A summary of surface seismic reflection data acquired at the Field Research Station near Brooks, Alberta

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ABSTRACT

We have been acquiring surface seismic reflection data at the Field Research Station near Brooks, Alberta, since 2014. The data include 3D3C, 2D3C and 2D1C surveys. All the seismic data had similar processing, designed to attenuate noise and enhance reflectivity, and were post-stack migrated. The 3D3C data acquired in 2014 exhibits the best imaging of the subsurface on both PP and PS sections. Offset gathers show that offsets of 200-400 m are best for imaging the Basal Belly River, which is the CO_2 injection sandstone, with PP surface seismic data. Preliminary investigations of distributed acoustic sensor data suggest that these data hold promise for real-time monitoring of the subsurface.

INTRODUCTION

The Containment and Monitoring Institute (CaMI), established by Carbon Management Canada, has a Field Research Station (FRS) near Brooks, Alberta, where technologies for the measurement, monitoring and containment of subsurface fluids, including carbon dioxide, will be developed, refined and calibrated. A well for injection of CO_2 was drilled in 2015 to a depth of 550 m and two nearby observation wells have been drilled since. Small amounts (up to 1000 tonnes per year) of CO_2 are being injected into the Upper Cretaceous Basal Belly River Formation, which is a water-wet sandstone capped by the shales, silts and silty sands of the Belly River Formation.

We have documented the geology of the study area and discussed the processing and interpretation of seismic data acquired here (Isaac and Lawton, 2014a; 2014b; 2015; 2016a, 2016b). In this paper we compare the different vintages of surface seismic data, discuss the impact of source-receiver offsets on the stacked data, and display some of the new data acquired with the fibre optic cable.

SEISMIC DATA

We have been acquiring seismic data at the FRS since 2014. The surveys are summarized in Table 1, which does not include any VSP surveys, and their locations are plotted in Figure 1.

All the seismic data were processed using a fairly standard processing flow which included refraction and residual statics, geometric spreading compensation, trace equalization, spike and noise burst edit, and air blast attenuation. The final datum was 800 m with a replacement velocity of 2600 m/s. Radial filters (Henley, 1999) or surface wave noise attenuation were applied to the data to attenuate noise. All the data had Gabor deconvolution (Margrave and Lamoureux, 2002) applied and we often also applied a spatial filter to help bring out the signal in the shallow section of interest. We post-stack migrated the data using a finite difference migration. We also applied a bandpass filter of 10-15-80-100 Hz and an AGC of 500 ms to the PP data for these displays. The 3D3C data acquired in 2014 appears to have the best continuity of reflections and consistency of seismic character so the other surveys were matched to this one with phase rotations and time shifts, where appropriate.

The primary reflection of interest is the Basal Belly River, which is the target injection horizon at a depth of 295 m KB (+489.5 m ASL). This event is the peak seen just below 0.25 s on the PP migrated seismic sections and about 0.5 s on the PS data. A secondary target as a potential deeper injection zone is the Medicine Hat sand, a thin sandstone at about 503 m KB, equivalent to about 0.39 s on the PP data and 0.72 s on the PS data.

Table 1. Brooks reflection seismic surveys.

Date	Survey type	Source interval	Receivers/recording	Comments
Feb 2014	2D N-S	20 m	10 m 1C	Test line
May 2014	3D3C 1 km^2 N-S and W-E grid	5 m and 10 m Tesla Envirovibe 8-150 Hz	5 m and 10 m 3C SM-7 (Inova Hawk nodal recorders)	20 source and 20 receiver lines 100 m apart with inner grid lines 50 m apart
May 2014	2D line 3	Envirovibe	1C (Aries) 3C (Inova Hawk)	
2015	2D	10 m Envirovibe 10-200 Hz	10 m 1C SM-24 (Aries) 30 m 3C SM-7 (Inova Hawk)	Aries and Hawk recording
May 2017	2D SW-NE line 13	20 m and 10 m	10 m 3C	
July 2017	3D star-shaped lines 21, 23,27	3 source lines at 20 m	10 m 3C along N-S receiver line 21	
July 2017	3D3C 100 m^2 grid	10 m	10 m 3C	
July 2017	DAS		Continuous fibre optic cable, equivalent to .25 m spacing	

2014

The February 2D line was shot in a N-S direction in the east of the area of interest. A 2D N-S line was acquired in May, and it was about 100 m to the west of the February line. This N-S line 3 was shot into 1C geophones recorded with the Aries system and 3C geophones recorded with Inova's Hawk digital sensors. Figure 2 shows the February 2D lines and the May 2D lines recorded by the two recording systems.

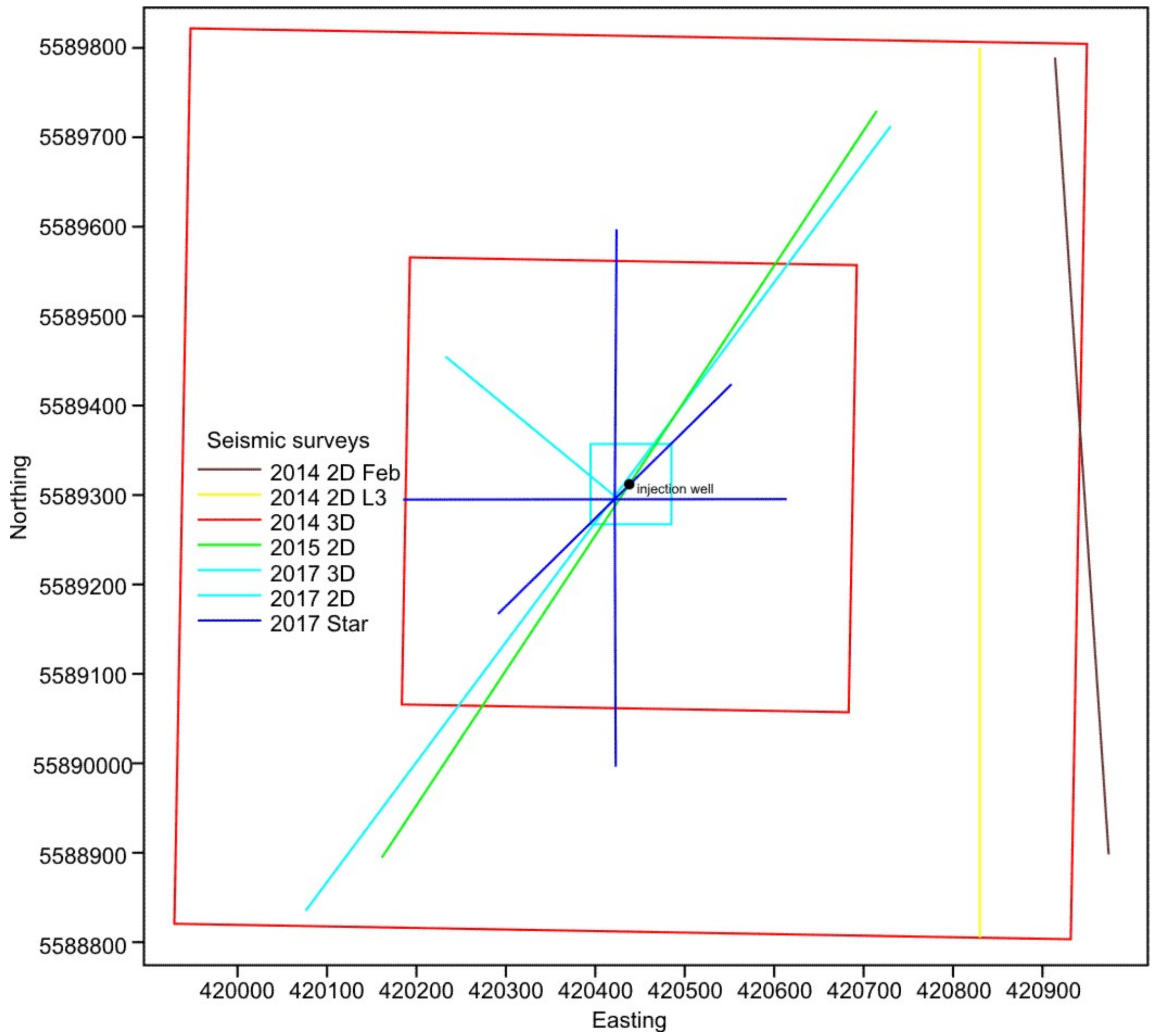

FIG. 1. Locations of the reflection seismic data acquired at the FRS at Brooks. The large and small red squares denote the outline of the areas covered by the 100 x 100 m grid and 50 x 50 m grid, respectively.

A small 1 km x 1 km baseline 3D3C seismic survey was acquired in 2014, centred on the new well that was to be drilled in 2015. The source was two Tesla Envirovibes operating simultaneously at source intervals of 10 m along 17 lines spaced 100 m apart in an outer grid, and 50 m apart in an inner grid, centred on the well. 3C receivers were spaced at 10 m intervals along 17 lines spaced 100 m and 50 m apart, and orthogonal to the source lines.

We processed the entire data set, both PP and PS, and also extracted the PP data from the inner 50 m grid and data from only the source and receiver lines at 100 m spacing to compare the results. Figure 3 displays inline 101 from the entire data set (a), inline 101 from the dataset covering the inner 50 m x 50 m grid (b), and inline 101 extracted from the dataset using only the 100 m source and receiver lines (c). Figure 3a and 3b look comparable while Figure 3c shows poorer resolution and continuity of the target Basal Belly River than do the other two. Figure 4 displays a zoomed picture of the zone of interest around the Basal Belly River injection horizon and the Medicine Hat secondary target.

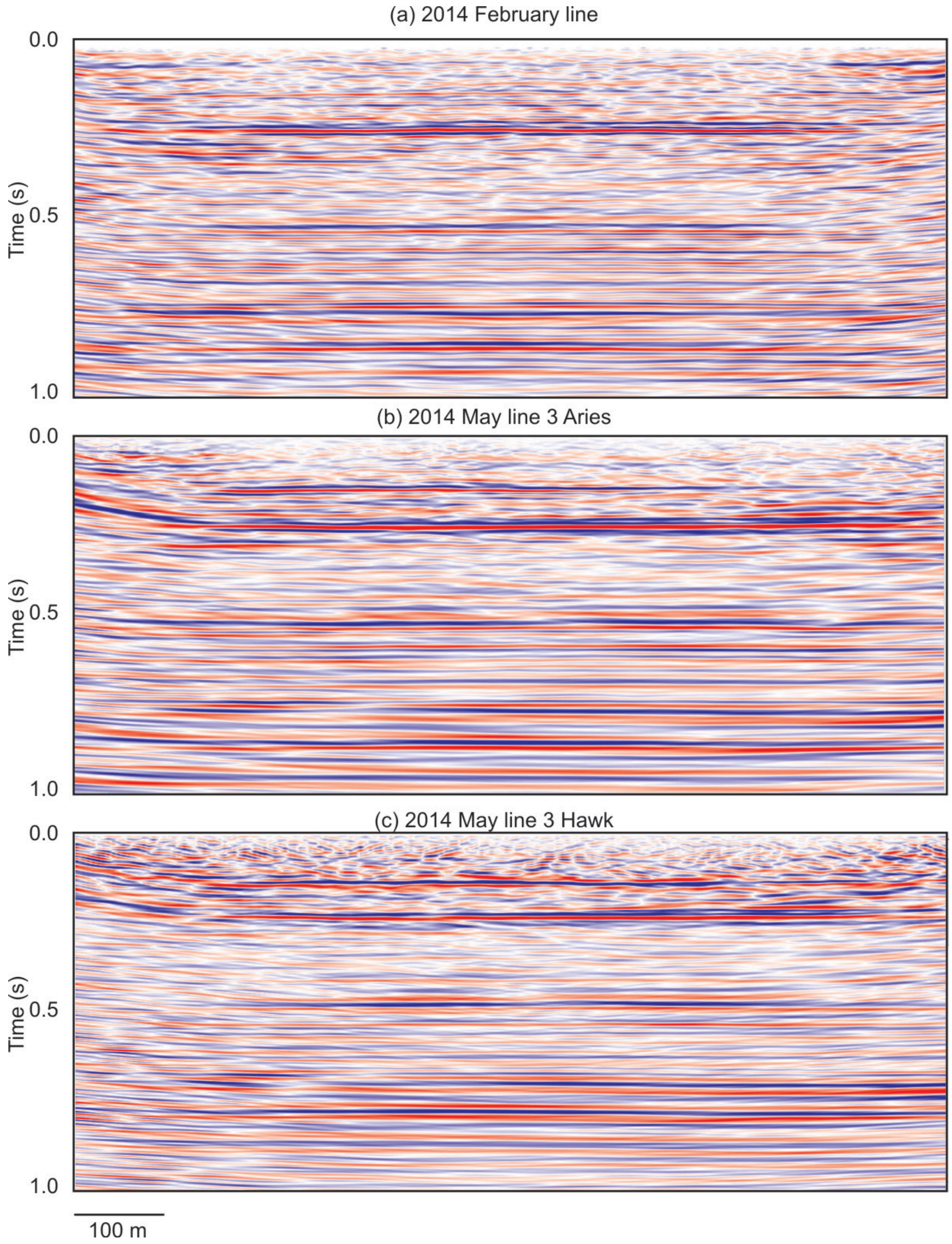

FIG. 2. Migrated versions of the 2D data acquired in 2014. May line 3 was recorded by two systems: the Aries (b) and the Hawk (c). The Basal Belly River event is the red peak just below 0.25 s.

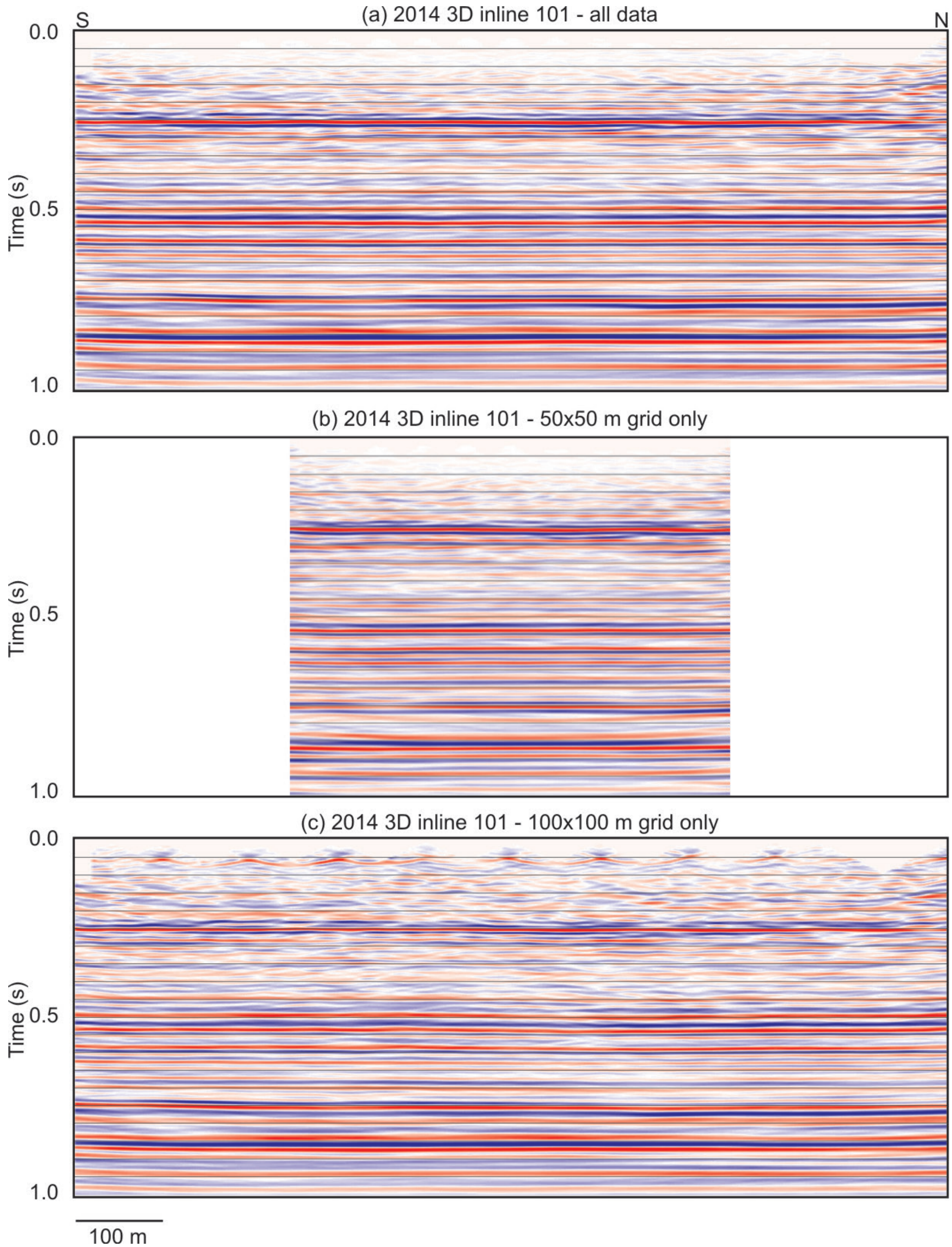

FIG. 3. 3D data acquired in 2014. (a) Uses all the data, (b) uses data from only the inner 50 x 50 m grid, and (c) uses data from source and receiver lines from the 100 x 100 m grid.

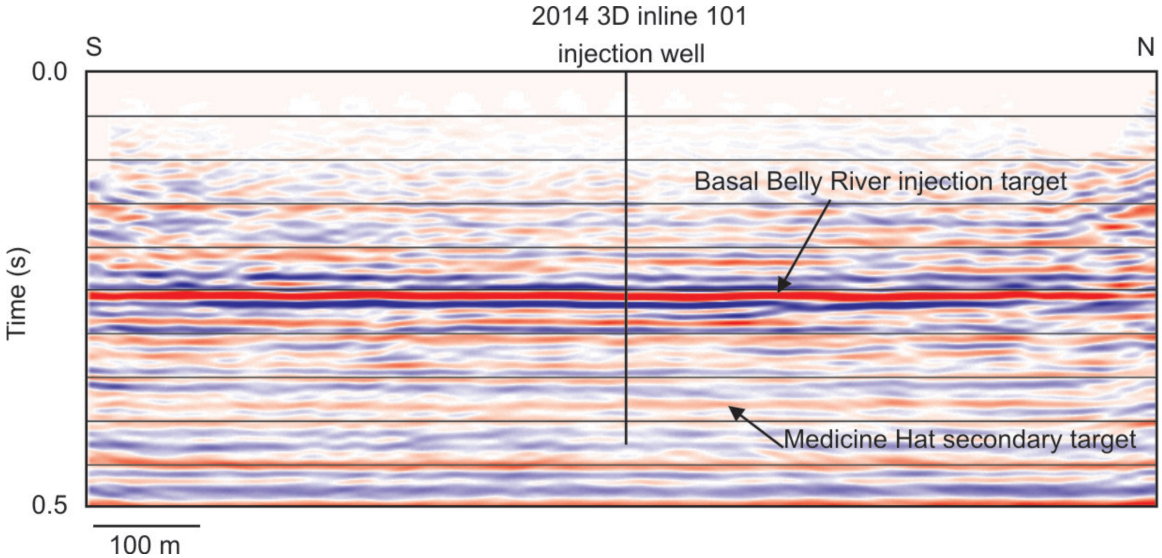

FIG. 4. A zoomed version of the line in Figure 3a, showing the target injection zones.

In Figure 5 we show the tie between a part of inline 101 and the synthetic seismogram created from the sonic and density logs acquired in the injection well and using a wavelet extracted over a 200-800 ms window from traces around the well location. The Basal Belly River target is very thin (6.5 m), and is close to tuning thickness for the wavelength of about 45 m so the reflection amplitude of this event is subject to tuning effects. The synthetic seismogram stack of multiple offset synthetic traces provides a much better character tie to the full-offset seismic data than does the normal incidence synthetic seismogram. A detailed discussion may be found in Isaac and Lawton (2016b).

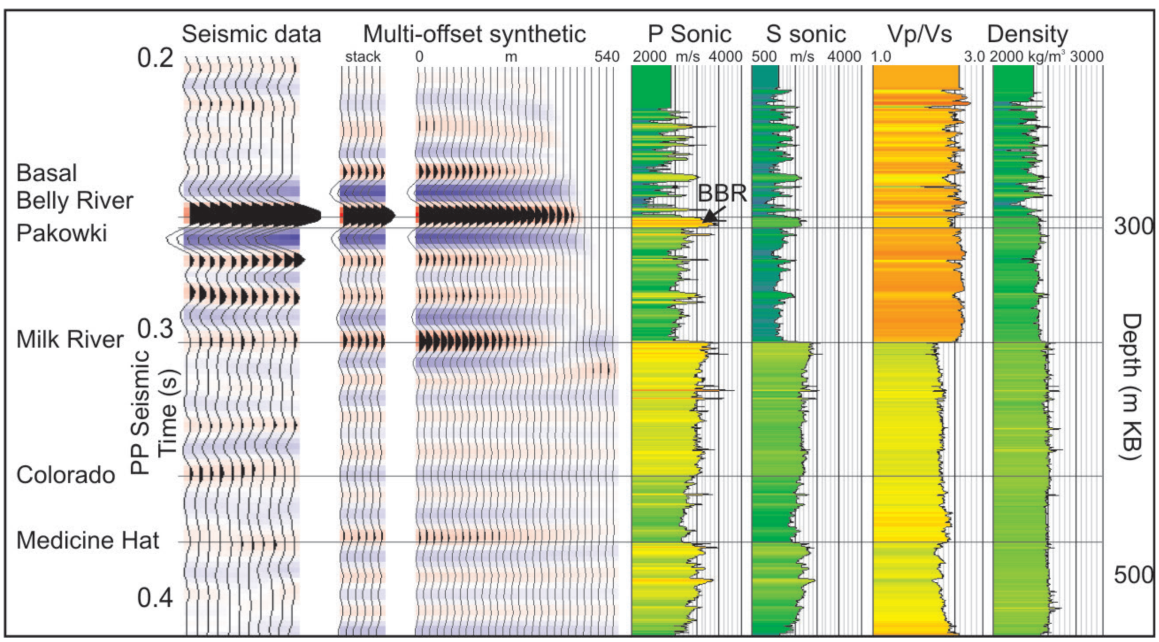

FIG. 5. Tie between PP seismic data and PP synthetic seismogram created from the sonic and density logs acquired in the injection well. The Basal Belly River sandstone (BBR) is seen clearly on the P sonic log.

2015

A 1-km 2D seismic line was acquired using both Aries and Hawk receivers and multiple shots. For both surveys the source was vibroseis at a station spacing of 10 m. The 101 Aries SM-24 receivers recorded data from geophones spaced 10 m apart while the 31 Hawk 3C nodal recorders recorded data from geophones spaced 30 m apart. The sources were repeated for a descending VSP tool and were also recorded by the surface receivers. When there were multiple shots for one source station we selected the best by visual inspection of the shot gathers.

The migrated data are shown in Figure 6, which also shows for comparison an arbitrary line extracted from the 2014 3D survey coinciding with the 2015 2D line. The strong event at about 0.25 s corresponds to the Basal Belly River sandstone. It is perhaps an unfair comparison of the Aries and Hawk systems as they recorded data from geophones at different station spacings.

2017

Line 13 (NE-SW) consisted of 76 shots with the Envirovibe source recorded on 112 channels of 3C geophones along line 13. Line 15 ran orthogonal to line 13 in a NW-SE direction and provided only source points, the data being recorded by the 3C receivers of line 13 and the 3D grid. A comparison between line 13 and an arbitrary line from the 2014 3D survey is shown in Figure 7, with the synthetic seismogram inserted at the injection well location. A match filter was derived between line 13 and inline 101 from the 3D survey and was applied to line 13 displayed here. The Basal Belly River does not appear as strong a reflector in the centre of the line as it does towards the sides. The area in the centre of the line has been disturbed by the drilling of the injection and observation wells and installation of sensing equipment, and it could be that this activity is affecting the seismic raypaths as they penetrate the area.

A star-shaped pattern of three lines (21, 23 and 27) was laid out and data were recorded by the geophones on the N-S line 21. Figure 8 shows this line and the corresponding arbitrary line from the 2014 3D survey. We have applied a match filter to line 21.

The shots from lines 13 and 15 were also recorded by the 3C geophones buried 1 m deep at 10 m intervals in a small 100 m x 100 m 3D grid. As we show in the next section, the source-receiver offsets contained in the data in the vicinity of the small 3D are too short to image the Basal Belly River reflector in the vicinity of the injection and observation wells.

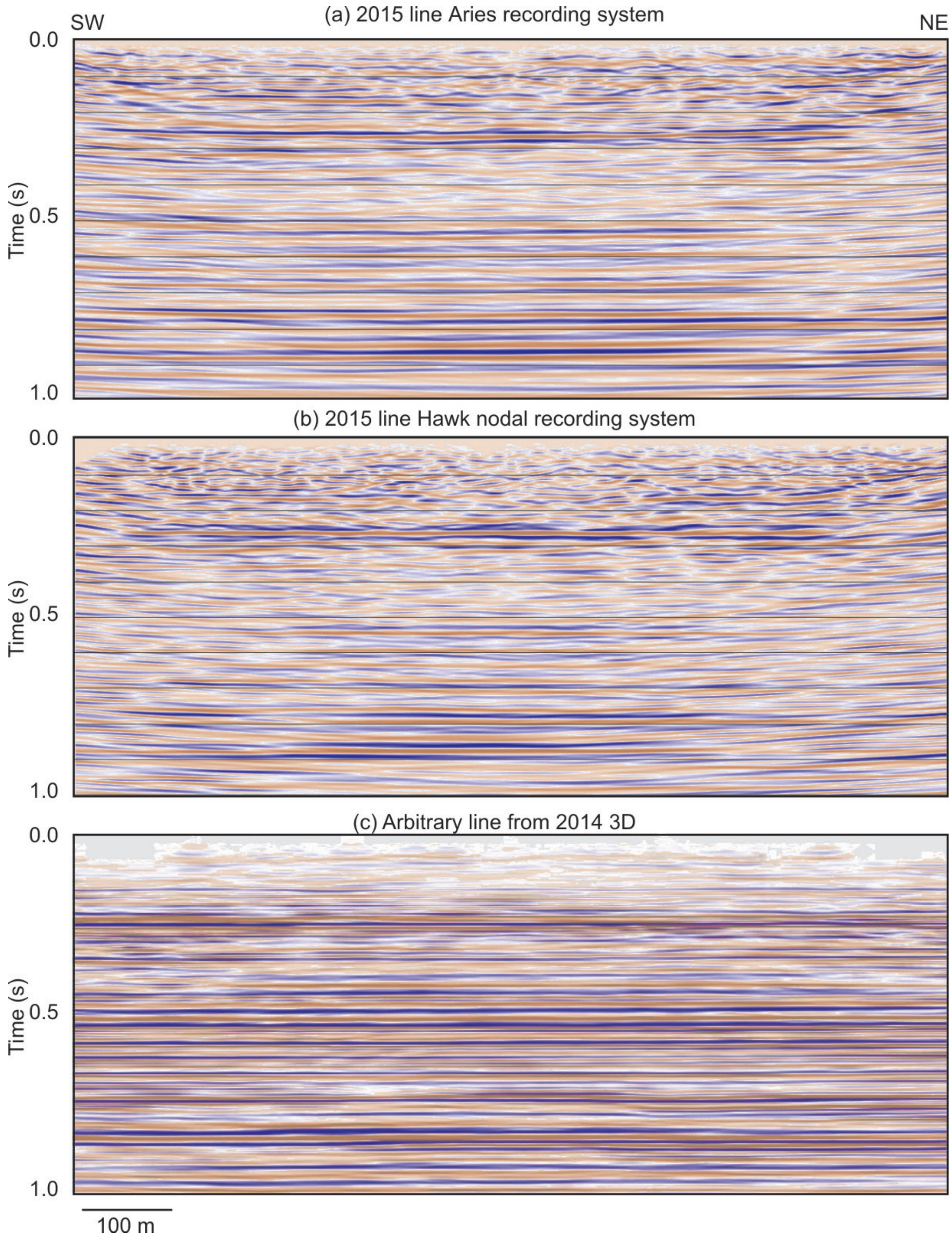

FIG. 6. 2015 2D line recorded by (a) Aries and (b) Hawk recording systems, with the corresponding arbitrary line extracted from the 2014 3D survey.

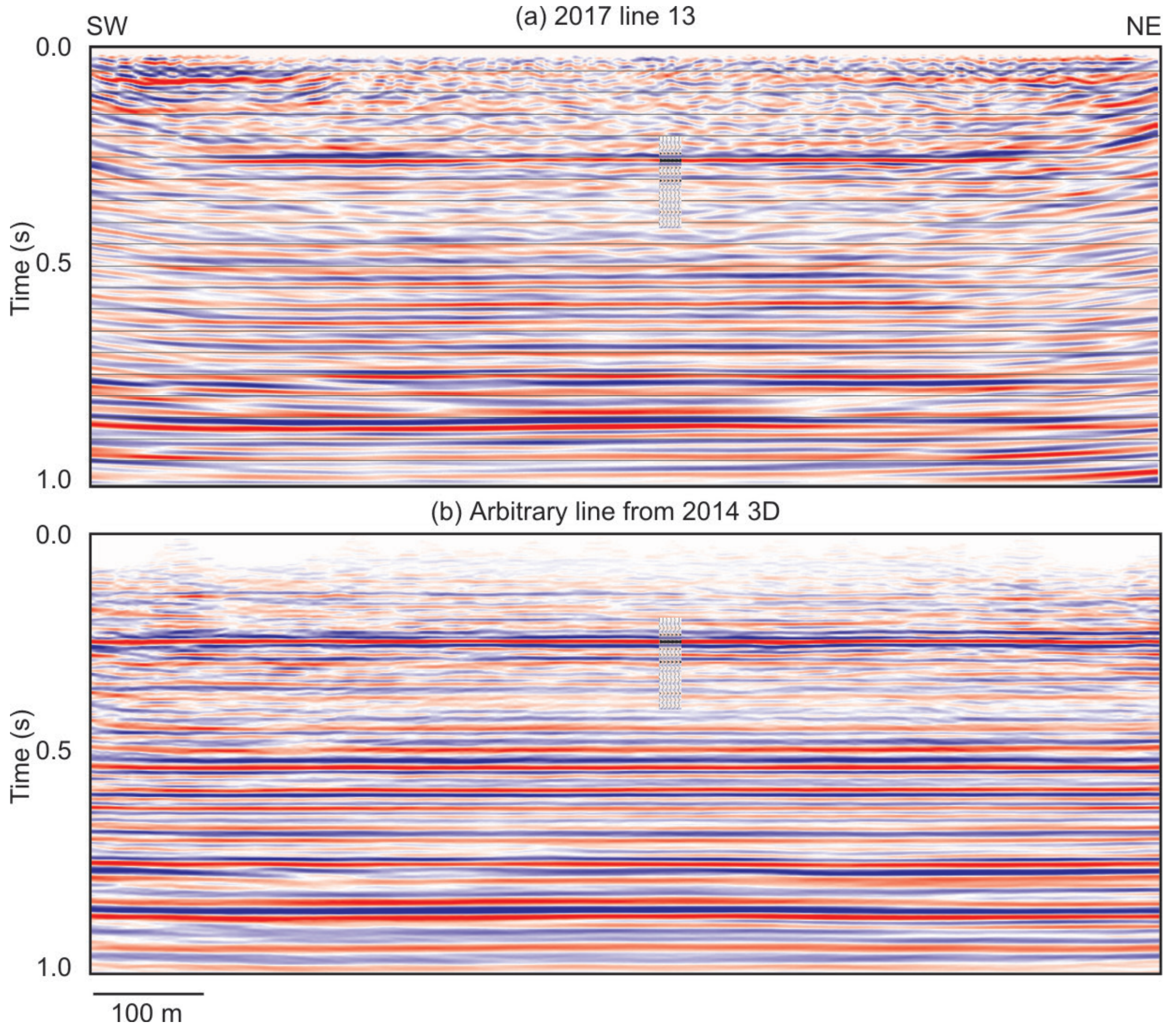

FIG. 7. Line 13, acquired in 2017, and the corresponding arbitrary line from the 2014 3D survey for comparison. Line 13 has had a match filter applied.

Offsets

By looking at offset gathers and NMO-corrected CDO gathers, we notice that the target Basal Belly River reflection is best imaged on offsets of 200-400 m. This effect is observed on offset gathers from multiple data sets (Figure 9). The offset distribution of traces recorded by geophones in the small 3D is shown in Figure 10. The green colour shows where the offsets are 200-400 m, best for imaging the Basal Belly River reflector, as can be observed in Figure 11. Here we display three inlines, 20, 40 and 60. Inlines 20 and 60 have offsets sufficiently long to image the Basal Belly River (150-500 m and 185-445 m, respectively) but inline 40 has offsets of only 10-160 m. This small array of buried geophones will have to be used for a purpose other than imaging surface seismic reflection data in their vicinity.

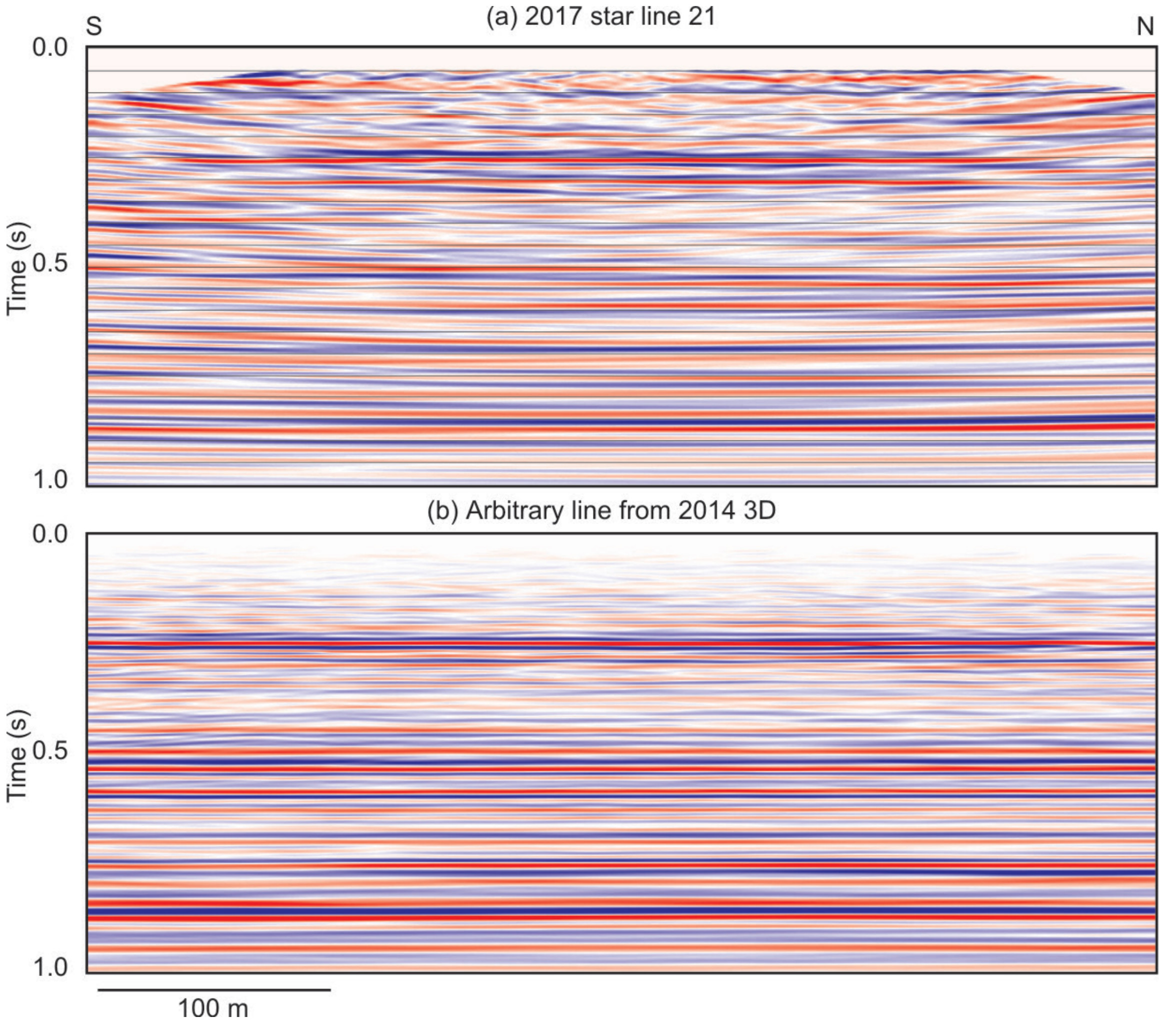

FIG. 8. Line 21 from the star-shaped survey acquired in 2017, and the corresponding arbitrary line from the 2014 3D survey for comparison. Line 21 has had a match filter applied.

Converted-wave data

Converted-wave data have been acquired in the study area and are of good quality. Figure 12 displays PS data from (a) the 2014 3D and (b) the 2017 2D surveys. The 3D data have imaged the subsurface with more consistency and better continuity of character across the section. Figure 13 shows the tie between the PS seismic data and a PS synthetic seismogram. The wavelet was extracted over a 0-1000 ms window from traces across the survey. The character match is very good and we are able to identify reflections to a PS time of 0.8 s. The Basal Belly River reflector is just below 0.5 s PS time.

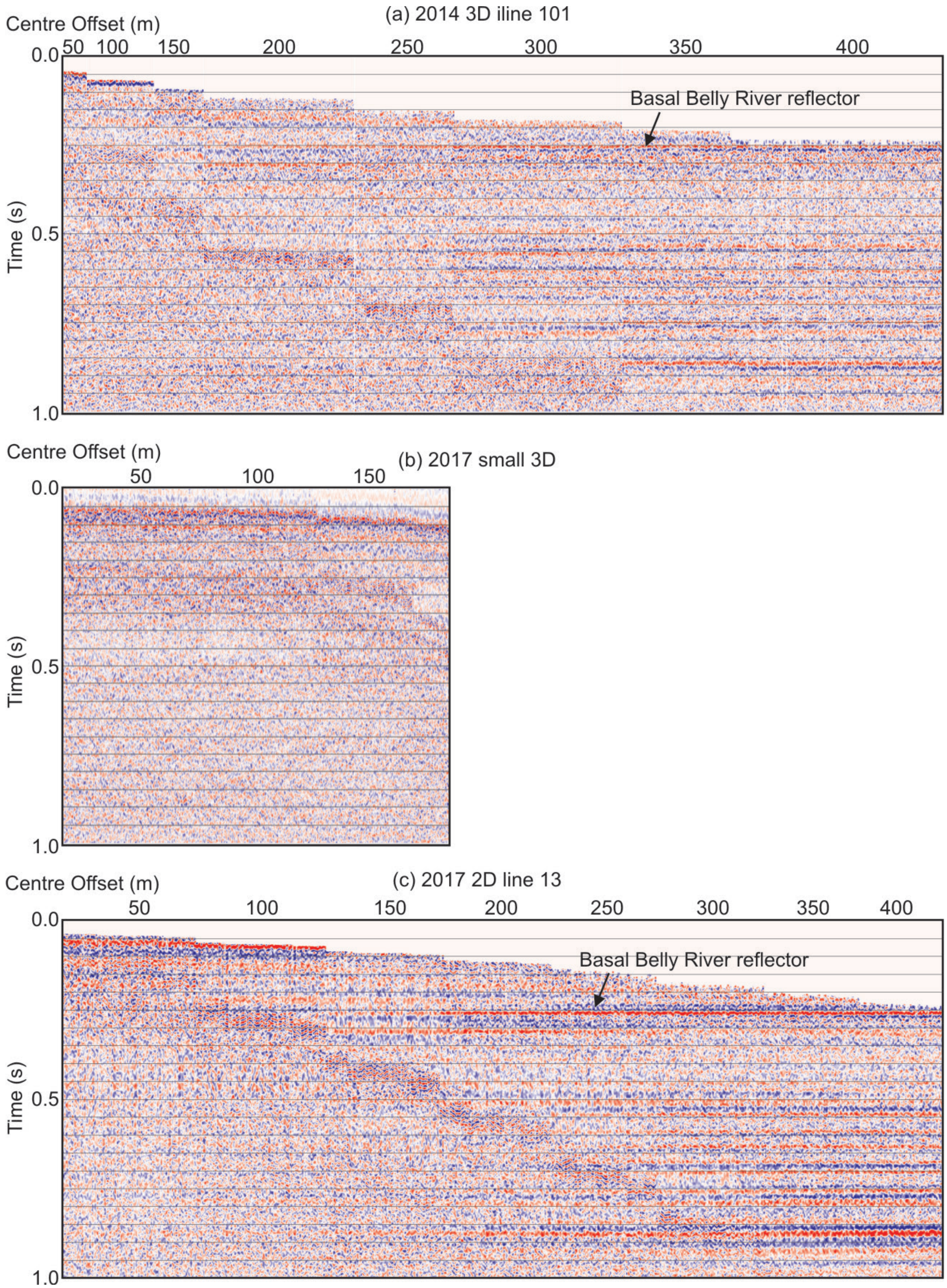

FIG. 9. Offset gathers from (a) 2014 3D inline 101, (b) 2017 small 3D, and (c) 2017 2D line, showing that the Basal Belly River is best imaged on offsets of 200-400 m.

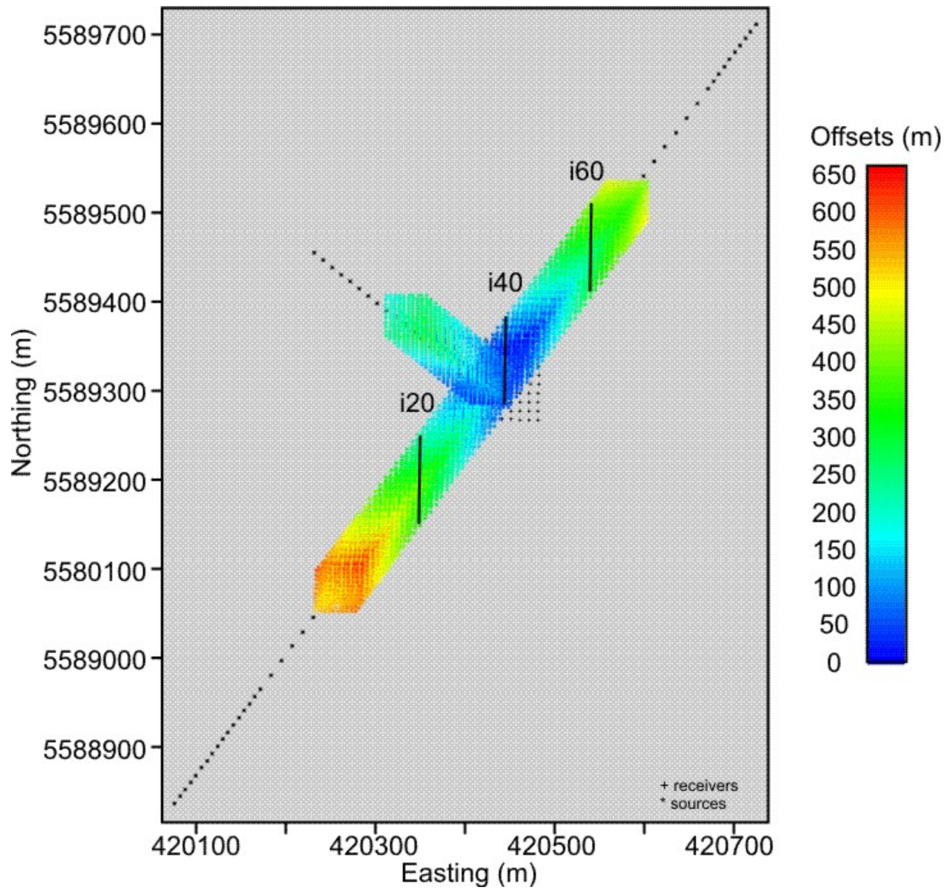

FIG. 10. Offset distribution of traces recorded by the geophones in the small 3D array. Offsets of 200-400 m (green) are best for imaging the Basal Belly River target. Inlines 20, 40 and 60 are displayed in the next figure.

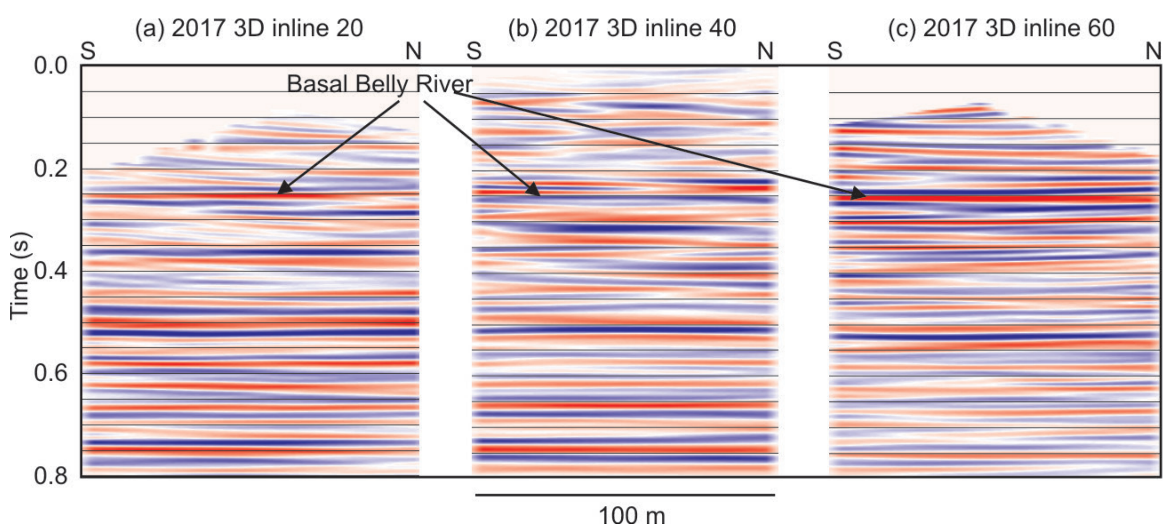

FIG. 11. Three images from the small 3D3C 2017 survey. Inlines 20 (a) and 60 (c) contain offsets sufficient for imaging the Basal Belly River, whereas inline 40 (b), which runs through the middle of the 3D receiver grid, does not.

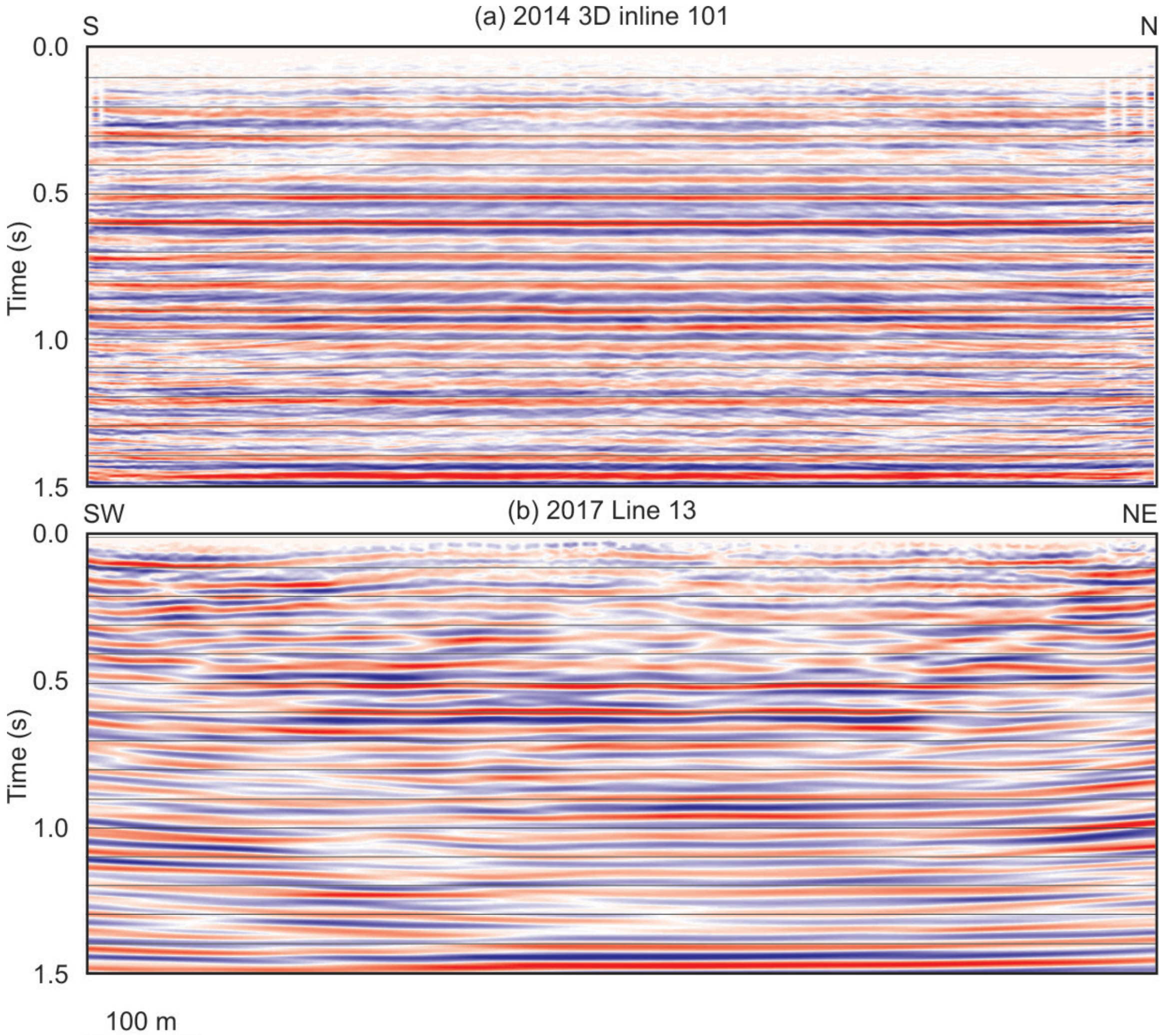

FIG. 12. Migrated converted-wave data. Inline 101 from the 2014 3D survey (a) and 2017 2D line 13 (b). The Basal Belly River reflector is the red peak near 0.5 s.

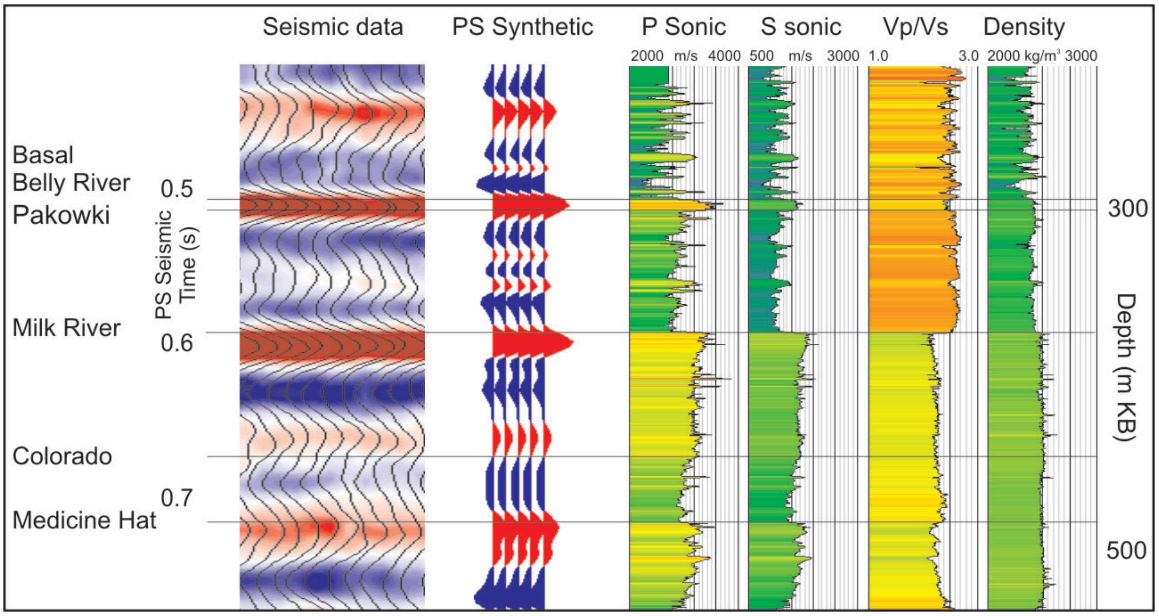

FIG. 13. Tie between PS seismic data and PS synthetic seismogram created from the sonic and density logs acquired in the injection well.

DAS fibre optic cable data

Distributed Acoustic Sensing (DAS) fibre optic cable and downhole data were also acquired in 2017. Conventional seismic data are used to image the subsurface at time intervals (4D) measured in months and may reveal changes in reservoir properties due to CO_2 injection. However, other methods are needed for real-time or short-term monitoring. An emerging technology for monitoring of CO_2 storage is DAS, where the fibre optic cable serves as a sensor (Daley et al., 2013). We acquired some DAS data by laying the cable in a 1-m deep trench which was about 1.1 km long. The cable ran as a continuous loop through the trench, into the observation wells and on to the shack. One source point of the DAS data is displayed in Figure 14, where we show the field data (a) and data after noise attenuation and Gabor deconvolution (b), intended to enhance the PP energy. The displayed traces have a spacing equivalent to 0.25 m. We can see reflections on the data and processing of multiple sources should help establish the applicability of this type of data.

CONCLUSIONS

We have complied and compared here the different vintages of surface seismic data at the FRS near Brooks, Alberta. The 3D3C data acquired in 2014 exhibit the best continuity of reflections and consistency of seismic character. The offset range that images the injection horizon, the Basal Belly River sandstone, best on PP seismic reflection data is 200-400 m. Thus, the small 100 x 100 m buried array of 3C geophones does not allow for adequate offsets for imaging reflections in the immediate vicinity of the buried geophones.

Preliminary investigations of DAS data suggest that these data hold promise for imaging reservoir changes in real time.

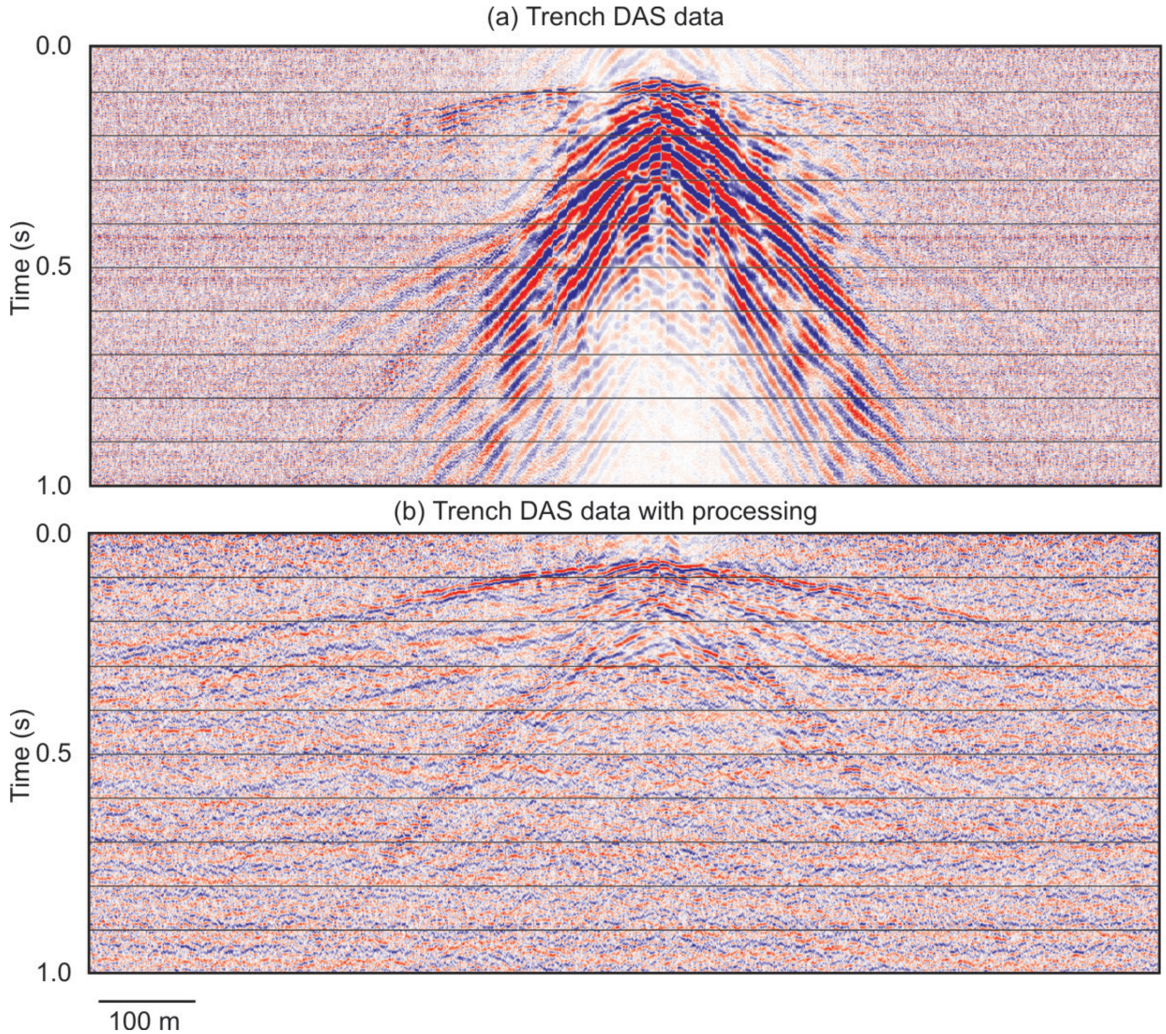

FIG. 14. Preliminary DAS data from the fibre optic cable. (a) Field data, (b) data with some processing, including Gabor deconvolution.

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