Seismic processing workflow for supressing coherent noise while retaining low-frequency signal

Patricia E. Gavotti and Don C. Lawton

ABSTRACT

Two different processing workflows were applied to the same dataset to evaluate the effect of noise attenuation methods while attempting to preserve low-frequency signal with the purpose of obtaining broadband seismic data to benefit inversion studies. The approach was based on a previously conditioned dataset with a conventional processing sequence versus applying a specialized processing sequence focused on attaining coherent noise. The conventional sequence used surface wave noise attenuation and spiking deconvolution processes, while the specialized sequence used radial filter and gabor deconvolution processes. The specialized processing flow resulted in better attenuation of low-frequency noise while succeeded in retaining the low frequency signal. In comparison with the previous processed stacked, current result showed higher low-frequency content around the target zone (~ 5-9 Hz) than the previous processing (~ 9-14 Hz), but showed a structural depression in the middle part of the section possibly related with a shallow channel caused by an old meander of the North Saskatchewan River. However, no velocity or statics anomalies were observed during the processing of this dataset.

AREA OF STUDY AND INPUT DATA

The study area is located in the Western Canada Sedimentary Basin (WCSB), approximately 70 km west of Edmonton, where the Wabamun Area CO_2 Sequestration Project (WASP) study was undertaken and Project Pioneer was planned to be built at the Keephills 3 power station (Figure 1).

The seismic data for this project was provided by TransAlta Corporation and consists of two 2D seismic lines of 17.38 km and 12.91 km, respectively. The raw gathers and processed stacks were available for this study. Table 1 summarizes the main parameters of both lines. Figure 2 shows the Highvale stacked section previously processed by C&C System with the location of the Well 8-17.

Table 1: 2D seismic lines main parameters

PARAMETERS	HIGHVALE	VIOLET GROVE
Source type	Dynamite (1Kg/18m)	Vibroseis
Source interval	80 m	132 m
Receiver interval	20 m	33 m
Sample rate	2 ms	2 ms
Record length	3 sec.	3 sec.
Number of channels	201	96
Lines length	17.38 Km	12.91 Km

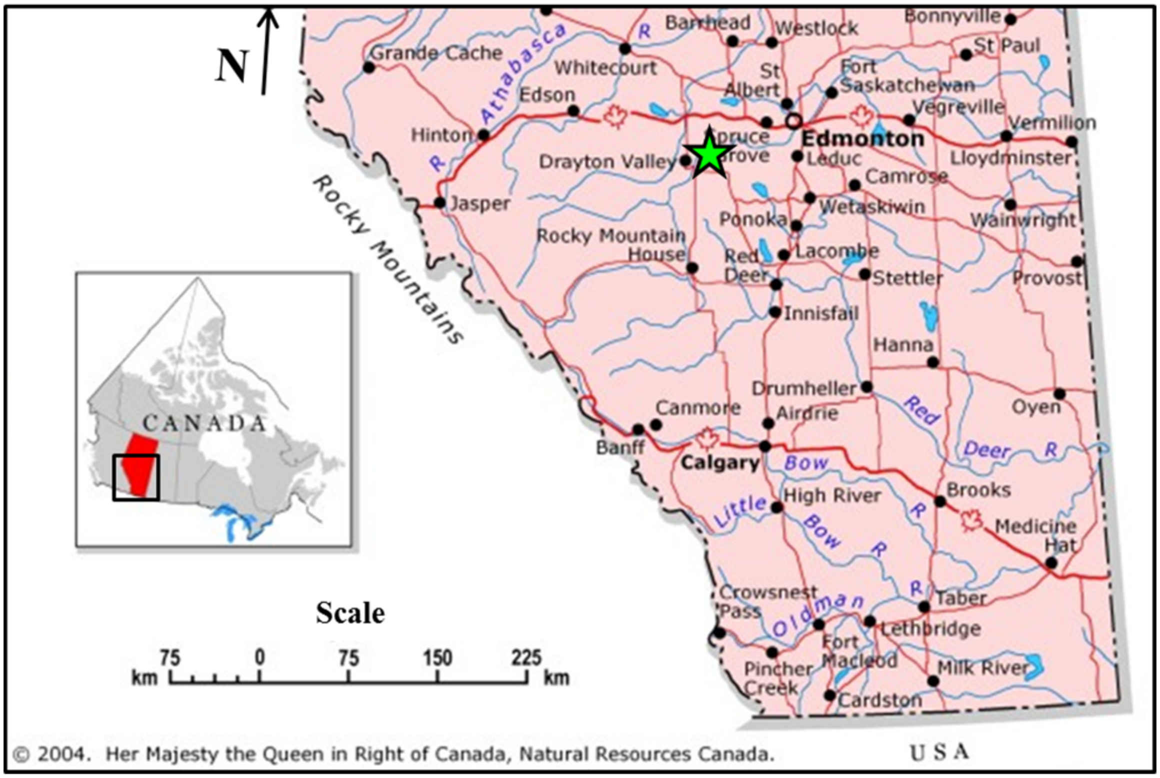


FIG.1. Location of study area in Alberta, Canada. Project Pioneer (green star) (modified from Natural Resources Canada, 2013).

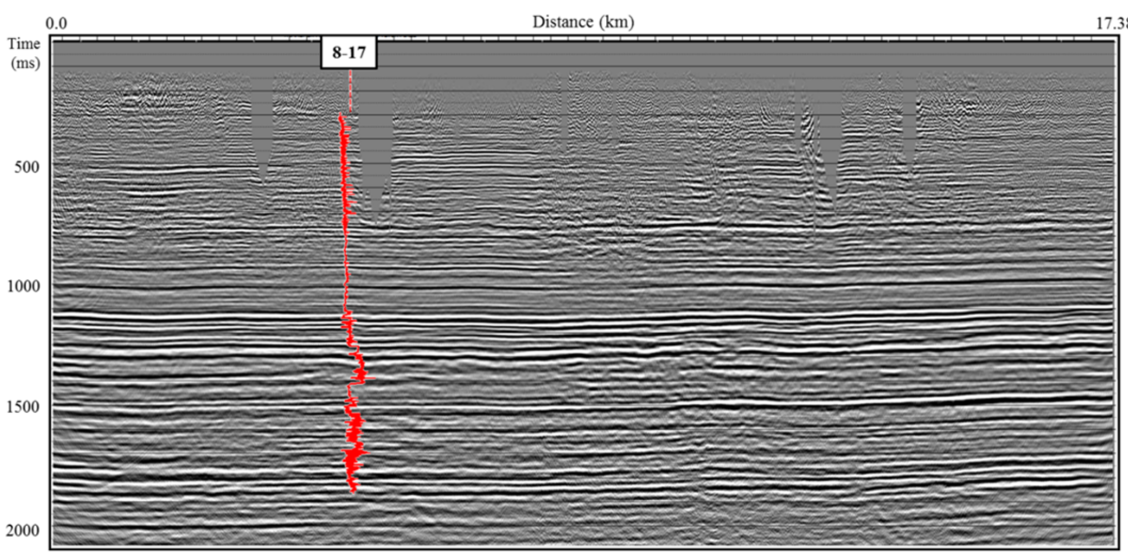


FIG. 2. Highvale stacked section with Well 8-17.

2D SEISMIC PROCESSING WORKFLOW

Survey Data

Two 2D seismic lines were used in this study. The first line, identified as Highvale, has an east-west trend located in the township/range 51-3W5. The line was acquired with 1 kg of dynamite with a source interval of 80 m and a receiver interval of 20 m. The total number of shots was 235 with a maximum number of 200 channels per shot. The array was split-spread with a maximum offset of 2000 m. The second line or Violet Grove has also an east-west trend located ~50 km southwest from the Highvale line. The line was acquired with vibroseis as the source with a source spacing of 132 m and receiver interval of 33 m. The total number of shots was 107 with a maximum number of 96 channels per shot. The array was split-spread with a maximum offset of 1700 m.

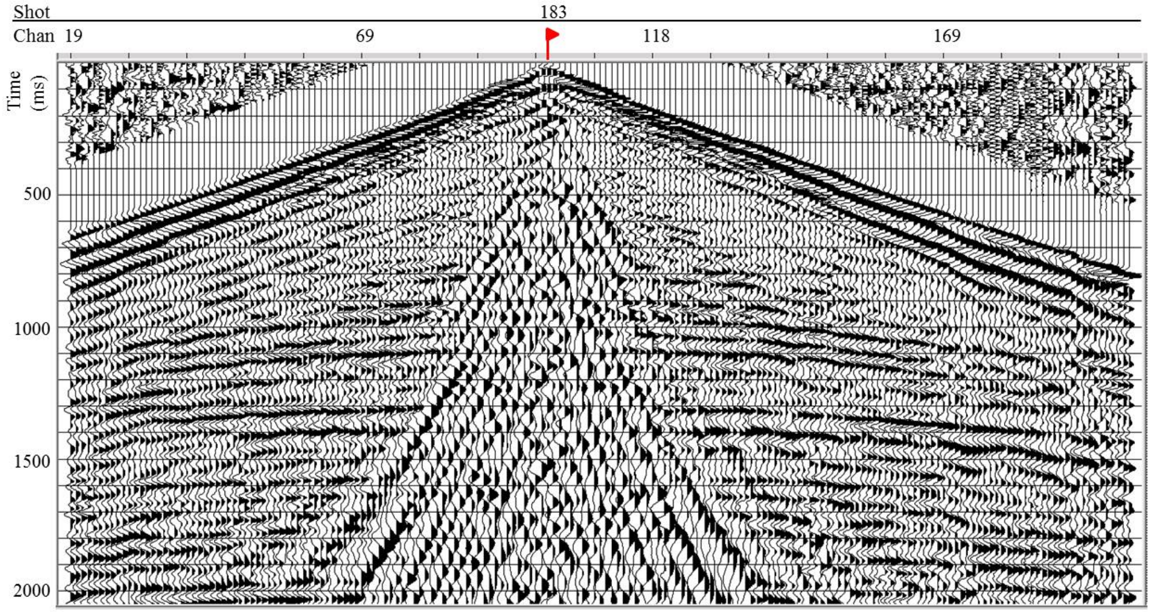
10 Hz Mark Products geophones (OYO-30CT) and ARAM 24 instrument were used. The recorded data has a length of 3 s with a 2 ms sample rate. Figure 3 (a) shows shot 183 from Highvale line where some reflections and ground-roll noise can be observed. In Figure 3 (b) shot 48 from Violet Grove line is displayed.

2D Seismic Processing

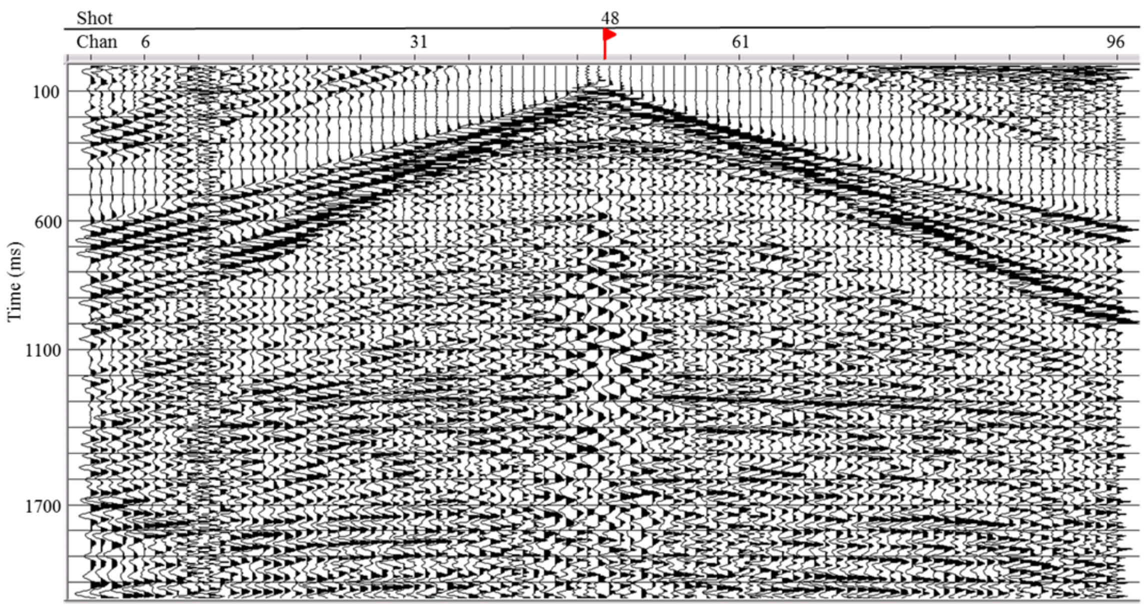
The seismic data consists of raw gathers that were processed with the software ProMAX with the guidance of Helen Isaac and David Henley. Table 2 illustrates the processing flow applied to the seismic data. The processing was focused on imaging the main reflectors, including the Nisku Formation, without compromising the low frequency character present on the seismic data. Especial attention was paid to noise attenuation processes which appear to be the greatest factor in attaining low frequency signal (Isaac, 2012). The processing flow will be explained using the Highvale line as a reference.

Table 2: Processing flow applied to the seismic lines Highvale and Violet Grove

General Processing Flow
Geometry definition
First break picking
Elevation and refraction statics correction
Amplitude recovery
Noise attenuation
Deconvolution
Velocity analysis and NMO Correction
CDP stack and residual statics
Post-stack Time Migration



a)



b)

FIG. 3. a) Shot 183 from the Highvale 2D seismic line, and b) shot 48 from the Violet Grove 2D seismic line. AGC has been applied.

Geometry Definition:

The first step, after loading the seismic data into ProMAX, was to correctly define the geometry into the database. ProMAX uses the database to sort the traces and further perform the processing (Isaac, pers.comm). The trace header usually has the field file identification number (FFID) and channel number. The FFID was related to the field shot station number and the channel number to the field recording station number.

First Break Picking:

The first break is the first recorded signal generated by the seismic source. First breaks are normally used for determining a near surface statics model (Promax manual, 2011). ProMAX has the automatic tool "First Break Picking" which searches for the first breaks within an offset-dependent time gate. A single time gate is usually enough unless the velocity of the near-surface refractors changes significantly in far offsets so a new window would have to be defined (Isaac, pers.comm). In general, the automatic first break picking worked well except in some shots between the shot ranges 410-570 which were corrected by manual picking. Figure 4 shows the Highvale line first break time window on shot 104 and an example of shot 173 where the trough was the chosen point to pick.

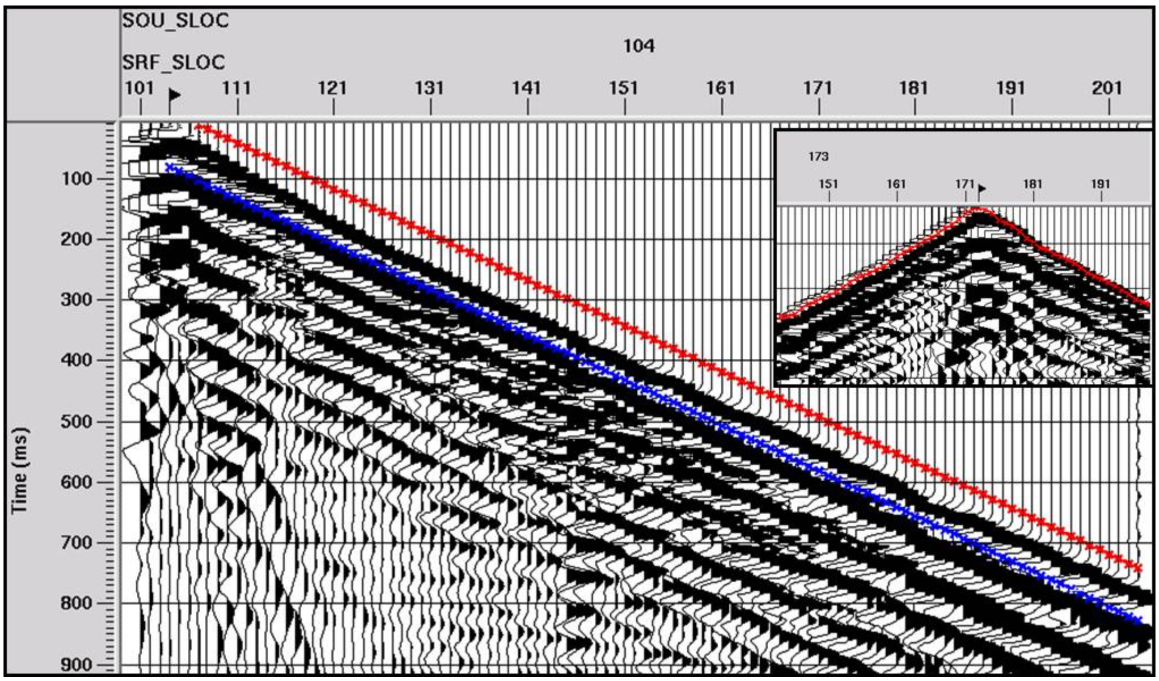


FIG 4. Highvale line first break time gate on shot 104 and an example of the automated picked trough on shot 173.

Elevation and Refraction Statics Correction:

Statics corrections are applied to seismic data to compensate for the effects of variations in elevation, weathering thickness and velocity, or reference to a datum (Promax user guide, 2011). Elevation statics correct the source and receiver elevations to a floating (NMO) datum (Isaac, pers.comm) by using the tool "Apply Elevation Statics". This datum is where the velocity analysis and CDP stack are performed and is a smooth function of the elevation profile. The selected reference datum was 865 m and the replacement velocity was 2700 m/s for both lines.

"First Break Statics" compares the average first break times of source and receivers with their neighbors to compute short period statics (Promax, 1997). Figure 5 shows the effect of applying the statics correction to Highvale line shot 104.

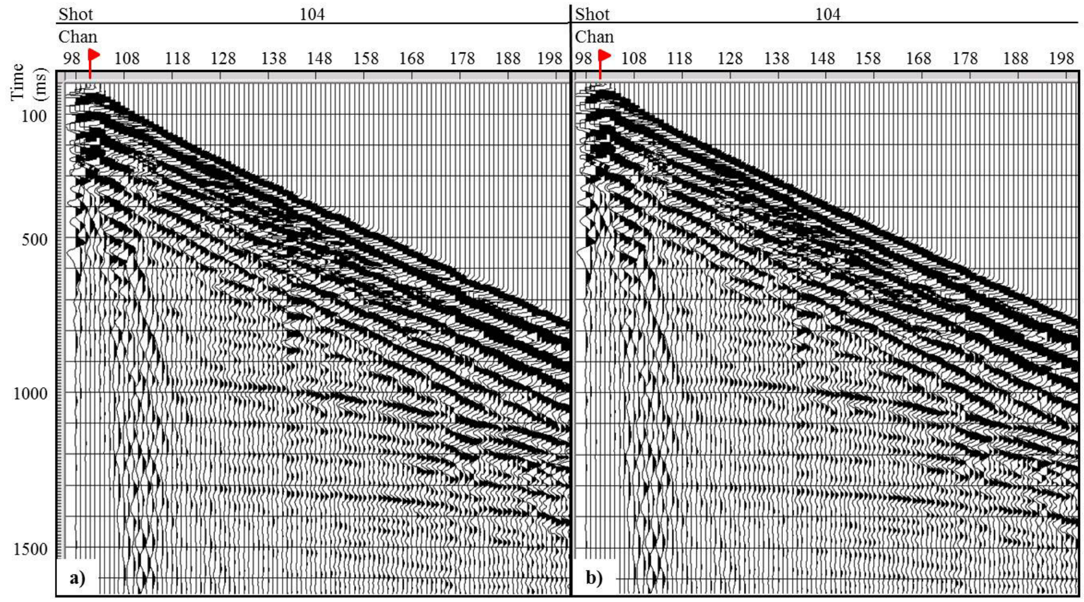


FIG 5. Highvale line shot 104 a) before and b) after statics correction.

Amplitude Recovery:

In this step the objective is compensate for the natural loss of signal due to geometric spreading and transmission losses (Isaac, pers.comm). The gain correction is performed by applying an amplitude adjustment in the form of time raised to a power correction:

$$g(t) = t^{POWER}, \tag{1}$$

where POWER is the time-power constant and was set as 2 . The correction was apply using the ProMAX process "True Amplitude Recovery" (Figure 6).

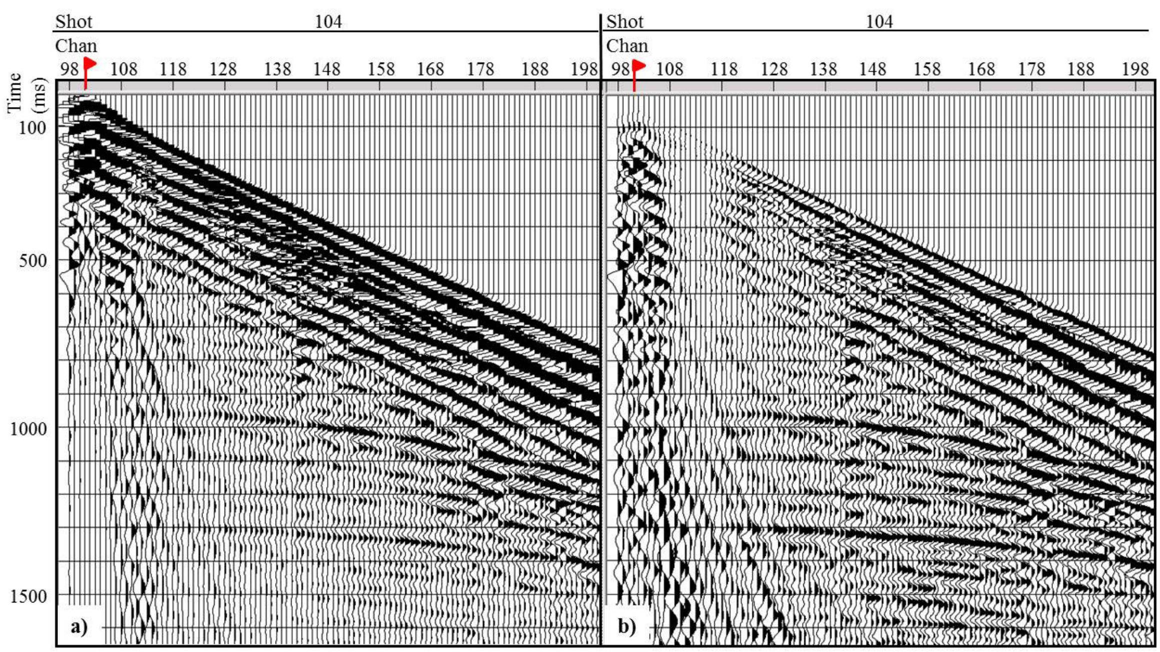


FIG. 6. Highvale line shot 104 a) before and b) after amplitude recovery compensation.

Noise Attenuation:

Noise present in the seismic data varies depending on the condition of the survey and can be shot generated (surface waves), externally generated (powerline interference) or receiver generated (bad coupling, noise burst). The shot gathers shown in Figure 3 have strong noise that obscures the reflections and is characterized by low frequency and low group velocity. Two noise attenuation techniques were applied separately in this project: Surface Wave Noise Attenuation and Radial Trace Filter. Using a conventional approach the former method attempts to attenuate surface-wave noise given the surface velocity and the frequency cut-off by forming low-frequency arrays. It transforms the data from the time-space domain to the frequency-space domain, where frequency components higher than the cut-off frequency remain unchanged (Promax, 1997). A more recent approach separates coherent noise or ground roll from reflections on seismic trace gathers (Claerbout, 1983) by applying the process known as "Radial Trace Filter". This technique was developed by David Henley (2011). The technique attempts to isolate the coherent noise from the reflection signal based on the separation in apparent velocity, source position and frequency content in the R-T domain (Henley, 2011). Coherent noise is characterized by linear trajectories that can be attenuated on the basis of its apparent velocity in the X-T domain; while in the R-T domain, source generated linear noises are mapped into compact group of radial traces with significantly lower frequency content (Henley, 2011). The events aligned with these parameters will be subtracted in the X-T domain (Henley, 2003). R-T filter is applied iteratively based on two approaches: first applying a general fan filter to attenuate multiple source-generated noises; and second, by applying a dip filter with a narrow radial trace fan to attenuates residual constant velocity noises (Henley, 2011).

In the case of applying surface wave noise attenuation, four successive filters were applied to the Highvale line data to attenuates the noise (100, 400, 500 and 600 m/s) with a frequency cut-off of 15 Hz. In the case of applying the radial trace filter one fan filter (-3000 m/s to 3000 m/s) and eight successive dip filters (+/-2400, +/-1500, +/-600 and +/-300 m/s) were applied to remove the ground roll. All the filters were designed with the same low frequency cut-off (5-9 Hz). After running the radial filter a band pass Ormsby filter of 3-6-55-70 Hz was applied for better imaging. Figure 7 shows the comparison between the surface wave noise attenuation and the radial filter outputs. An evident reduction of the coherent noise and enhancement of the reflections is appreciated with respect to the data on Figure 6. Radial filter succeeds in attenuating first arrivals and allows a better separation between noise and reflections while keeping the low frequency signal unaltered.

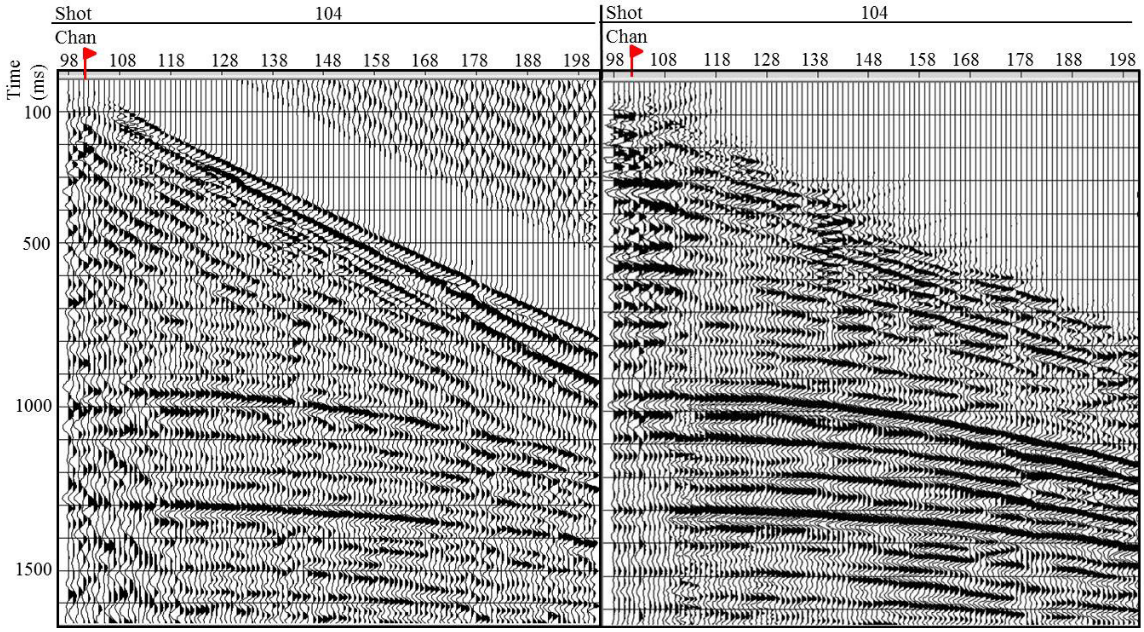


FIG. 7. Shot 104 of the Highvale line a) after surface wave attenuation and b) after radial trace filtering.

Deconvolution:

Deconvolution is the process that aims to remove the seismic wavelet from the seismic trace and, therefore, improves the temporal resolution (Yilmaz, 2001). It can attenuate multiples and balance the spectrum (Isaac, pers.comm). There are several deconvolution methods (spiking, predictive, etc.) which assume, among other things, that the wavelet is invariant in time where the effects of attenuation and frequency and amplitude variation are not taken into account (Margrave and Lamoureux, 2002). This stationary assumption of the seismic wavelet motivates the development of an extension of seismic deconvolution to the non-stationary case capable of removing the effects of attenuation in the earth and the source signature (Henley and Margrave, 2008). Margrave and Lamaroureux (2002) developed the Gabor deconvolution which attempts to estimate the time and frequency variant Q function, or attentuation function, for each seismic trace. This function is calculated via the Gabor Transform and then it is included in the deconvolution operator to remove the effects of Q from the seismic trace simultaneously with inverting the source waveform (Henley and Margrave, 2008). Figure 8 shows the result of applying Gabor Deconvolution and a bandpass filter of 5-6-55-70 Hz to attenuate boosted high frequency noise on shot 104.

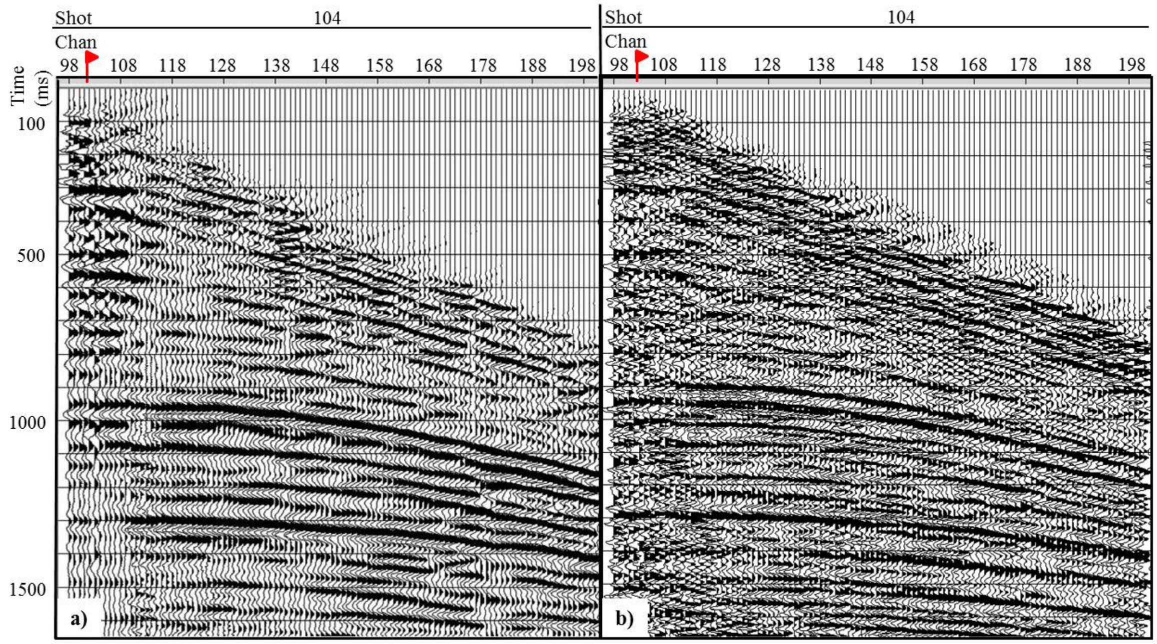


FIG. 8. Shot 104 of the Highvale line a) before and b) after applying Gabor Deconvolution and a bandpass filter of 3-6-55-70 Hz.

Velocity Analysis and NMO Correction:

The next step in the processing flow is to perform velocity analysis to enable application of normal move out (NMO) correction on CDP gathers (Yilmaz, 2001). Based on the assumption that reflection travel times with offset follow hyperbolic trajectories, the NMO correction is the process to remove the move out effect on travel times by making all traces zero-offset. Reflection travel times are described by the following hyperbolic relationship:

$$t^2 = t_0^2 + \frac{x^2}{V_{RMS}^2} \tag{2}$$

where t is the recorded time at offset x, t_0 is time at zero offset and V_{RMS} is the root mean squared velocity. The NMO correction is given by the difference between $t - t_0$ and it can be reduced to:

$$\Delta t_{RMS} = t - t_0 = \sqrt{t_0^2 + \frac{x^2}{V_{RMS}^2}} - t_0 \sim \frac{x^2}{2V_{RMS}^2 t_0} \tag{3}$$

This approximation is valid for $x \ll V_{RMS}t_0$. The RMS velocity is obtained from the velocity analysis which is performed on selected CDP gathers or array of gathers (super gather) by measuring the signal coherency along hyperbolic trajectories ruled by velocity (semblance panel). ProMAX uses the process "Velocity Analysis" to interactively pick the velocity field using the semblance panel and velocity stacks that best corrects CDP gathers. In Figure 9, the semblance panel is shown on the left where the red color indicates maximum semblance; in the next panel is the super gather (group of 7 CDP gathers every 50 CDPs from CDP 205 to CDP 1959 on the Highvale line) as a function of time and offset and it is followed by its stacked section. The final panel includes the stacked traces created after applying move out with the different velocity functions. The final picked velocity is shown with a white line on the semblance panel and with a red line on the velocity functions stack panel. The result from this process can be seen on a 2D velocity model on Figure 10 and reflects the geological scenario where generally flat layers are expected.

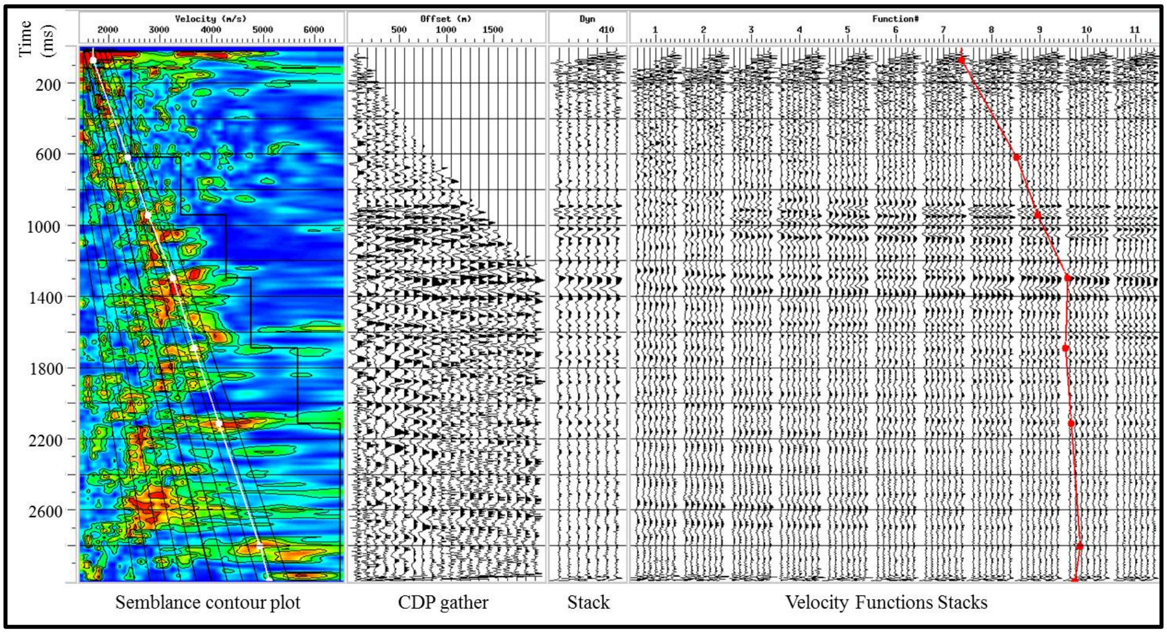


FIG. 9. From left to right: semblance panel, CDP gather and velocity functions stack panels from the velocity analysis on the Highvale line. The final velocity function is shown with a white line on the semblance panel and a red line on the stack panel.

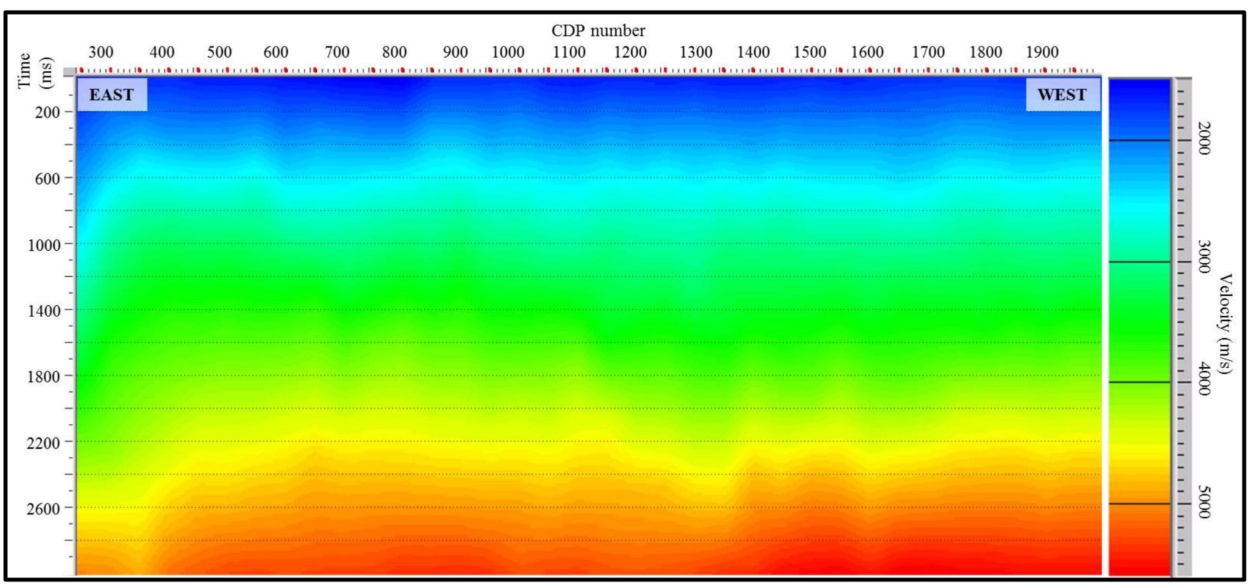


FIG. 10. Velocity model obtained from the velocity analysis.

CDP Stack and Residual Statics:

As mentioned before, the purpose undertaken the velocity analysis was to get a velocity field to apply the NMO correction. This process intends to align the events on CDP gathers using the RMS velocity. All traces are then stacked to create a seismic section.

Residual statics attempt to align a target event in MNO corrected CDP gathers by applying static shifts (Isaac, pers.comm). “2D/3D Maximum Power Autoestatics” is the ProMAX tool for applying this surface-consistent process based on the cross-correlation of a pilot trace, formed from summing several traces in a target window along the autoestatic horizon, with other traces with the same source and receiver and the difference in time defines the shift to apply the correction. Figure 11 shows the section after applying NMO correction, residual statics and a time variant band pass filter. Strong reflections are easily identified in the middle of the section. As showed in Figure 10 the geology of the area presents flat layers with no major structures. After applying the NMO correction, a depression can be observed in the middle of the section possibly related with a shallow channel caused by an old meander of the North Saskatchewan River. No velocity or statics anomalies were observed during the processing of this dataset. This depression is not present in the previous processing performed by C&C (Figure 2).

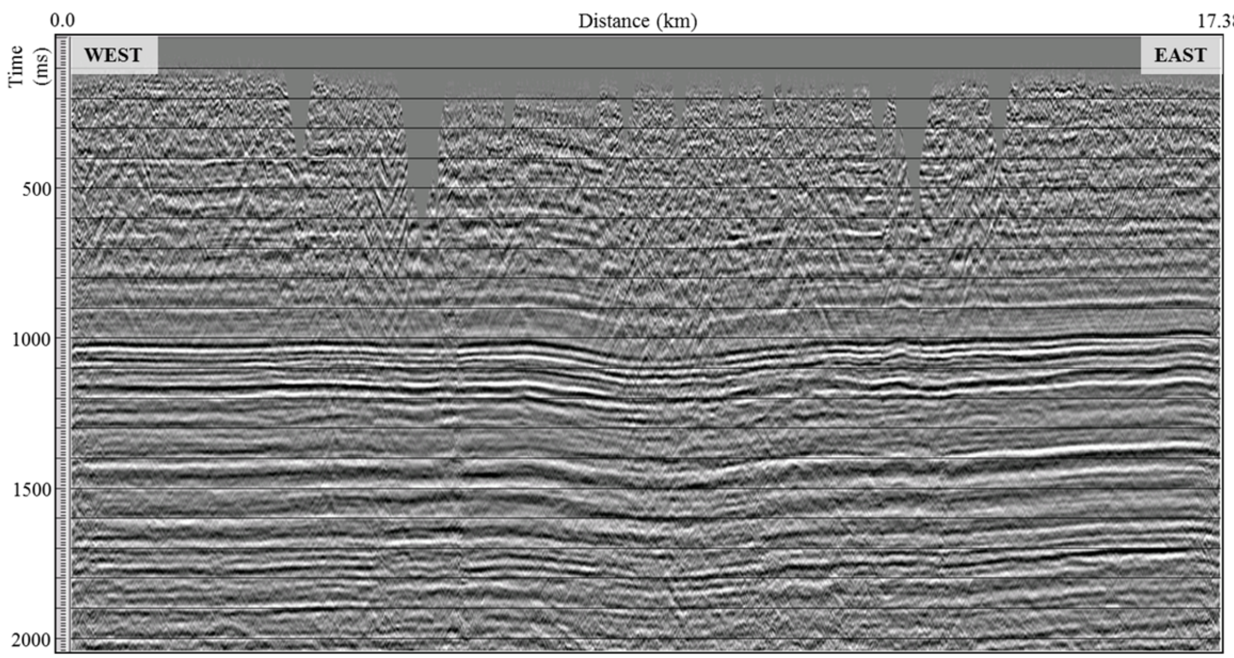


FIG. 11. Highvale CDP stacked section. Clear reflections are easily identified across the section.

Post-stack Time Migration:

Post-stack time migration attempts to move the reflections to their correct subsurface location. Several post-stack migration techniques have arisen depending on geological complexity and the characteristics of the seismic data. In this case Implicit Finite Different Time Migration was the chosen technique which performs a post-stack time migration using a Finite Difference algorithm capable of imaging steep dips (Promax, 1997). The Highvale migrated sections using the two processing flows are shown in Figures 12 and 13, 100% of the interval velocity field was used. Figure 12 shows the result of applying conventional processes (surface wave attenuation and spiking deconvolution), while Figure 13 shows the result of applying more specialized processes (radial filter and gabor deconvolution). Since the geology character is flat no major changes are seen in comparison with the section in Figure 11. An improvement in continuity and resolution is evident. It is important to mention that after migration an F-X Decon was applied to produce an output section with less random noise than the input data. F-X Decon applies a Fourier transform to each trace of stacked data. It applies a complex Wiener Levinson prediction filter in distance for each frequency in a specified range, and then inverse transforms each resulting frequency trace back to the time domain (Promax, 1997). In this case, 50 traces were used in the horizontal prediction window and the frequency range was set to 5-80 Hz.

Both results are very similar but, as shown in the pre-stack data in Figure 7, the radial filter was successful in attenuating noise while keeping more low frequency signal. The events are more continuous in Figure 13.

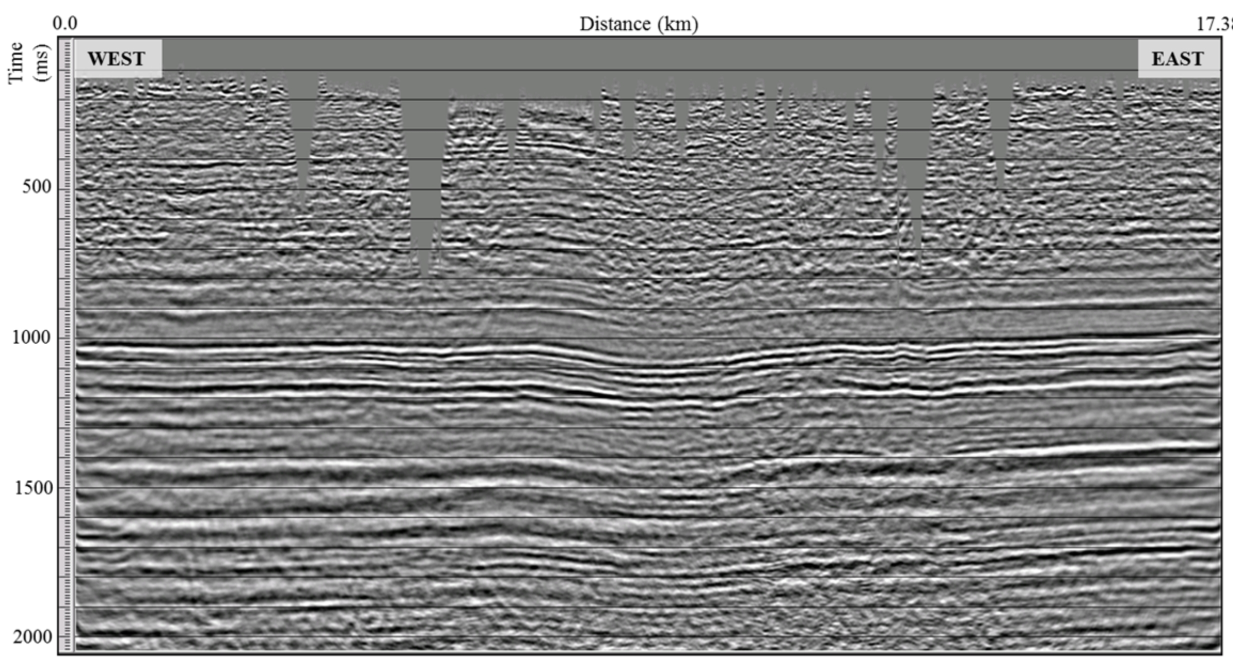


FIG. 12. Highvale stack section after applying conventional processes and Implicit Finite Difference Time Migration and F-X Deconvolution. No major changes are observed in terms on the position of the reflectors due to the flat character of the events.

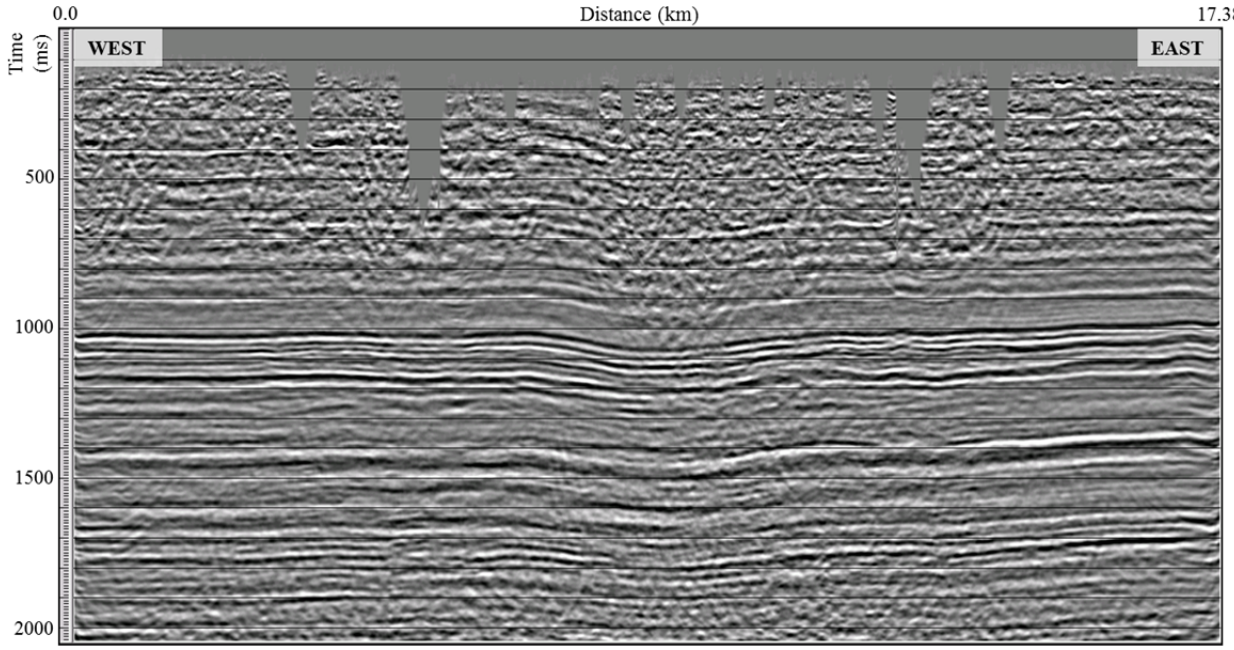


FIG. 13. Highvale stack section after applying special processes (Radial Filter and Gabor Deconvolution) and Implicit Finite Difference Time Migration and F-X Deconvolution.

Figure 14 shows the final processing result on the Violet Grove line after applying a conventional processing flow. Similar quality to the Highvale line is observed.

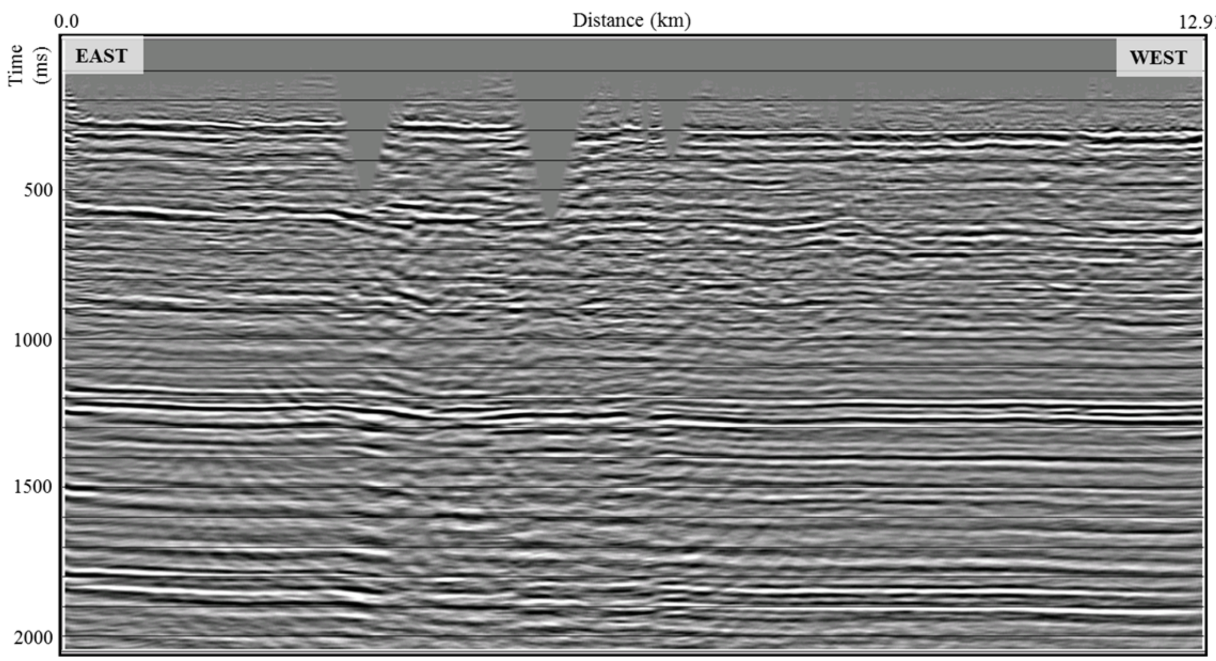


FIG. 14. Violet Grove stack section after applying conventional processes and Implicit Finite Difference Time Migration and F-X Deconvolution.

Figure 15 shows a comparison of three different processing results around the well location a) previous processing (C&C); b) current processing with the specialized sequence (radial filter and gabor deconvolution); and c) current processing with a conventional sequence (surface wave attenuation and spiking deconvolution). The frequency content, resolution and continuity vary between the C&C result and the other two results.

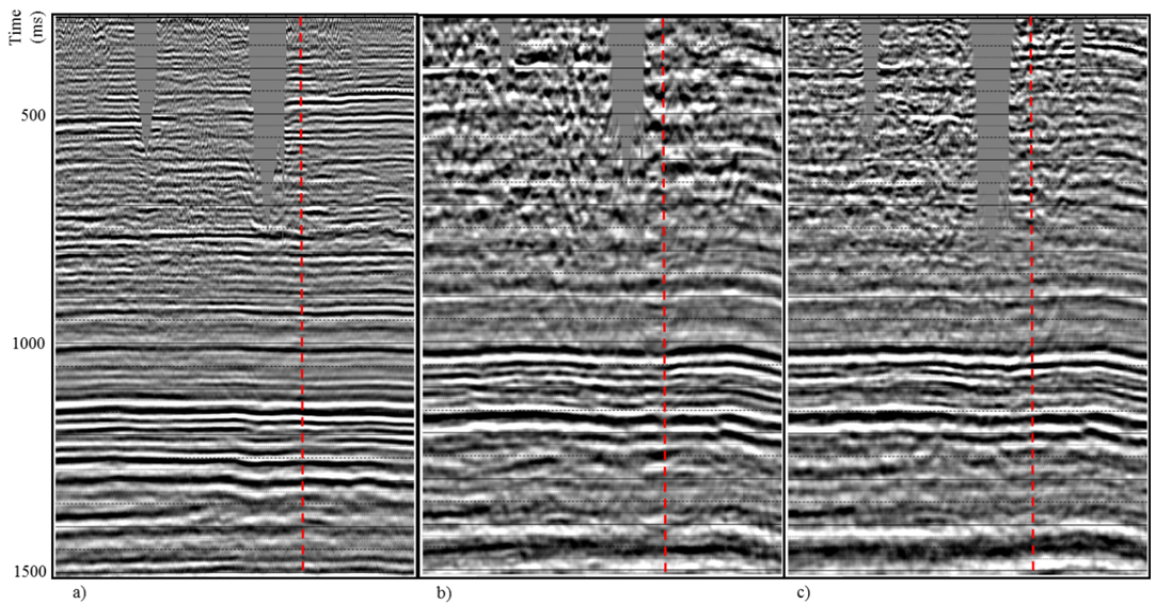


FIG. 15. Comparison of processing results: a) previous processing b) current specialized sequence and c) current conventional sequence. Note the difference in frequency content, resolution and continuity of the events depending on the processing applied. The red dotted line shows the location of the Well 8-17.

Retaining the low frequency component in the seismic data benefits inversion studies since decreases the influence of the initial model in the final result (Lindseth, 1979). In Figure 16 the amplitude spectra for each dataset are displayed and were calculated in a window of 700 ms (800 ms to 1500 ms) along the entire section. As can be observed, the low frequency content includes ~5-9 Hz in cases b) and c), while in case a) the frequency content includes only ~10-14 Hz.

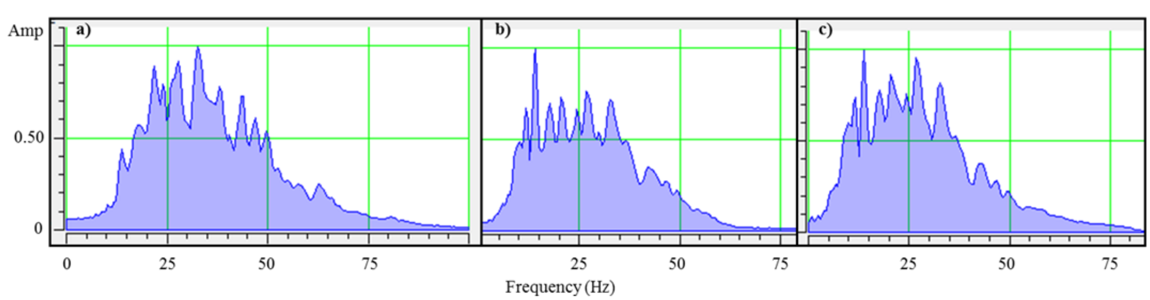


FIG. 16. Frequency spectra of the datasets shown in figure 3.17 in a 700 ms window around the target formation. Note the low frequencies include 5-9 Hz in cases b) and c), while in case a) the frequency content includes 10-14 Hz.

CONCLUSIONS

Two different seismic processing sequences were applied to the same dataset to evaluate the effect of noise attenuation methods while attempting to preserve low-frequency signal with the purpose of obtaining broadband seismic data to benefit inversion studies. For this purpose seismic data from Project Pioneer was provided by TransAlta Corporation and consisted in two seismic lines with the processed stacks and raw gathers.

The raw gathers were fully processed using two sequences, a conventional one and a specialized one; the conventional sequence used surface wave noise attenuation and spiking deconvolution processes, while the specialized sequence used radial filter and gabor deconvolution. As expected, the specialized processing flow resulted in better attenuation of low frequency noise while keeping the low frequency signal. In comparison with the previous processed stack, current result showed higher low frequency content around the target zone (~ 5-9 Hz) than the previous processing (~ 9-14 Hz), but showed a structural depression in the middle part of the section possibly related with a shallow channel caused by an old meander of the North Saskatchewan River. However, no velocity or statics anomalies were observed during the processing of this dataset.

Both processing sequences have similar results but, the radial filter was successful in attenuating noise while keeping more low frequency signal. The events are more continuous in the specialized sequence.

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