CO_2 monitoring at the CaMI Field Research Station - update

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ABSTRACT

The Containment and Monitoring Institute of Carbon Management Canada collaborates with CREWES on several aspects of monitoring of CO_2 storage at a Field Research Station (CaMI.FRS) in southern Alberta. An important role of CaMI.FRS is also to provide a field opportunity to test new seismic and other monitoring technologies for general purposes but also for monitoring CO_2 storage. In the summer of 2021, an ultra-high-density 3D surface seismic program was recorded at the site in a partnership between Explor, STRYDE and CMC, with CREWES staff also contributing personnel to the acquisition program. The purpose of the acquisition program was to evaluate the viability of using ultra-high-density surface sampling to improve imaging and detection of reservoir characteristics at the site and to aid future designs of 4D time lapse surveys at this and other sites. A total of 19,872 STRYDE nodes were deployed on a 7.5 x 7.5 m grid over an area of 1 km x 1 km into which 9,041 shots were recorded using a new proprietary seismic Explor source (PinPoint). In addition to 3,910 records obtained using the University of Calgary Envirovibe source, making this arguably the highest trace density of a land 3D survey ever recorded. The processing of the data is continuing, the main processing challenge being generally a high level of noise observed in data. However, initial results are very promising for imaging the full sedimentary section at CaMI.FRS, including the CO_2 injection zone.

INTRODUCTION

The Containment and Monitoring Institute Field Research Station (CaMI.FRS) is located 200 km south-east of Calgary in Newell County. It was developed and is operated jointly by Carbon Management Canada (CMC) and the University of Calgary, with the purpose of advancing Carbon Caption and Storage (CCS) as a technology for reducing emissions of CO_2 into the atmosphere. Full details about this facility are available from Lawton et al. (2019) and Macquet et al. (2019). At this site we are injecting a small amount of CO_2 (several tens of tonnes/year) into the shallow subsurface (300 m depth) to simulate CO_2 leakage from a deeper and larger scale CO_2 storage project. The injection program is being monitored by a broad range of geophysical and geochemical technologies. The small, controlled amount of injected CO_2 enables us to determine the detection threshold for gas-phase CO_2 at shallow to intermediate depths, to improve and develop monitoring technologies, and to de-risk CO_2 storage in general. An important role of CaMI.FRS is also to provide a field opportunity to test new seismic and other monitoring technologies for general purposes but also for monitoring CO_2 storage. This report is about a new ultra-high-density seismic survey that was conducted at CaMI.FRS in 2021. Other papers in this year's Research Report are updates of some of the research being undertaken collaboratively between CaMI and CREWES on seismic theory, modelling and data analysis.

ULTRA-HIGH-DENSITY 3D SURFACE SEISMIC SURVEY

In early summer of 2021, an opportunity arose to record an ultra-high-density (UHD) 3D surface seismic survey at CaMI.FRS, undertaken by a Explor, a seismic acquisition company from Calgary, STRYDE from the UK and CMC from Calgary. The purpose of the acquisition program was to evaluate the viability of using UHD surface sampling to improve imaging and detect surface reservoir characteristics at a CO_2 gas injection site and to aid future designs of 4D time lapse surveys on this and other sites. Receivers deployed for the survey were STRYDE nodes and two source types were used. The main survey was acquired with a proprietary source developed by Explor, known as PinPoint, an ultra-light-weight impulsive chemical seismic source weighing less than 1 kg, with integrated RTK GNSS positioning. In addition to the PinPoint survey, another source grid was also acquired over the same receiver spread using the University of Calgary Envirovibe source. The sweep used was 10-120 Hz over 10 seconds, with 1 sweep per VP. The acquisition parameters for the 2 surveys are summarized in Table 1.

Table 1. Ultra-high-density 3D seismic survey parameters.

Receivers	Source #1	Source #2
STRYDE nodes	PinPoint	Envirovibe (10-120 Hz) over 10 seconds
135 receiver lines	134 shot lines	34 shot lines
7.5 m x 7.5 m grid	3 x interleaved 15 m x 15 m grids (nominal)	30 m line x 7.5 m shot.
19,872 nodes	9,041 shots	3,910 shots
Binning: 3.75 m x 3.75 m	Binning: 3.75 m x 3.75 m	Binning: 3.75 m x 3.75 m

Figure 1 shows the crated STYDE nodes prior to deployment and Figure 2 shows a picture and details of the PinPoint source.

FIG 1. STRYDE nodes ready for deployment

~~The end of the receiver lines were initially surveyed in and then the~~ The nodes were placed at 7.5 m intervals along each line using real-time GNSS~~RTK~~ positioning, and precise locations were then determined by GPS coordinates recorded by each node. Similarly, stakeless acquisition was undertaken with the two~~2~~ source types. The PinPoint survey was undertaken during the day and the Envirovibe survey was undertaken in the evenings. Weather conditions varied from calm to very windy. Acquisition continued during windy periods in order to fully evaluate the outcomes of the ultra-high-density acquisition in all conditions.

(a) (b)

FIG 2. (a) PinPoint source (b) Envirovibe source equipped for night acquisition

Figure 3 displays the fold maps for the surveys undertaken for full fold (all offsets) and for offsets limited to 500 m (maximum offset for imaging the CO_2 injection target at 300 m depth). For the PinPoint survey, a total of ~179 million traces were collected, and for the Envirovibe survey, a total of ~77 million traces were collected, for a total count ~256 million traces, arguably the highest trace density seismic survey ever recorded on land, albeit over a 1 sq km area. All data were binned into 3.75 m x 3.75 m natural bins, resulting in maximum fold of close to 4,000 for the Envirovibe survey and over 10,000 for the PinPoint survey (all offsets) and 850 and about 3000 respectively, for offsets limited to 500 m.

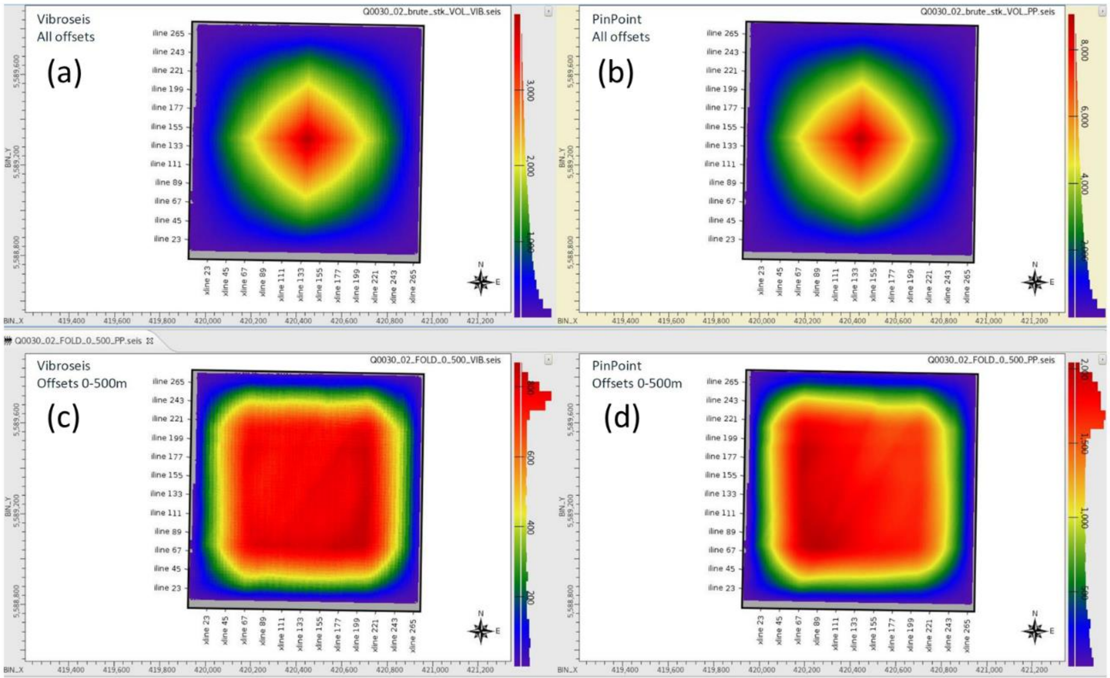


FIG 3. UHD survey fold maps; (a) Envirovibe survey with all offsets; (b) PinPoint survey will all offsets; (c) Envirovibe survey offsets limited to 500 m; (d) PinPoint survey offsets limited to 500 m.

DATA PROCESSING

Refraction Statics

The processing is being carried out by STRYDE, using Reveal processing software in conjunction with TomoPlus software for near-surface model calculation via 3D Tomographic Inversion using first break picking.

Although the topography of the survey area is relatively flat, the near-surface geology is quite complex with about 30 m of glacial till present, including suspected rafted pieces of sandstone bedrock, thus causing static issues which need resolving for processing. Refraction tomography was used to solve for the near-surface velocity model. First break pick times required for the calculation of tomo models were picked by an autopicker within the TomoPlus package, followed by manual editing and removal of anomalous picks. The raw first arrivals were clean and well-defined for the Envirovibe data and a good quality pick times were obtained for all of the offset range (up to 1400 m), granting good penetration of the ray paths and an optimum model depth for the subsequent Tomographic Inversion.

The PinPoint data were noisier and on raw data good first arrivals were obtained for offsets up to 500 m, therefore the resulting tomo model, although very detailed and matching the Envirovibe shallow part, it was thinner than its Envirovibe counterpart. This was first remediated by PinPoint data preconditioning, which revealed more offsets to pick which in turn provided a deeper model which however smoothed some of the details previously seen on the raw data derived model. To retain those details, a hybrid solution was derived where the deep model derived from the pre-conditioned data was used as an initial model for a re-run of the tomography with the raw near offset data. The hybrid approach provides both the sufficient depth and details of the near surface model for the PinPoint data.

Figure 4 shows the static solutions determined from the PinPoint and Envirovibe first arrival data.

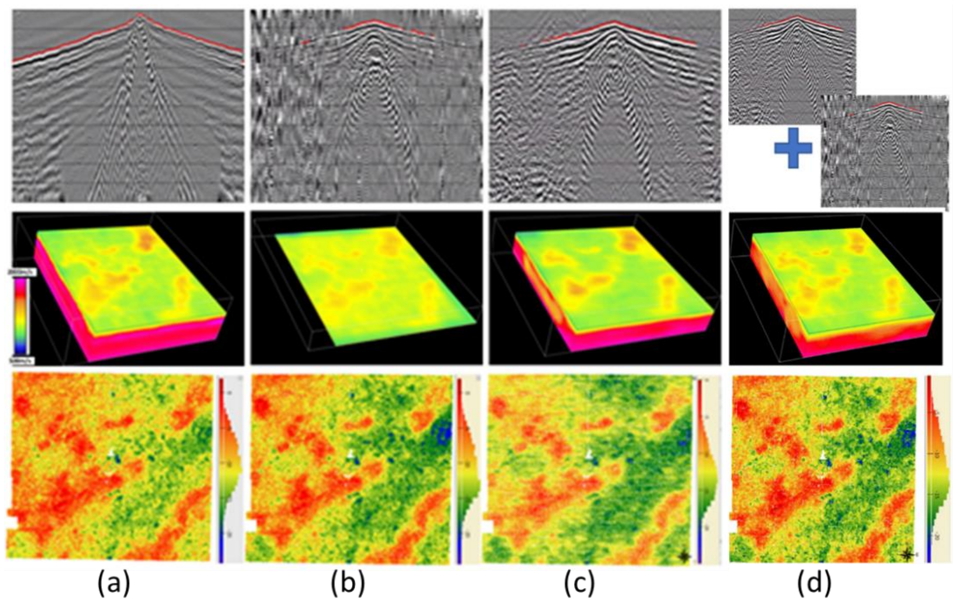
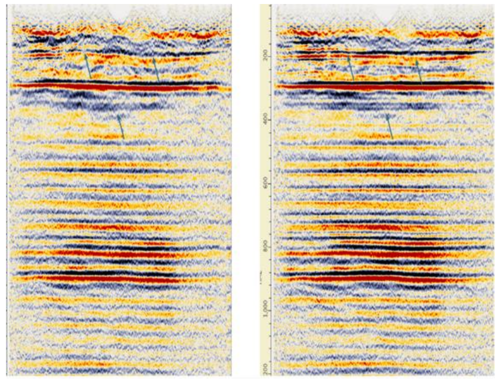


FIG 4. Static solutions (a) Envirovibe; (b) Raw PinPoint; (c) Pre-conditions PinPoint; (d) Hybrid PinPoint. The upper row shows example shot gathers; Centre tow the near-surface velocity model and the bottom row the static solution

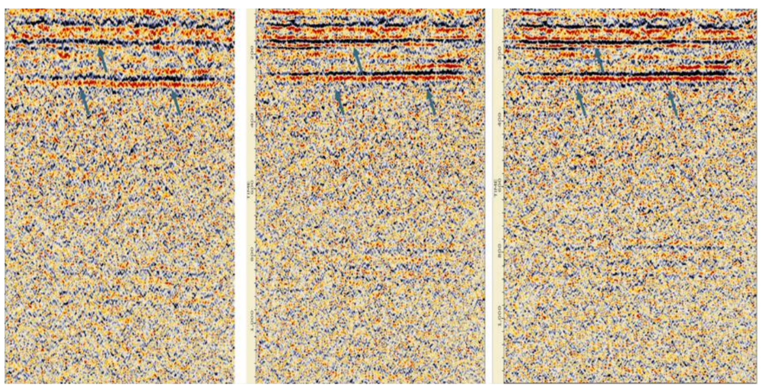
The resulting tomo-statics calculated for each of the models (including the initial thinner PinPoint tomo model) resolved all statics issues in the data and provided an excellent event continuity on the stacked sections. Testing of the pseudo datum for the tomo-statics indicated that the majority of the statics are generated in the first ~50 m of the near-surface model, which means that for this data and its specific geological conditions, the depth of penetration of the velocity model is not critical.

The impacts of applying the static solutions and pre-conditioning of the PinPoint data are shown in Figures 5 and 6 for the Envirovibe and PinPoint data respectively emphasizing that even for a such thin weathering layer, solving the statics was indeed critical before proceeding with the rest of the processing.



(a) (b)

FIG 5. Inline display of a brute stack from the Envirovibe data (a) without tomostatics and (b) with tomo-statics applied.



(a) (b) (c)

FIG 6. Inline display of a brute stack from the PinPoint data (a) without tomostatics and (b) with tomo-statics (raw data); (c) with pre-conditioning and tomo statics applied.

Noise attenuation

In general, the PinPoint data were noisier than the Envirovibe data. However, frequency panel analysis and brute stacks and, in particular Post-Stack Time-Migrated data revealed a good level of signal present in the PinPoint data, especially at higher frequencies. A careful, multi-pass denoise routine was derived for both the Envirovibe and PinPoint datasets, using the same core applied processes. PinPoint data generally needed more passes targeting different amplitude thresholds, spatial gates or time windows for optimum application, and were therefore longer to process compared to their Envirovibe data.

The denoise routine started with a despike which was carried out in several passes on both datasets to target spikes and isolated high amplitude noise bursts. This was followed by FKK linear noise attenuation (FKK) in cross-spread domain. The cross-spread gathers contained high amounts of surface wave noise that is aliased, even with the dense receiver grid. Several passes of FKK in a cross-spread domain were undertaken in different ways (NMO wrap or applied within a conal geometry) were effective for tackling several modes of ground roll whilst protecting the primary events. These processes were followed by air-blast removal within a defined corridor to attenuate some residual groundroll.

FX prediction filter was calculated in various frequency panels and applied to remove random noise. This was performed in shot and receiver domain to further diminish the noise patterns. Both the Envirovibe and PinPoint data responded well to the applied denoise routines, as shown in Figures 7 and 8. In particular, the noise attenuation for the PinPoint data was very effective (Fig 8).

Surface consistent processing (SCP)

The amplitude of any given trace may be affected by a number of factors including the shot type, the response or coupling of the receiver, and velocity contrasts in the near subsurface for example. The variable nature of the surface condition (hard and soft ground) in the survey area as well as the different coupling depths of the PinPoint sources were expected to add variations to the coupling of both sources and receivers, hence the surface consistent processing stage was included in the processing sequence.

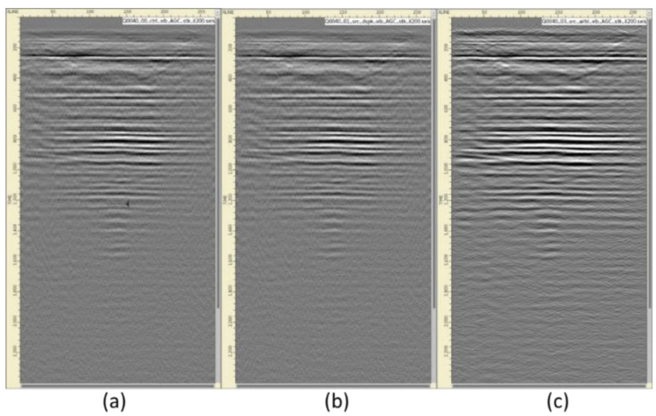


FIG 7. Denoising processing Envirovibe data. (a) control stack; (b) after despike; (c) after LNA and RNA

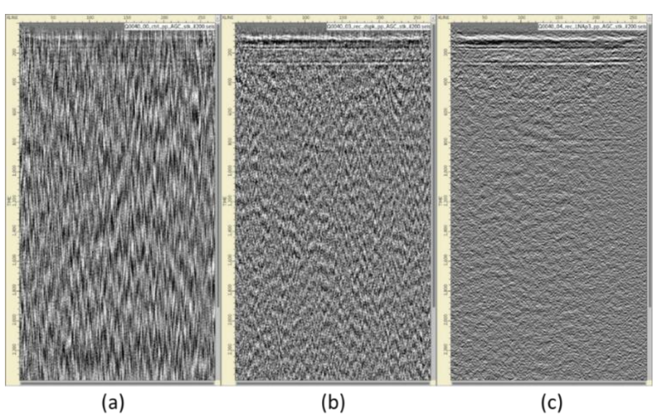


FIG 8. Denoising processing PinPoint data. (a) control stack; (b) after despike; (c) after LNA and RNA

To eliminate non-geology-related amplitude variations, surface consistent amplitude corrections were estimated within a very shallow window, calculated around the CO_2 injection target. Input data were pre-conditioned with additional denoise in CMP domain, not included in the main processing sequence. The interleaved sources acquired on separate days with very different weather conditions provided a very challenging environment for SCP as the variation in amplitude due to the environment noise were biasing the calculation of the SCP filter and corrections, more time would need to be spent on this aspect in a full production sequence to get the level of noise low enough for SCP to work in an optimum way. The several passes of pre-conditioning denoise helped the surface consistent amplitude scalars to provide a good balance across the survey, as shown in Figure 9.

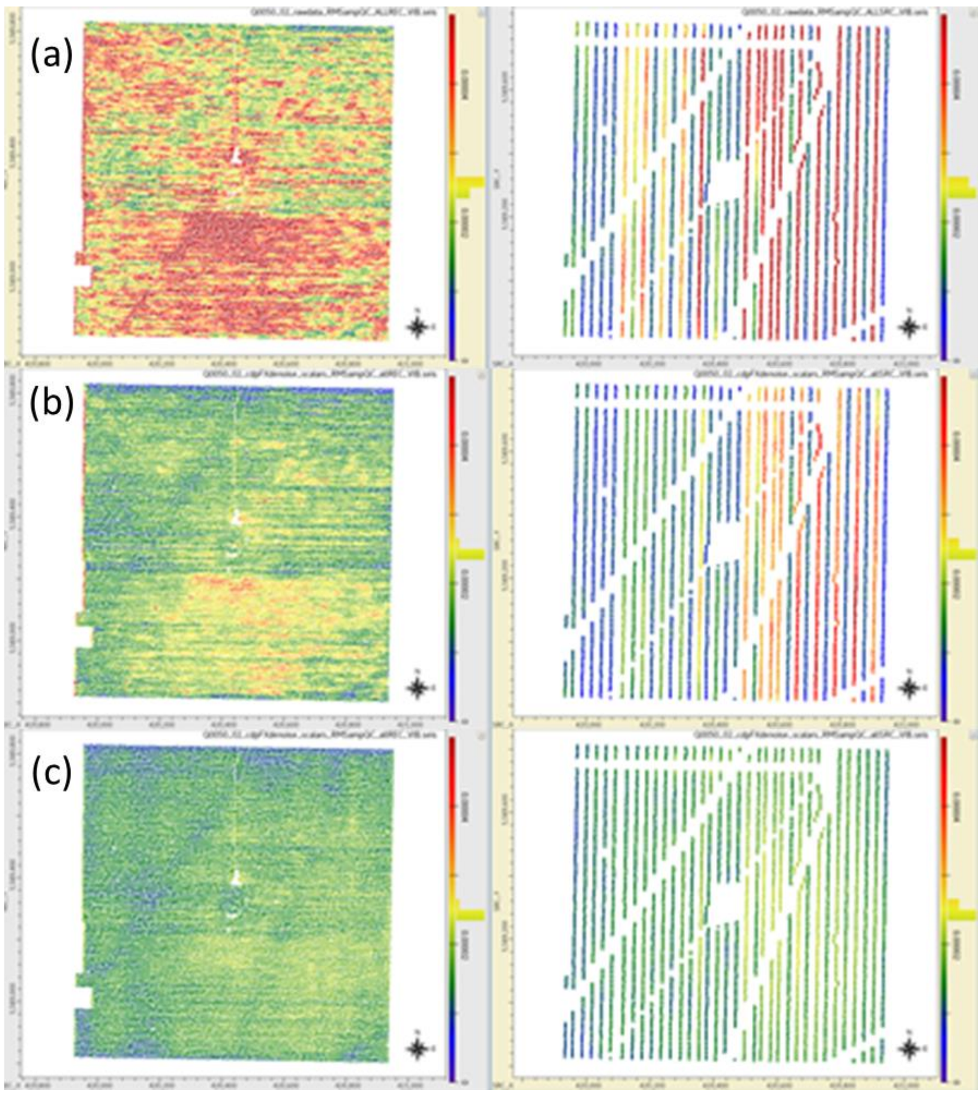


FIG 9. SCAMP for Envirovibe data, receivers (left), sources (right). (a) RMS amplitude, no CMP denoise. (b) RMS amplitudes with CMP denoise; (c) RMS amplitudes with CMP denoise and surface consistent amplitude scalars.

At this stage of the processing, the data were put through a fast-track processing sequence to include post-stack and pre-stack time migration. Figures 10 and 11 show the example in-line sections of the post-stack time migration for the Enviro and PinPoint sources respectively. For each set of panels, the post-stack time migrated data from the legacy baseline survey is also shown for comparison.

DISCUSSION AND CONCLUSIONS

The ultra-high-density seismic survey recorded with the PinPoint source an STRYDE nodes was very successful and processed data are comparable to that recorded with the Envirovibe source. The high spatial density enabled effective noise reduction in the pres-stack data. Initial processing through to post-stack migrated sections shows that reflections from basement are captured with both sources. The CO_2 injection zone at around 250 ms reflection time, was particularly well imaged with the PinPoint source. This project represents a very fruitful collaboration between CaMI and CREWES.

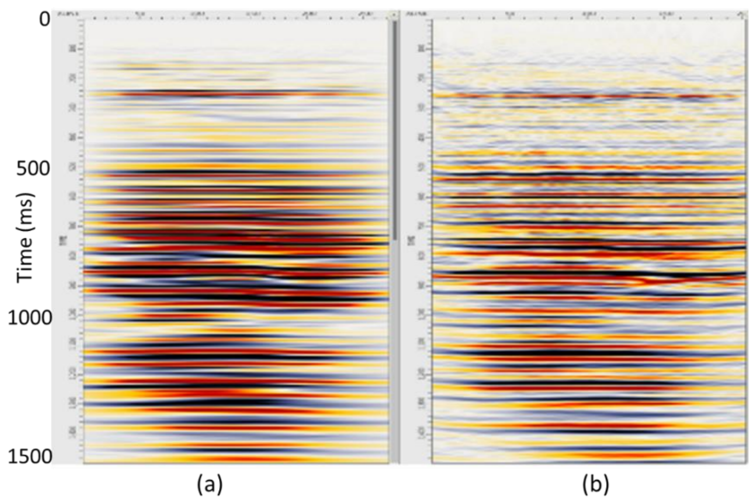


FIG 10. Initial post-stack migrated in-line section (a) Envirovibe data (b) legacy baseline data.

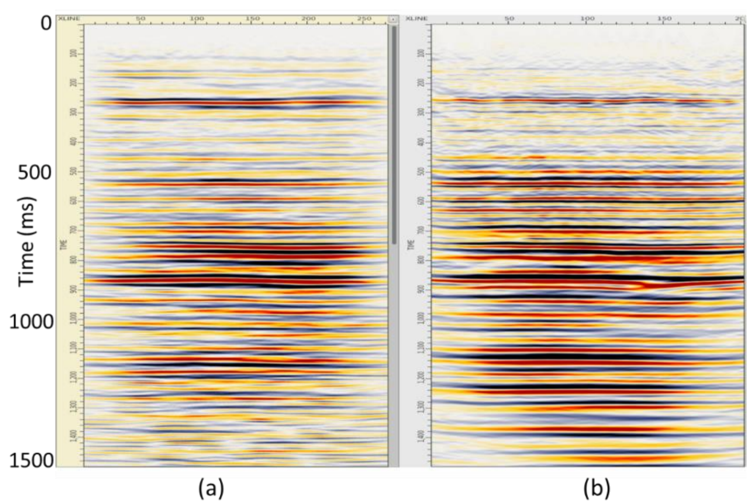


FIG 11. Initial post-stack migrated in-line section (a) PinPoint data (b) legacy baseline data

ACKNOWLEDGEMENTS

We acknowledge Explor, STRYDE and CMC for taking the opportunity to undertake this ultra-high-density seismic survey. We thank CaMI.FRS JIP sponsors and CREWES sponsors for support as well as NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 543578-19. Research at the CaMI field site is also supported by the Canada First Research Excellence Fund, through the Global Research Initiative at the University of Calgary.

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