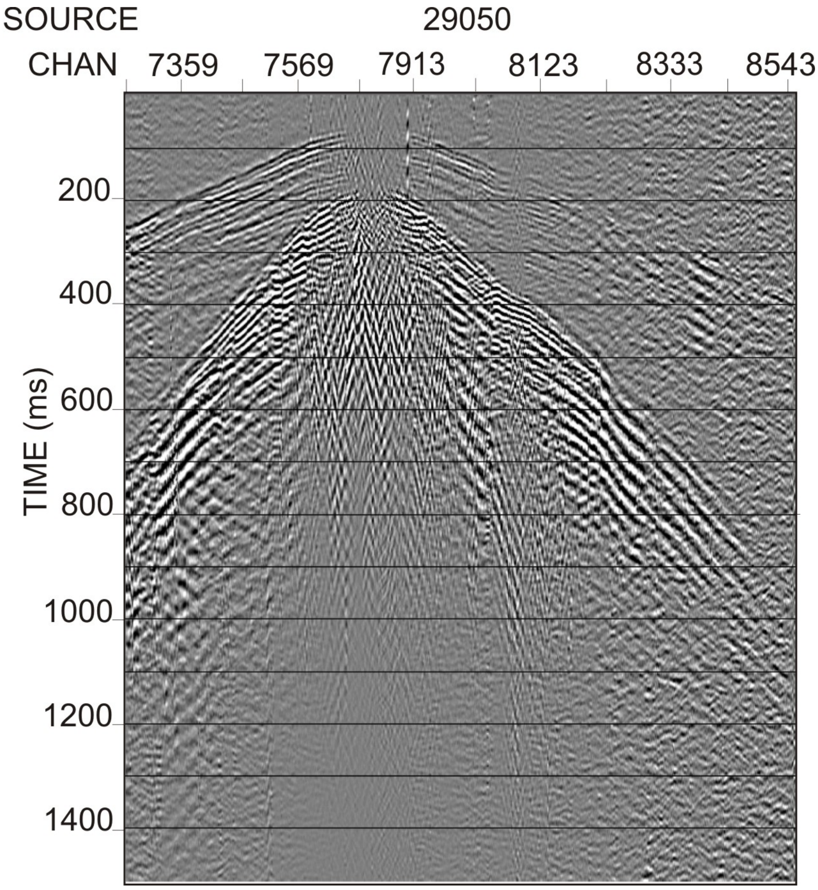

Figure 9. DAS data shot section after the application of a 2D convolutional filter for airwave removal.

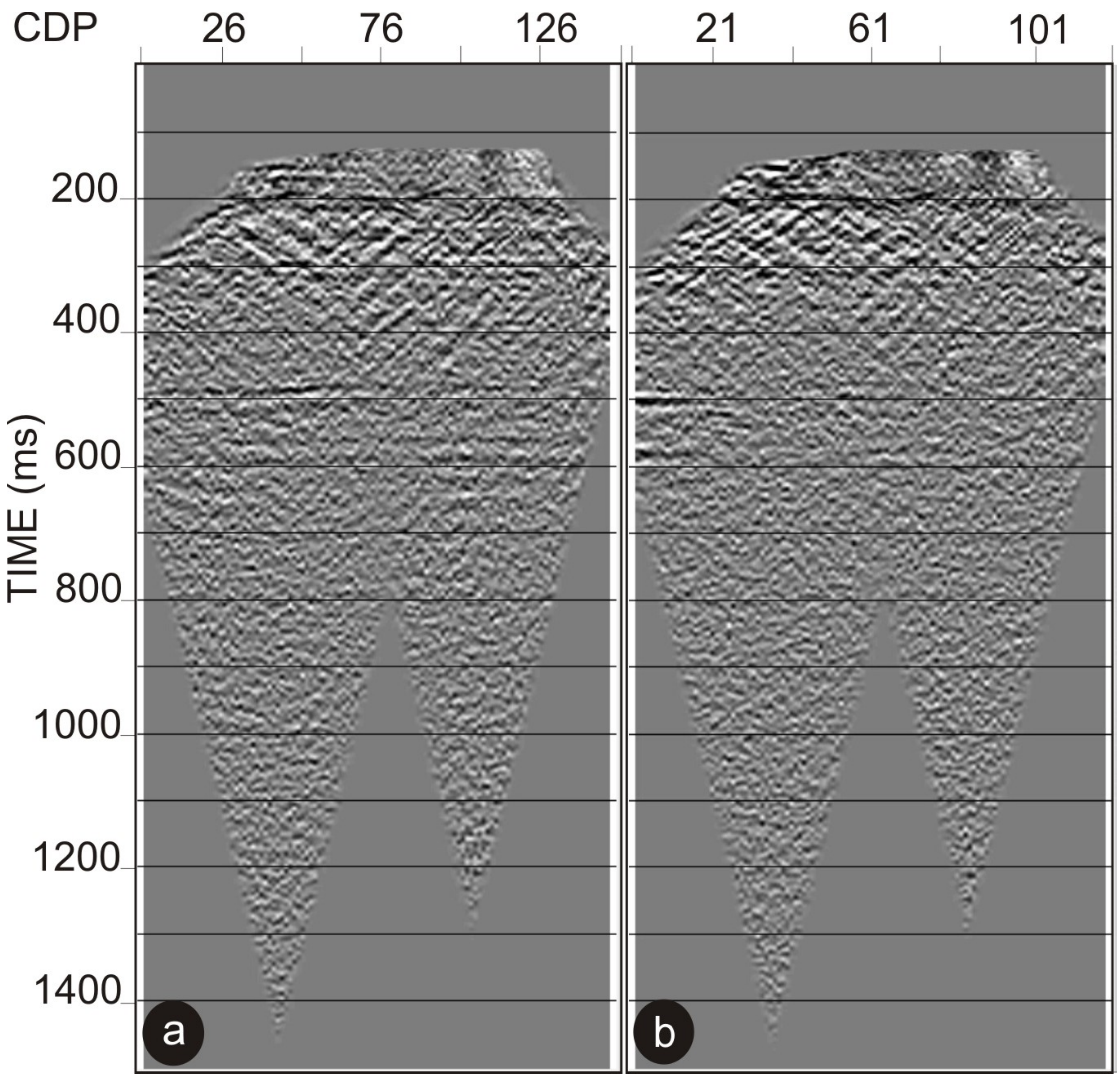

Figure 10. The brute stack sections of a) limited standard fibre-optic and b) HWC DAS data.

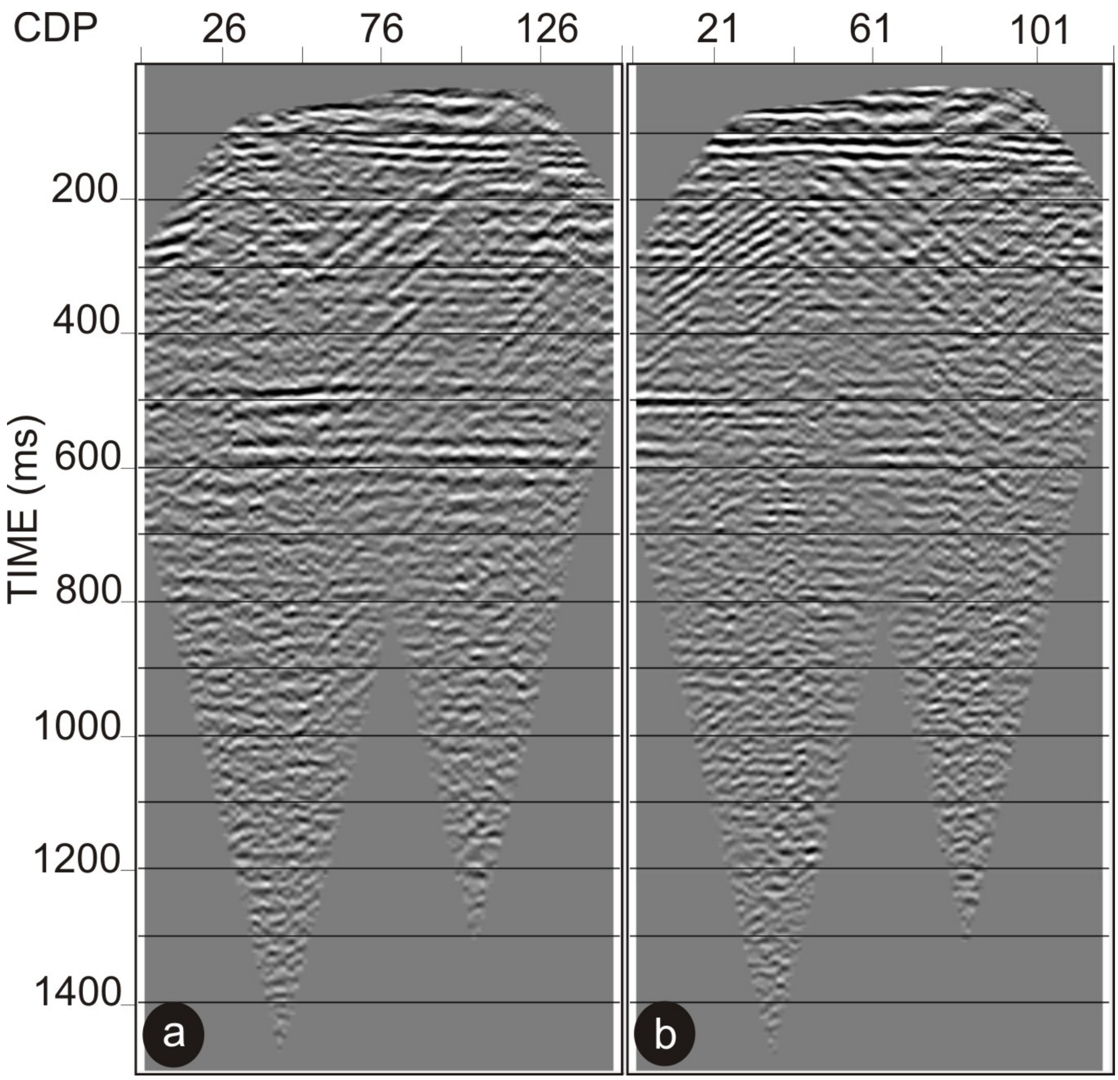

Figure 11. The final stack sections of a) limited standard fibre-optic and b) HWC DAS data.