Shaken, not stirred: Priddis 2009 3C-2D hi-res acquisition

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ABSTRACT

Over the last several years, CREWES has designed and conducted several field experiments intended to explore the limits of seismic resolution, coherent noise attenuation, and the practical and logistical limits of field acquisition pertaining to source effort and sensor density. We describe here the latest experiment in the sequence, carried out in March 2009 at our Priddis field site. The goals of this experiment were two-fold: we wanted a 3C-2D profile through the proposed site of our future permanent 4D test site; and we wanted yet another test of high-resolution seismic acquisition, this time increasing receiver spacing to obtain longer offsets, but decreasing source spacing to retain spatial resolution. We display here some of the results of that field work, which show that, in conditions of good source and receiver coupling, we can, indeed, increase receiver spacing and compensate by decreasing source spacing. This gives us the same processing power over surface wave noise, and the increased source effort results in remarkably good depth penetration, showing reflections down deeper than 2.5 seconds.

INTRODUCTION

In 2006, shortly after the Geoscience Department at the University of Calgary obtained its own seismic acquisition system (Bertram et al. 2005), CREWES began a series of field experiments intended to investigate some of the problems associated with very high resolution acquisition, and discussed earlier by Hoffe et al. (2002). Thus in 2006, we performed two small seismic experiments along a 1 km portion of a section line road near Longview, Alberta. For the first experiment, we planted single vertical component geophones at the relatively short spacing of 5 m and observed that much of the coherent source-generated noise was well sampled, enabling us to filter it out of the data with some success. Since we could still see some aliased noise on these data, we went back to the same site later in 2006 and repeated the survey for a line 937 m long, with phones planted every 2.5 metres. The mini-vibrator source occupied every other station, for a source spacing of 5 m. The results obtained from this survey and the subsequent processing and analysis were striking (Henley et al. 2006), showing that spatial sampling directly affects not only lateral resolution, but vertical bandwidth (resolution) as well. We further demonstrated that recording single phones and attenuating noise with appropriate radial filter processing was, in every case, superior to simulating geophone arrays by appropriate horizontal summation of the same input data.

To push the envelope even further, in March 2008, we performed another experiment, this time at our Priddis field site, with the receiver spacing further reduced to 1 m to try to eliminate any hint of aliasing in the visible coherent noise, whether earthborne or airborne. We used 3C phones for this experiment, and because of equipment limitations could only record 200 phones. Hence, the spread was only 200 m in length. The source line was offset from the receiver line by 5 m, but was 400 m long, with source points every 10 m (Henley et al. 2008), (Suarez et al. 2008). Our experience with this line once again demonstrated that when coherent noise is sampled without aliasing, suitable processing can extract broadband reflection signal from beneath an impressive amount of coherent noise, enabling us to image the subsurface with great resolution and bandwidth. The small linear dimensions of this survey precluded the observation of reflection energy below about 1 second; and no converted wave energy was imaged, likely due to insufficient source-receiver offsets (the maximum offset was 300 m).

The requirement for a 3C-2D line crossing the proposed permanent 2D geophone array at Priddis (Lawton et al. 2008) gave us yet another opportunity to study high resolution acquisition methods. In this instance, the required linear dimension of the line (800 m) and the limited equipment supply (only 200 3C phones) dictated that we change our acquisition strategy. Had we continued our earlier trend, we would have planted 800 3C phones with 1 m spacing and placed source points every 5 or 10 m. Even if we had possessed 800 phones, however, we would not have been able to connect all 2400 components simultaneously to the recorder. Furthermore, the ground was frozen, requiring laborious hand drilling of holes for the geophones. Based on our actual field experience planting just 200 phones (a day and a half of effort), a full 800 phones would have taken a week or more. In view of these practical considerations, we elected to use our 200 phones to cover the required 800 m with 4 m phone spacing, and to compensate with 2 m source spacing, thus trading off receiver density for source effort. With uniform ground coupling for source and receiver (because of the winter conditions), we surmised that we should be able to do our usual noise attenuation processing on receiver gathers for this survey, instead of on the usual source gathers. In addition, the much larger offset range should provide more traces outside the low velocity noise cone that is usually a prominent feature of trace gathers from surveys at this site.

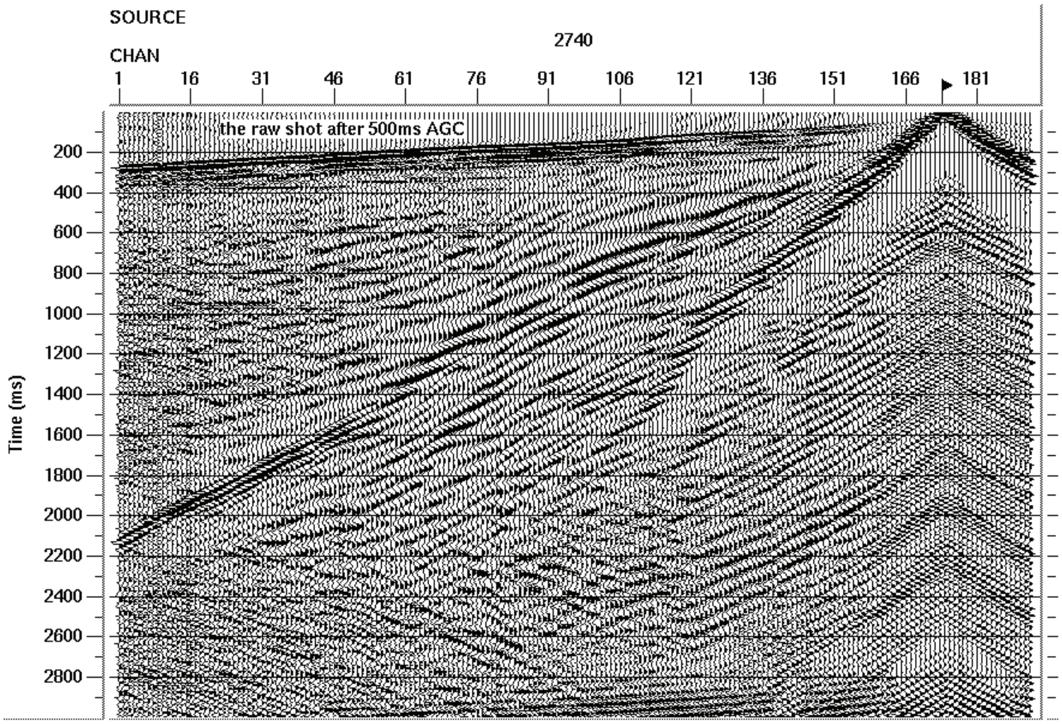
EXPERIMENT DETAILS

The March 2009 Priddis 3C-2D survey was laid out on a NE-SW trending line, 800 m long, that crossed the potential site of a future permanent 3D test site at the University of Calgary Priddis property. Because of the frozen ground, all 200 3C geophone positions had to be drilled into the surface, requiring about 1 ½ days for complete deployment. In addition, a vehicle lane was ploughed through the snow down to bare ground just adjacent to the receiver line on its north side, in order to accommodate the mini-vibrator source. The data were recorded over a period of about a day using our mini-vibe with a sweep of 8-150 Hz, four sweeps per source point. Since the source points were spaced 2 m apart, there were a total of 400 source positions for the line. Since the ground was frozen, good coupling was observed for the source at all positions, as well as for all 200 receivers. Good reflections could be seen even on the unprocessed monitor records. The line was recorded from high station to low, beginning on the high ground to the east, to minimize the problems associated with moving the vibrator over the frozen ground (downhill rather than uphill).

PROCESSING

The data were originally processed by Han-Xing Lu using a conventional processing flow, which yielded a final migrated section for each of the three components. In addition, the vertical data were processed by Dave Henley to attenuate coherent noise before stack in an attempt to extract more bandwidth for the final section.

Figure 1 shows a typical vertical component shot gather for the survey, on which can be seen a strong first arrival and much strong coherent noise. Hints of coherent reflections can be seen on the traces at farther offsets, however. After conventional processing, the migrated CDP stack of all the shots is shown in Figure 2.



Raw shot at source point 2740

FIG. 1. Typical vertical component shot gather for the 2009 Priddis 2D 3C survey. Although coherent noise is abundant, there are fragmentary reflections above the obvious noise cone at farther offsets.

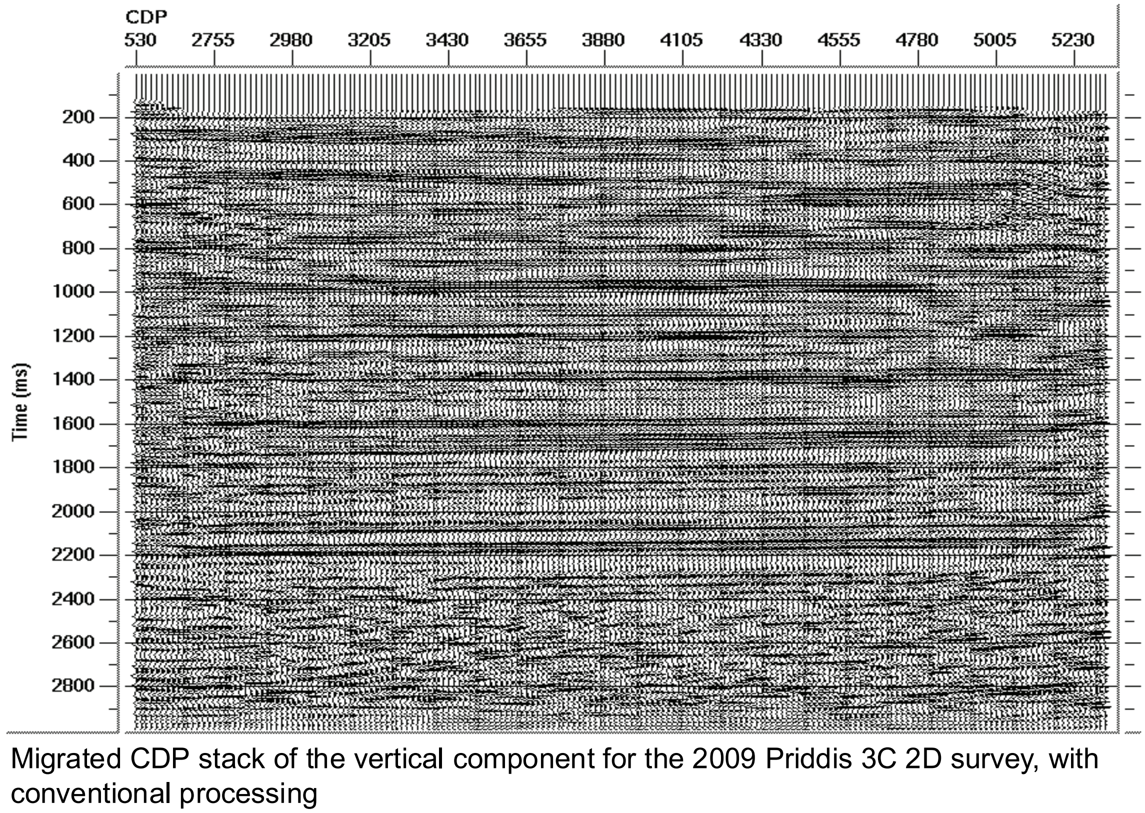
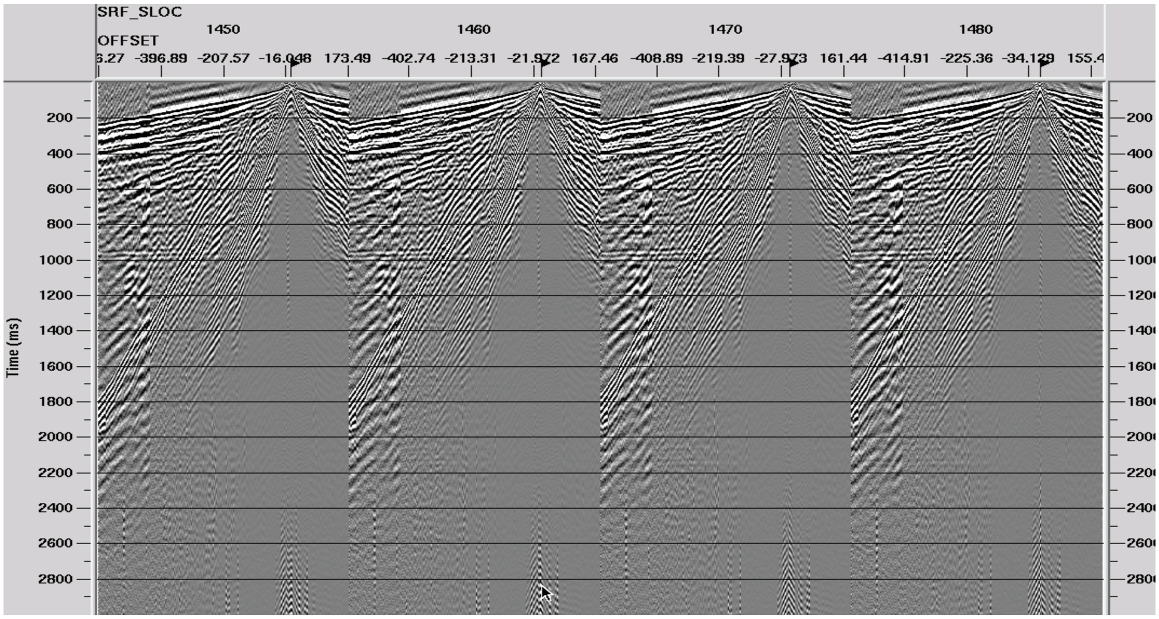


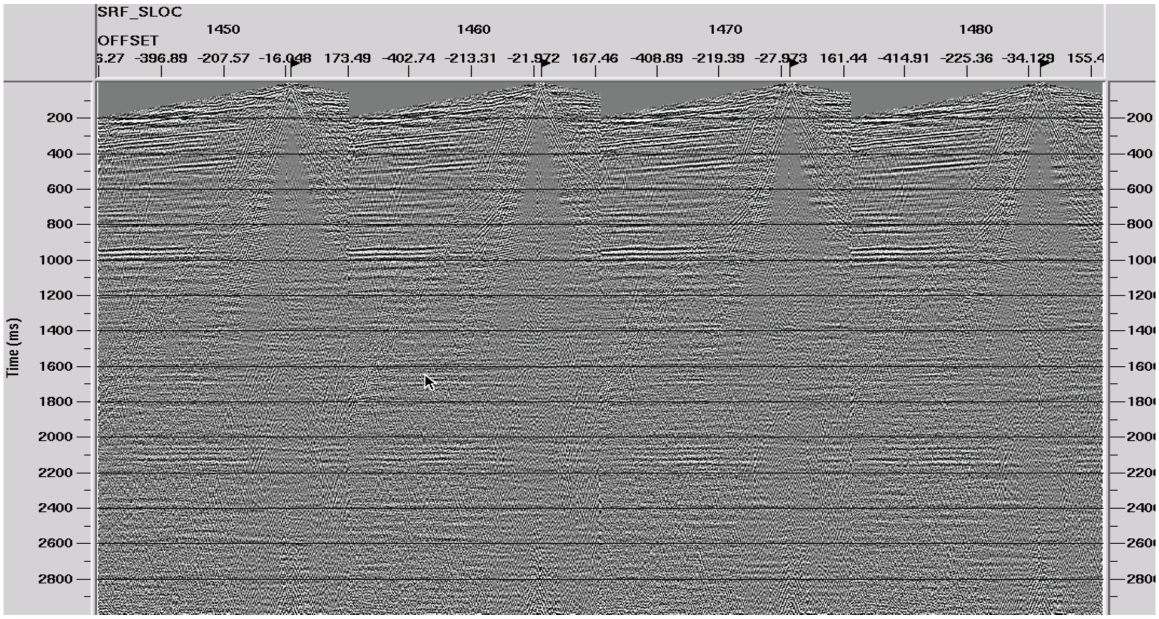
FIG. 2. Migrated stack of the vertical component data for the 2009 Priddis 2D 3C survey. Note the strong reflections down to 2400 ms. Fragmentary reflections appear even below that time.

Remarkably, even though we used a relatively weak source, reflections are visible down to nearly 3 seconds on this section, and the image shown was obtained without resorting to extensive pre-stack noise attenuation. We attempted to extend the bandwidth of this image, however, by applying pre-stack radial trace filtering (Henley 2003a, 2003b), followed by Gabor Deconvolution (Margrave et al. 2001, 2002a, 2002b, 2003). In order to most effectively filter these data, we sorted them to receiver gathers, which have only half the spatial sampling (2 m shot spacing) of the shot gathers (4 m receiver spacing). Figure 3 shows four vertical component receiver gathers before any filtering, while Figure 4 shows the same four receiver gathers after several passes of radial trace filtering and one pass of Gabor deconvolution.



Vertical component receiver gathers

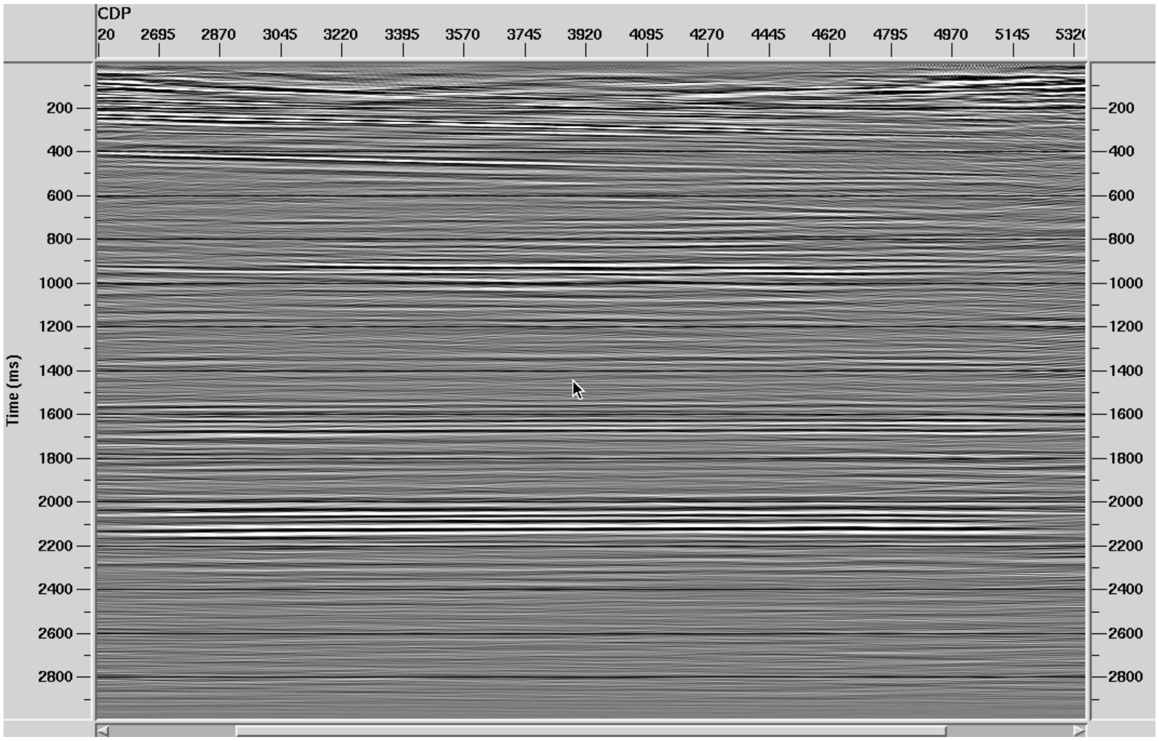
FIG. 3. Typical receiver gathers for the vertical component of the 2009 Priddis 3C-2D survey. Since the source spacing was 2 m, these gathers are twice as finely sampled spatially as the shot gathers (receiver spacing was 4 m), making them the best choice for coherent noise attenuation. Note the sudden change in trace character near the left end of each gather—to be discussed later.



Vertical component receiver gathers after coherent noise attenuation, deconvolution

FIG. 4. Vertical component receiver gathers from Figure 3 after several passes of radial trace filtering and one pass of Gabor deconvolution. Note that the processing has removed several layers of coherent noise, applied depth-dependent gain, and removed the character differences seen in Figure 3.

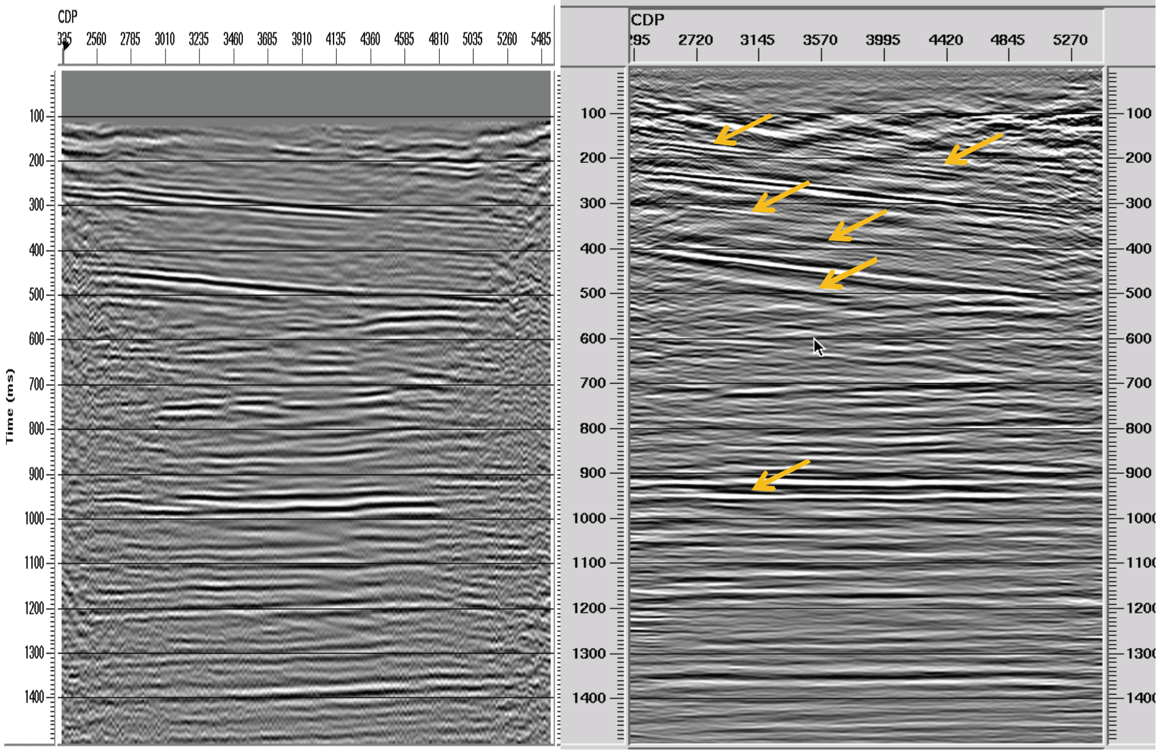
The resulting migrated CDP stack of these filtered gathers is shown in Figure 5.



Vertical component migrated stack, after coherent noise attenuation and deconvolution

FIG. 5. Migrated CDP stack of the vertical component from the Priddis 2009 3C-2D survey after coherent noise attenuation and Gabor deconvolution on pre-stack data

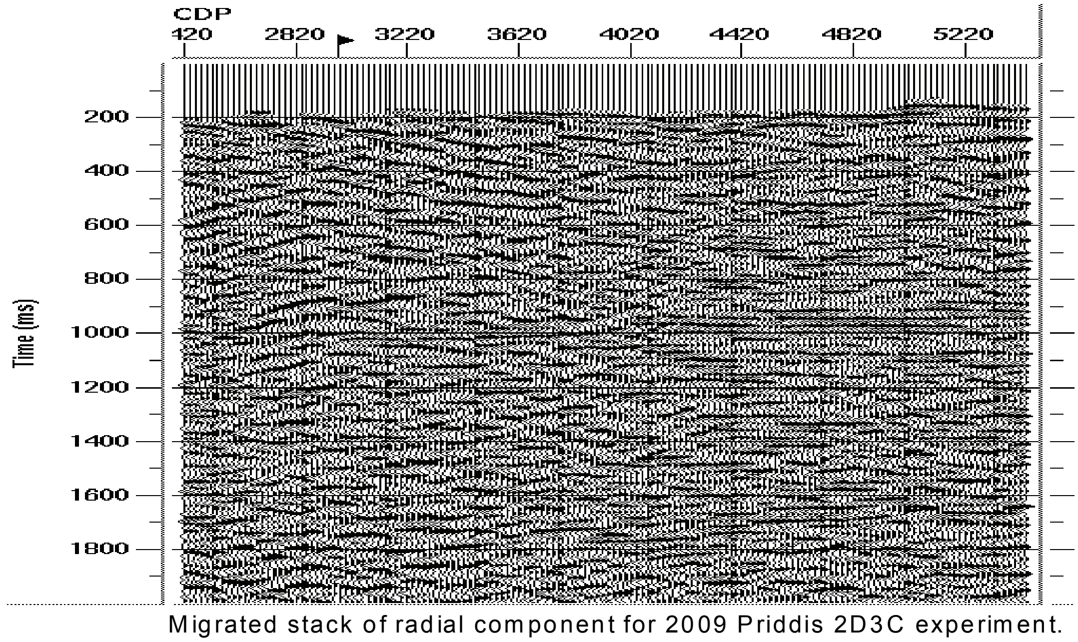
In order to visually compare bandwidth and resolution between the conventionally processed data and the pre-stack filtered data, we refer to Figure 6, where the upper 1500 ms of both sections are displayed. Both sections have been compressed laterally to move the aspect ratio closer to 1.0 in order to improve interpretability. Visual comparison of corresponding events shows that the pre-stack filtered result does, indeed, have greater bandwidth than the conventionally processed result, particularly in the shallowest portion of the section, above 500 ms, where several thin, relatively low amplitude events may be readily seen on the high resolution section but are either not seen or are very indistinct on the conventional section (reflections at about 200 ms and 300 ms, in particular). It can also be seen that the reflections at the edges of the section fade into the background noise more rapidly on the conventionally processed section than on the high resolution section as the stack fold decreases toward the ends of the line. This indicates lower S/N on the individual traces, prior to stack, for the conventional processing.



Priddis 2009 2D 3C survey vertical component, migrated stack. Conventional processing (left), vs. high resolution processing, including prestack filtering (right). Arrows mark parts of the section where particular improvement in resolution may be seen.

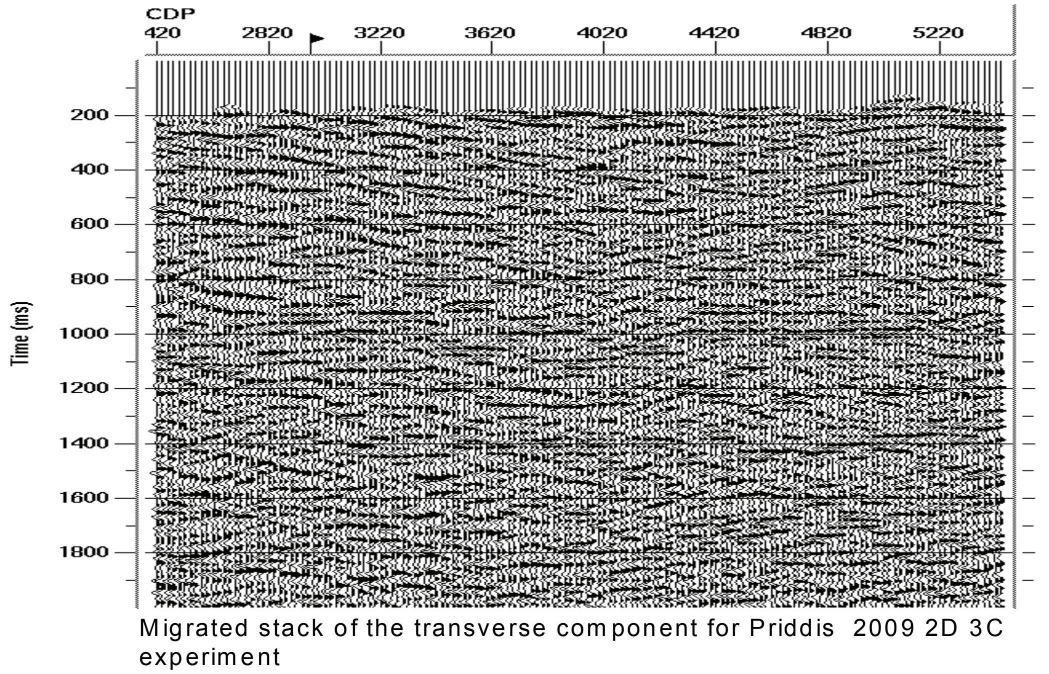
FIG. 6. Comparison of conventional processing and 'high resolution' processing on the vertical component of the Priddis 2009 3C-2D survey. The arrows on the high resolution section on the right indicate several places where particular features are better delineated than on the conventional section. Note, as well, that the reflections at the edges of the conventional section fade into the noise more rapidly than those on the high resolution section as the stack fold decreases, indicating lower S/N on the individual traces contributing to the stack for the conventionally processed data.

Relatively rudimentary processing has been done on both horizontal components of this 3C line in order to identify potential converted wave events. Figure 7 shows the stack of the radial (inline) component data, while Figure 8 shows the transverse (crossline) component stack. A prominent event at 1000 ms on Figure 7 might be a candidate for a converted wave event, except that any possible reflection event corresponding to it on the vertical component stack should have significant dip and is unlikely to correspond to a converted wave event that is essentially flat. Also, since there is a strong reflection at 1000 ms on the vertical component stack, the event in Figure 7 could be leakage from the vertical component. Similarly, the weak event at 1000 ms on the transverse component stack (Figure 8) is probably leakage from the vertical component.



Migrated stack of radial component for 2009 Priddis 2D3C experiment.

FIG. 7. Migrated stack of the radial component of the 2009 Priddis 3C-2D survey. The relatively strong event near 1000 ms may be leakage from the vertical component, since there are no strong corresponding events on the vertical component section above 1000 ms that have no dip; and there is a strong reflection on the vertical section at 1000 ms.

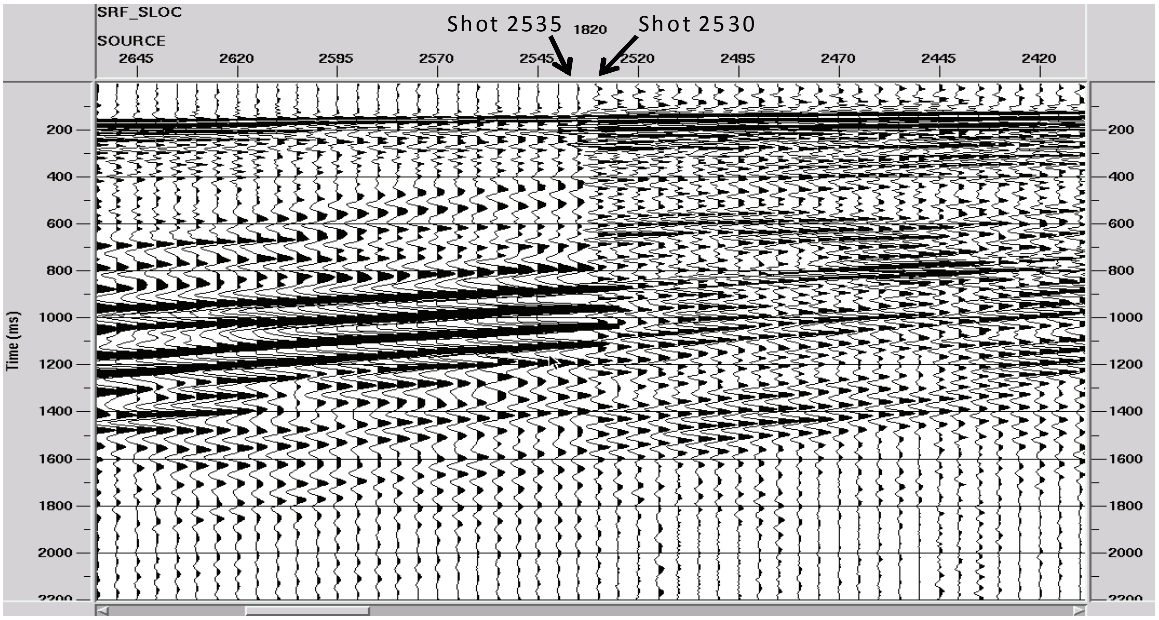


Migrated stack of the transverse component for Priddis 2009 2D 3C experiment

FIG. 8. Migrated stack of the transverse component for the 2009 Priddis 3C-2D survey. Any coherent events on this section are probably leakage from the vertical and/or radial components.

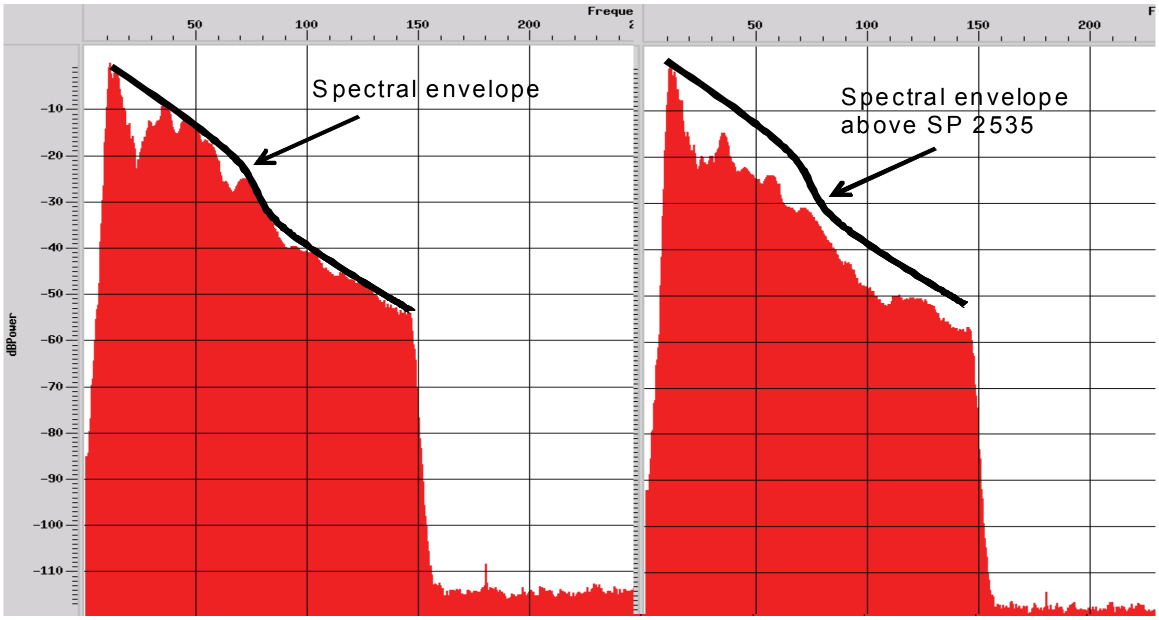
A MYSTERY

A closer examination of the receiver gathers in Figure 3 shows an anomaly near the left edge of all four displayed gathers—the group of traces at that end of the gather differ markedly in character from all the others in the gather. When we examine all the receiver gathers on the line, we find the same anomalous character on every gather, leading us to the inevitable conclusion that the data characteristics recorded for the shots represented by those traces is fundamentally different from those for all the other data on the line. Figure 9 shows a close-up comparison for one of the gathers, on which the differences are quite striking. In essence, all shots from number 2535 up to the end of the line have one type of character, while those from number 2530 down to the other end of the line have another, distinctly different character. As can be seen from Figure 4, noise attenuation and deconvolution practically remove the character difference, but we can't, at this point, identify a cause for the anomaly. We have reviewed field notes and the memories of those involved in the acquisition and can find no reason why the data character should change so abruptly. The obvious possibilities, like filter settings and sweep parameters have been considered and mostly dismissed as causes of the problem. Figure 10 shows, via a spectral comparison, that there is, indeed, a systematic difference in the spectra of the two groups of shots. At this point, however, we have no explanation for the observed phenomenon, except to state that it is almost certainly due to some overlooked change in acquisition parameters, not logged on the observer's record.



Priddis 2009 vertical component receiver gather showing the abrupt character change between shots 2530 and 2535—no AGC applied

FIG. 9. Zoom of the abrupt character change observed on all receiver gathers at the boundary between shots 2535 and 2530.



Spectrum of traces for 37 shots above source point 2535 vs spectrum of 37 shots below source point 2530 . Note significant change in spectral envelope for shots below 2530.

FIG. 10. Spectral comparison of character differences between shots above shot point 2535 and shots below shot point 2530. The sudden character change is unexplained at this point, but likely due to some acquisition parameter change.

CONCLUSIONS

The results of this field experiment further confirm that fine spatial sampling during seismic data acquisition enables pre-stack coherent noise attenuation and deconvolution that results in significant increase in detail and bandwidth in the final processed image over more conventional sampling, and that high-fold finely sampled data are well imaged even by a conventional processing flow. We have shown, as well, that under some conditions (particularly the uniform coupling afforded by winter conditions) we can trade off fine receiver spacing for fine source spacing. Under these conditions, we are able to attenuate source-generated noise just as well on receiver gathers as on source gathers, as long as the source spacing is less than receiver spacing and is not too irregular. Our results are yet another confirmation that when coherent noise is not aliased, it can be effectively attenuated pre-stack, and that pre-stack filtering will improve image resolution even when stack fold is very high. This experiment also shows that the mini-vibrator is a very effective seismic source, in this case returning reflections from nearly 3 seconds two-way travel time.

ACKNOWLEDGEMENTS

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REFERENCES

Bertram, M.B., Lawton, D.C., Gallant, E.V., and Stewart, R.R., 2005, New seismic reflection and other geophysical equipment available to CREWES: CREWES 2005 research report, **17**.

Henley, David C. 2003, Coherent noise attenuation in the radial trace domain, Geophysics, **68**, No. 4, pp1408-1416, 2003.

Henley, D.C., 2003, More coherent noise attenuation in the radial trace domain, CREWES 2003 research report **15**.

Henley, D.C., Bertram, M.B., Hall, K.W., Bland, H.C., Gallant, E., and Margrave, G.F., 2006, The power of high effort seismic acquisition: the Longview experiment: CREWES 2006 Research Report, **18.**

Henley, D.C., Hall, K.W., Bertram, M.B., and Gallant, E., 2008, Pushing the resolution limits: the Priddis 2D 3C survey: CREWES 2008 Research Report, **20.**

Hoffe, B.H., Margrave, G.F., Stewart, R.R., Foltinek, D.S., Bland, H.C., and Manning, P.M., 2002, Analyzing the effectiveness of receiver arrays for multicomponent seismic exploration: Geophysics, Vol. **67**, No. 6, (Nov-Dec 2002), pp1853-1868.

Lawton, D.C., Bertram, M.B., Stewart, R.R., Lu, Han-Xing, and Hall, K.W. 2008, Priddis 3D seismic survey and development of a training centre:CREWES research report, **20.**

Margrave, G.F., and Lamoureux, M.P., 2001, Gabor deconvolution: CREWES 2001 research report, **13**.

Margrave, G.F., Lamoureux, M.P., Grossman, J.P., and Iliescu, V., 2002, Gabor deconvolution of seismic data for source waveform and Q correction: 72nd Ann. Internat. Mtg. Soc. Expl. Geophys., Expanded abstracts, 2190-2193.

Margrave, G.F., and Lamoureux, M.P., 2002, Gabor deconvolution: 2002 CSEG Annual Convention, Expanded abstracts.

Margrave, G.F., Linping Dong, Grossman, J.P., Henley, D.C., and Lamoureux, M.P., 2003, Gabor deconvolution: extending Wiener's method to nonstationarity: CREWES 2003 research report, **15**.

Suarez, Gabriela, 2008, Side-by-side comparison of 3C land streamer versus planted geophone data at the Priddis test site: CREWES 2008 Research Report, **20.**