Priddis pulse/probe experiment: still ambiguous

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ABSTRACT

It has been conjectured that exciting the earth with a strong, stationary acoustic field will change the relative impedance of rock layer interfaces due to the induced motion of the pore fluids relative to the rock matrix, and that these changes in impedance should be detectable as changes in seismic reflectivity. A small seismic survey experiment to test this theory was conducted in 2008 at our Priddis test site; but the resulting analysis of the data yielded ambiguous results. The present report describes further analysis of those data. Specifically, we contrasted comparably processed CDP stacks of the survey data set acquired with dynamite only and the data set acquired with dynamite in the presence of a constant-frequency acoustic field in the earth. Comparisons were done using both straight subtraction and least-squares subtraction. We conclude from our analysis of those data that the results are still ambiguous, and the conjecture unconfirmed.

INTRODUCTION

It has been suggested by Quiroda-Goode (2004) that the acoustic response of the layered, porous earth can be changed dynamically by exciting the earth with an intense, but constant acoustic field, which acts to force the pore fluids to oscillate harmonically with respect to the pore spaces, thus changing the effective acoustic impedance of the porous rock layers. The implication of this is that a seismic survey performed in the presence of the strong perturbing sound field will record a different reflectivity response than the same survey performed in the absence of the sound field; and that the relationship between compressional reflectivity and shear “convertivity” will be different for the two experiments (with and without sound field).

To test this concept, we designed and performed a small field experiment in August 2008 (Margrave et al, 2008) at our Priddis field site. The experiment is described in detail by Margrave et al (2008); but it can be summarized as follows: A 200 m spread of 3C geophones was laid out, with the phones spaced 1 m apart. Along this line and offset from it by 1 m was a source line consisting of 11 source points spaced 20 m apart. A steel-cased reloadable 2m deep shot hole was placed at every source point. Two baseline surveys were performed, one using mini-vibrator only, with a 10-200 Hz sweep, at each source point, the other using dynamite only (60 g in water-filled casing). Next, the vibrator was stationed at the centre of the spread, but offset 50 m from the line. It was then operated in constant frequency mode for each of three frequencies (20, 50, and 100 Hz) while the dynamite survey was repeated for each of the fixed vibrator frequencies. The point of the experiment was then to see whether the results of any of the dynamite-plus-vibrator surveys differed in any significant way from the dynamite-only survey. Since the anticipated effect is likely small, and our constant field source (mini-vibe) is of limited power; our goal was to image any near-surface reflecting interfaces (perhaps the water table) in the 20-100 ms range and look for changes in reflectivity.

PREVIOUS RESULTS

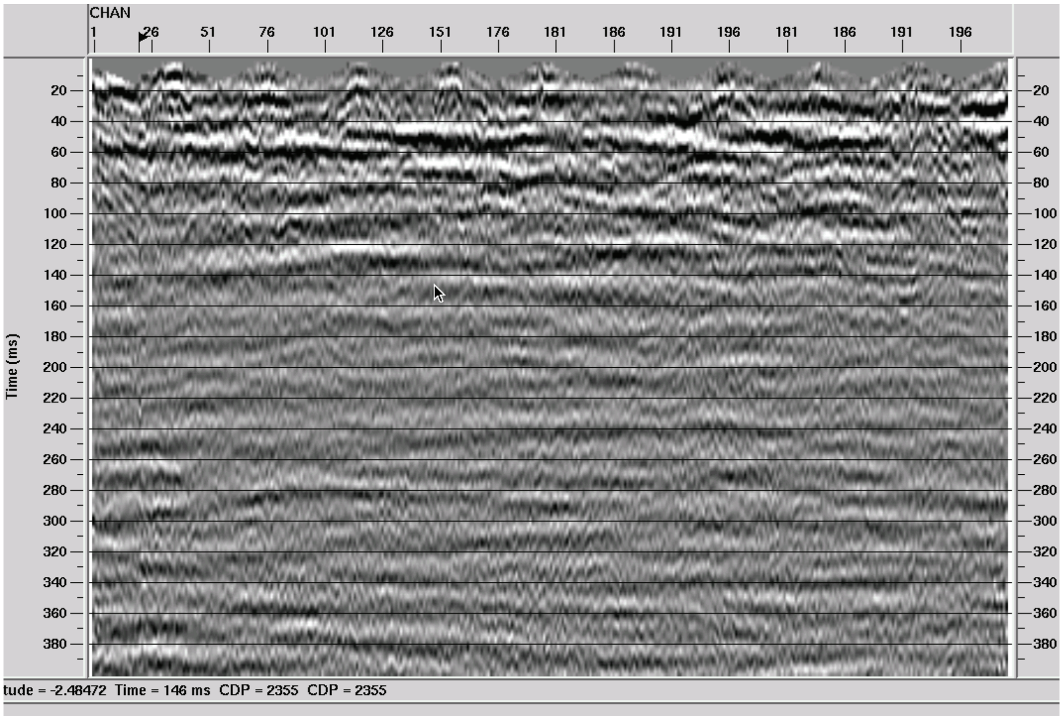
The data were processed and analyzed independently by both Han-Xing Lu and Dave Henley, using different processing approaches (Margrave et al, 2008). Both researchers, however, attempted to process all the data sets in exactly the same way so that they would be easy to compare. Han-Xing's analysis relied on visual comparison of final stacks of all the data sets, while Henley compared final stacks and also attempted to compute a difference between the stack of dynamite-plus-vibroseis and dynamite-only to emphasize any systematic differences. In all these comparisons, differences can be seen between all the surveys, but there seems to be no particular systematic difference (like a continuous and coherent reflection) that appears in any of these analyses. One difficulty for the analysis is that for this short spread, any shallow reflections are masked by strong refraction arrivals, and the events can be successfully stacked using either NMO or LMO of the same velocity. Even using very harsh radial filters to attenuate the 2000 m/s refraction arrivals, we can see a possible continuous reflection at about 25 ms, but only fragmentary reflections down to about 100 ms. While some of the images reported in Margrave et al (2008) are 'suggestive', we felt that no firm conclusions could be drawn at that time.

LATEST ANALYSIS

Our current analysis emphasis is to try to do the best difference analysis possible between the three dynamite-plus-vibroseis data sets and the dynamite-only data set. We decided to apply both straight subtraction and least-squares subtraction, not only to the final stacks of the data sets, but to the individual shot gathers, as well. All the shots of each survey were processed identically; including spectral clipping to remove the monochromatic vibrator energy and its harmonics, several passes of radial trace filtering to remove linear refraction and surface wave energy, and Gabor deconvolution to whiten the reflections. All parameters for these processes were identical for each of the data sets.

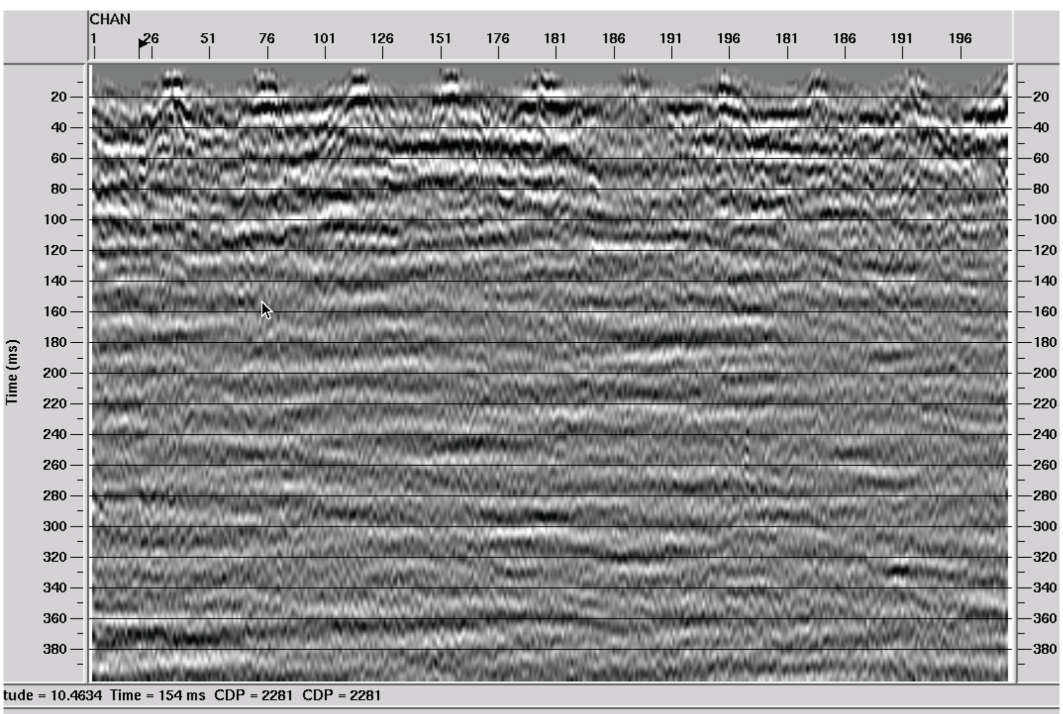
Prior to stacking, three new data sets were created by subtracting the dynamite-only shot gathers from their corresponding dynamite-plus-vibrator shot gathers, using least-squares subtraction. The seven data sets (four original data sets plus three 'difference' data sets) were corrected for NMO, and CMP stacked. To complete the analysis, the stack of the dynamite-only survey was subtracted from each of the dynamite-plus-vibrator data sets, using both straight subtraction and least-squares subtraction.

Figure 1 shows the image resulting from straight subtraction of the dynamite-only stack from the dynamite-plus-20Hz stack, Figure 2 shows the same result for the dynamite-plus-50 Hz stack, and Figure 3 shows the dynamite-plus-100 Hz stack difference. These images share no particularly striking features in common, even in the shallowest portions.



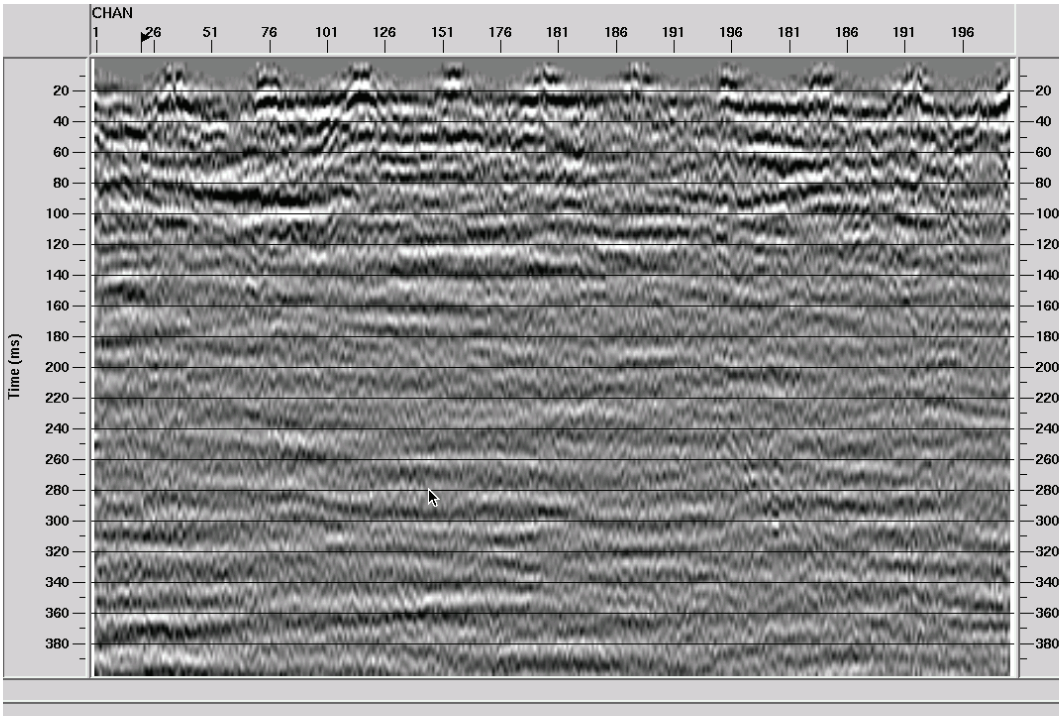
Priddis pump-probe—straight subtraction of 'dynamite only' from 'dynamite plus 20 Hz'

FIG 1. Straight subtraction of stack for 'dynamite only' from stack for 'dynamite plus 20 Hz'



Priddis pump-probe—straight subtraction of 'dynamite only' from 'dynamite plus 50 Hz'

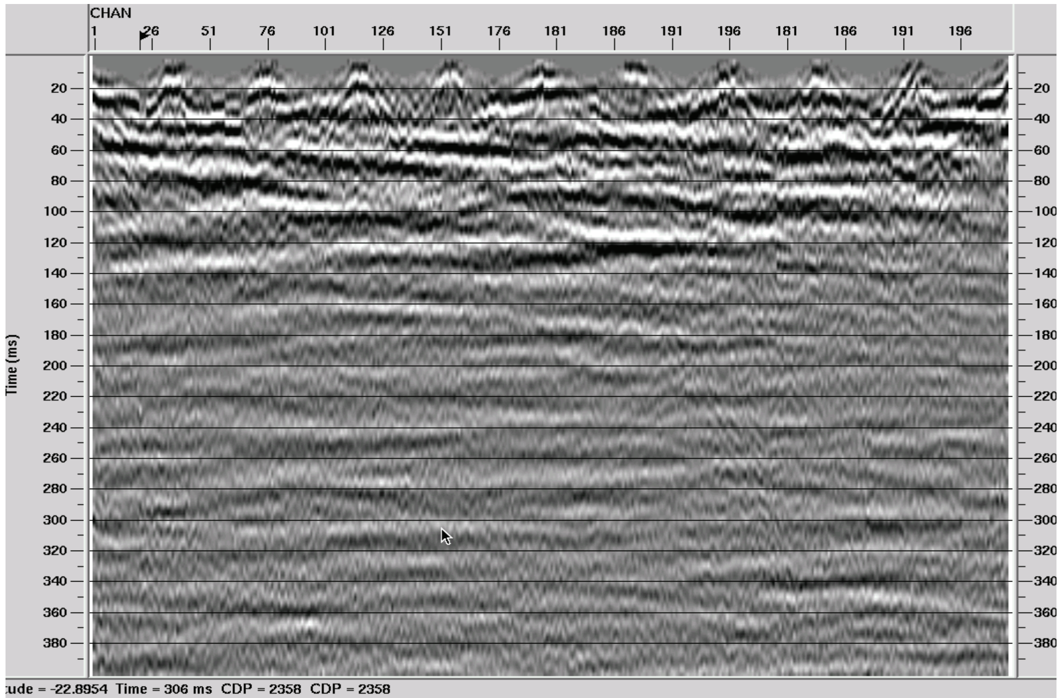
FIG. 2. Straight subtraction of stack for 'dynamite only' from stack for 'dynamite plus 50 Hz'



Priddis pump-probe—straight subtraction of 'dynamite only' from 'dynamite plus 100 Hz'

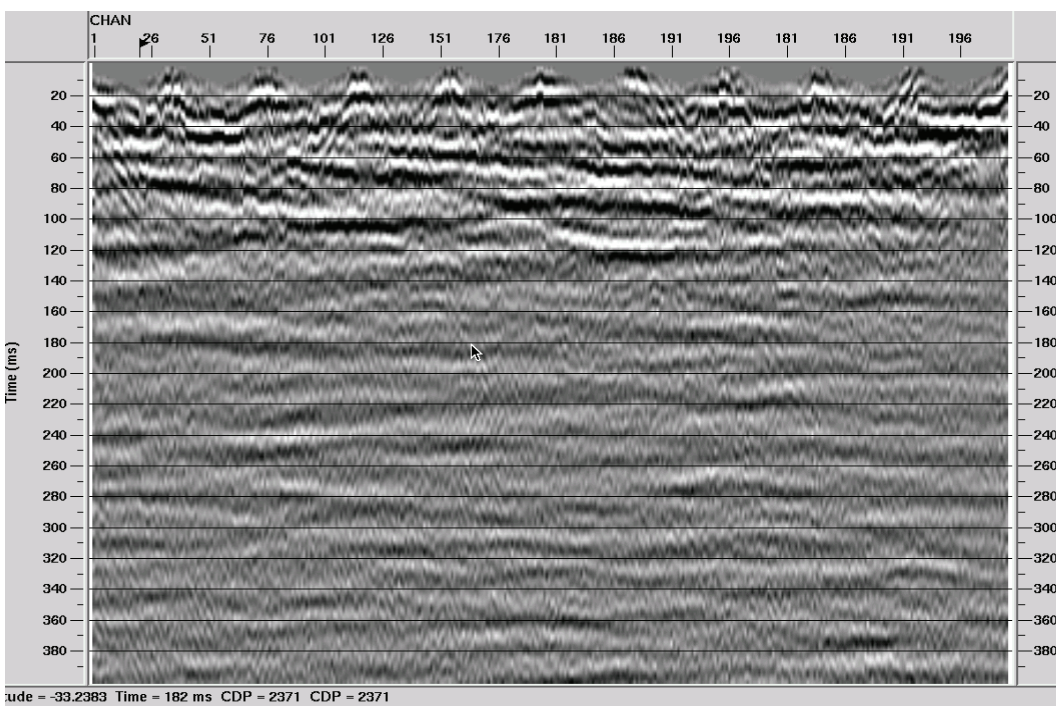
FIG. 3. Straight subtraction of stack for 'dynamite only' from stack for 'dynamite plus 100 Hz'

Figures 4, 5, and 6 are the images resulting from least-squares subtraction of the dynamite-only stack from the dynamite-plus-vibrator stacks, and Figures 7, 8, and 9 are the corresponding least-squares gain factors applied to the dynamite-only data prior to the subtraction from the dynamite-plus-vibrator data.



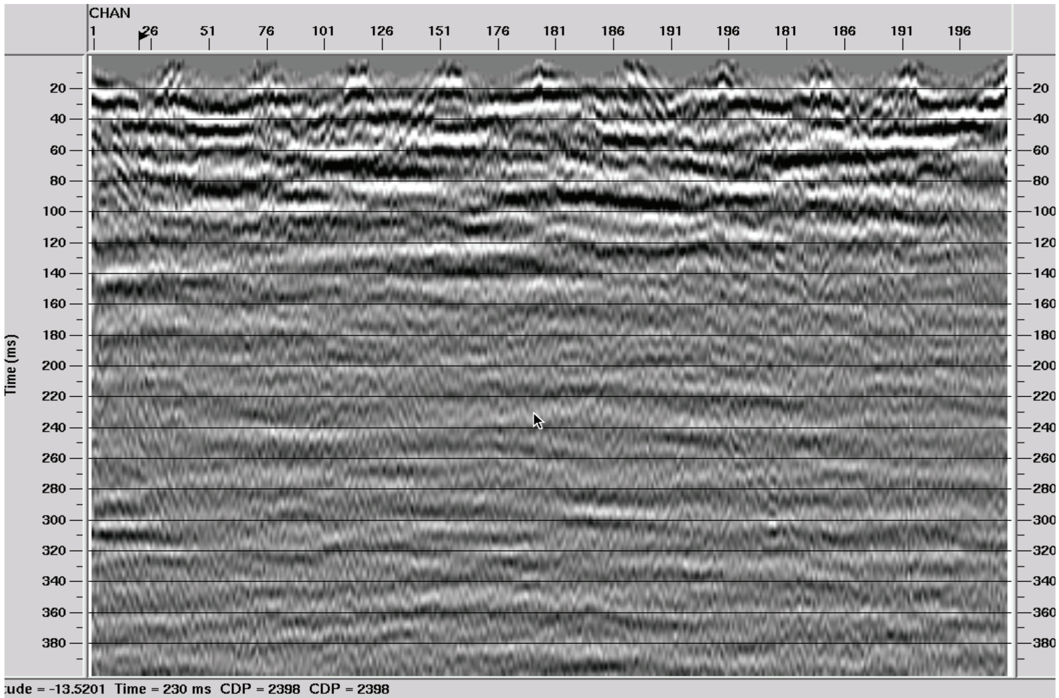
Priddis pump-probe—lsq subtraction of 'dynamite only' from 'dynamite plus 20Hz'

FIG. 4. Least-squares subtraction of stack for 'dynamite only' from stack for 'dynamite plus 20 Hz'



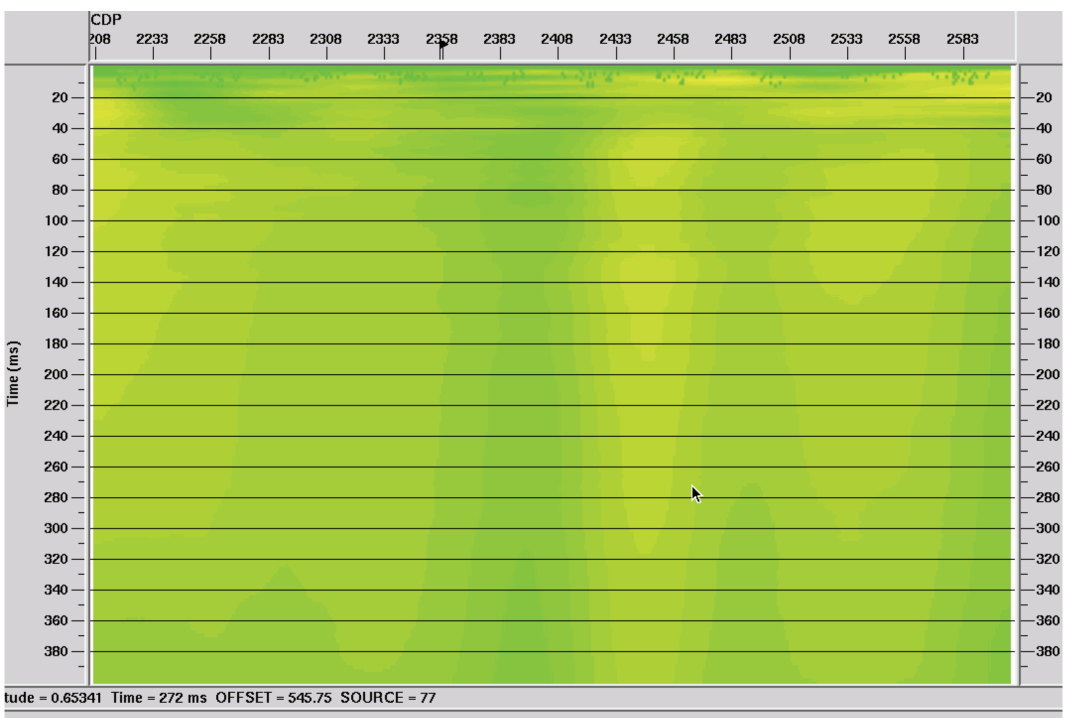
Priddis pump-probe—lsq subtraction of 'dynamite only' from 'dynamite plus 50 Hz'

FIG. 5. Least-squares subtraction of stack for 'dynamite only' from stack for 'dynamite plus 50 Hz'



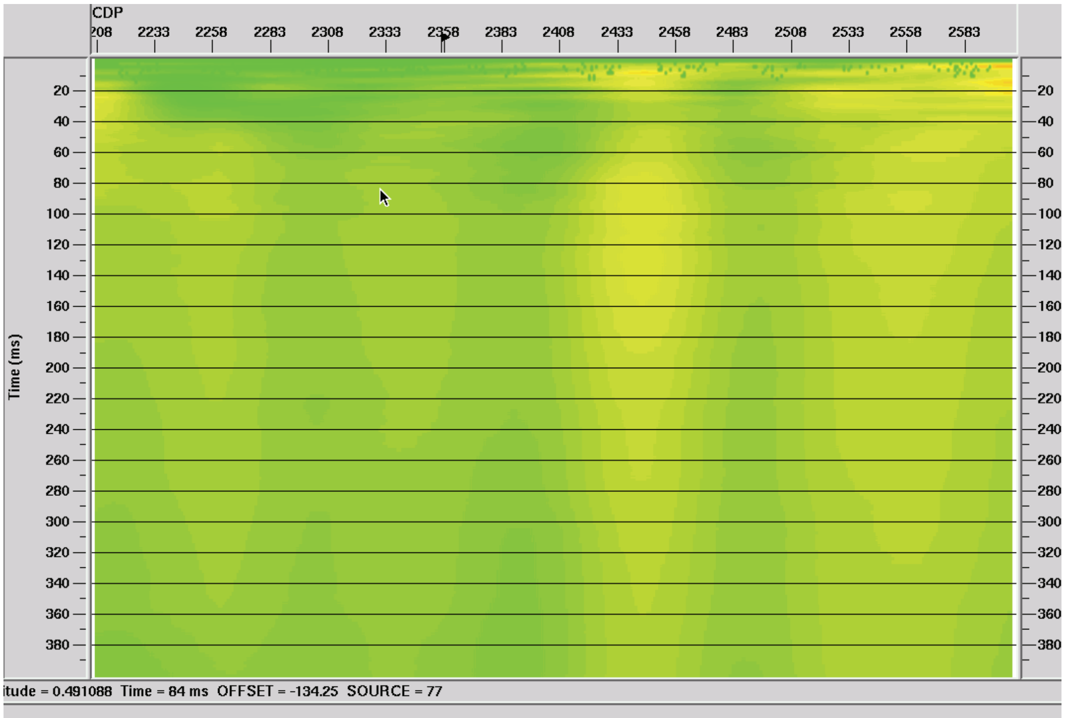
Priddis pump-probe—lsq subtraction of ‘dynamite only’ from ‘dynamite plus 100 Hz’

FIG. 6. Least-squares subtraction of stack for ‘dynamite only’ from stack for ‘dynamite plus 100 Hz’



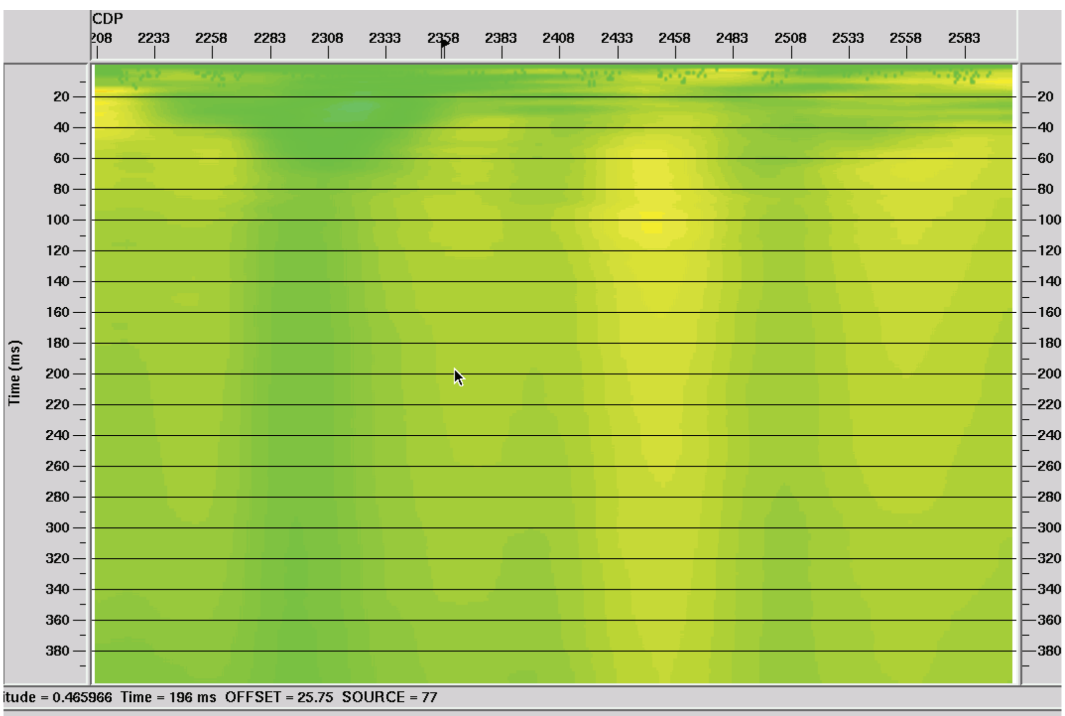
Priddis pump-probe—normalization factor for lsq subtraction of ‘dynamite plus 20Hz’

FIG. 7. Gain factors applied to ‘dynamite only’ stack before subtraction from ‘dynamite plus 20 Hz’ stack.



Priddis pump-probe—normalization factor for lsq subtraction of 'dynamite plus 50 Hz'

FIG. 8. Gain factors applied to 'dynamite only' stack before subtraction from 'dynamite plus 50 Hz' stack.

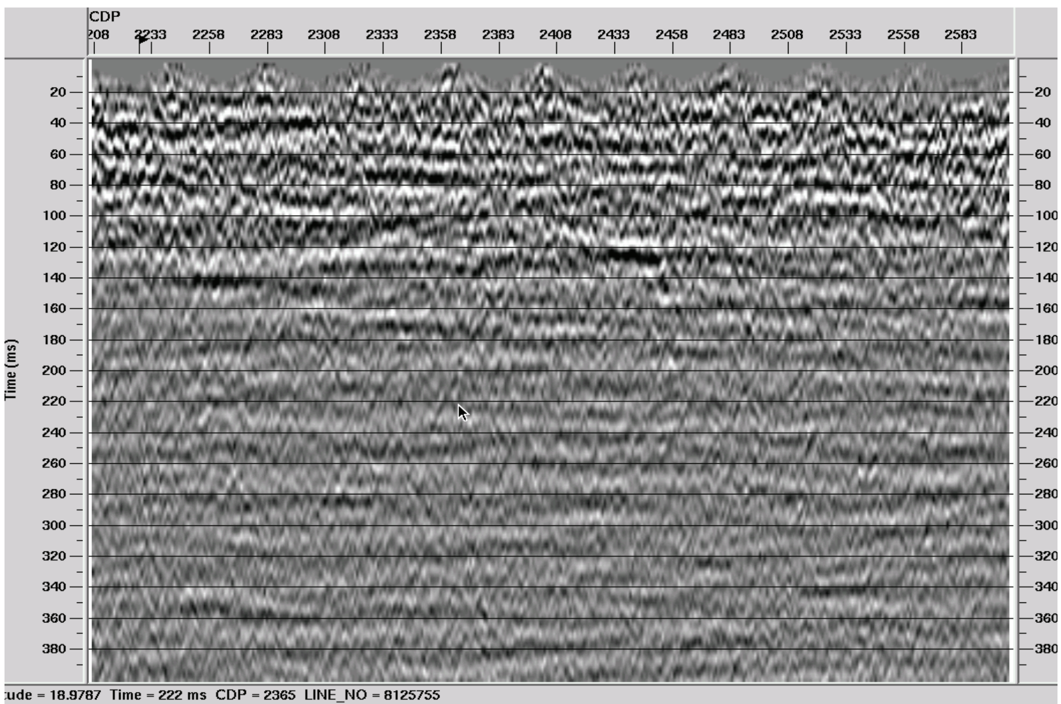


Priddis pump-probe—normalization factor for lsq subtraction of 'dynamite plus 100 Hz'

FIG. 9. Gain factors applied to 'dynamite only' stack before subtraction from 'dynamite plus 100 Hz' stack.

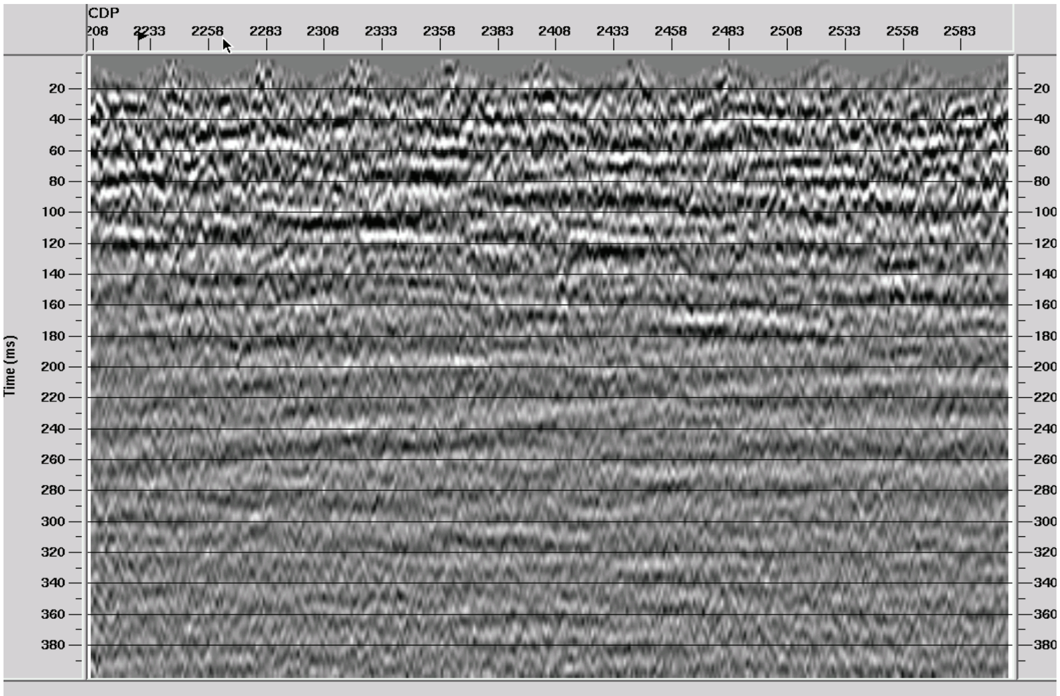
The images in Figures 4, 5, and 6 are certainly more similar than those in Figures 1, 2, and 3, and there are some events which seem similar on all three images. While suggestive, this result doesn't seem strong enough to definitely confirm our hypothesis. The gain factor plots suggest that the dynamite-only survey differs in a fairly consistent way from each of the three dynamite-plus-vibrator surveys, and the differing gain magnitudes intuitively explain why the least-squares subtraction results look more similar than the straight subtraction results.

Figures 10, 11, and 12 are the images resulting from the stack of the 'difference' shots created from the least-squares subtraction of the dynamite-only shots from dynamite-plus-vibrator shots. This may be the most rigorous way to do the difference comparison, and we see much less significant reflection-like energy in any of these images. There are, nevertheless, some similarities between them, including some apparent reflection fragments in common. Once again, the results are suggestive, but must be considered still ambiguous.



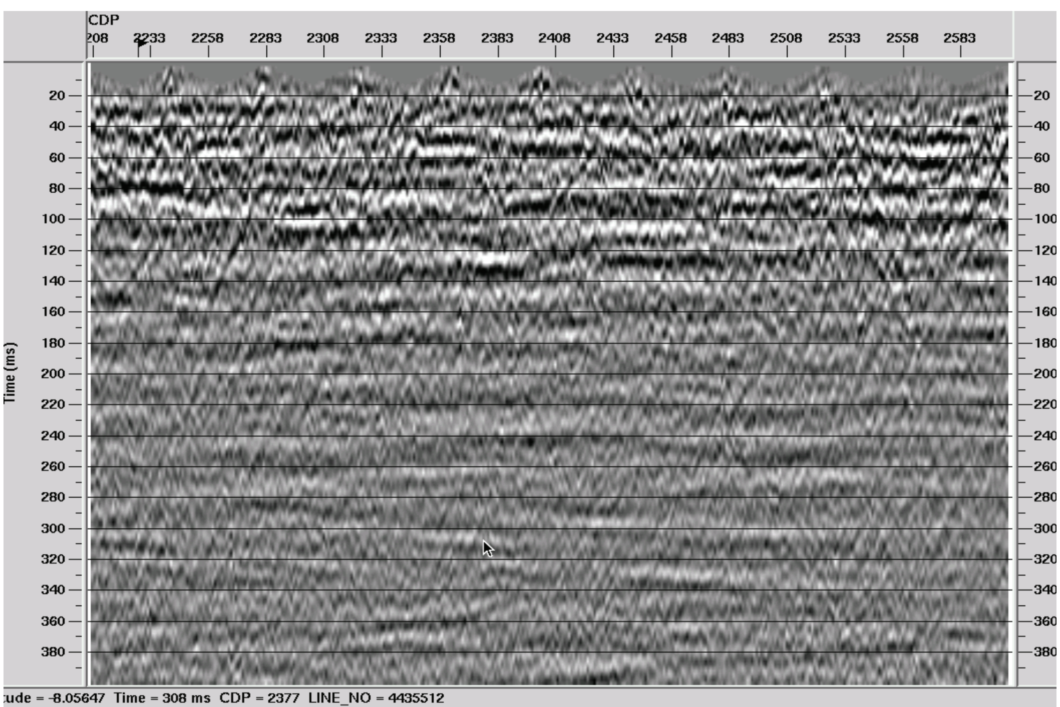
Priddis pump-probe—stack of difference shots—dynamite + 20 Hz minus dynamite

FIG. 10. Stack of difference shots, where least-squares subtraction was used to subtract all 'dynamite only' shots from corresponding 'dynamite plus 20 Hz shots.



Priddis pump-probe—stack of difference shots—dynamite + 50 Hz minus dynamite

FIG. 11. Stack of difference shots, where least-squares subtraction was used to subtract all ‘dynamite only’ shots from corresponding ‘dynamite plus 50 Hz’ shots.



Priddis pump-probe—stack of difference shots—dynamite + 100 Hz minus dynamite

FIG. 12. Stack of difference shots, where least-squares subtraction was used to subtract all ‘dynamite only’ shots from corresponding ‘dynmaite plus 100 Hz’ shots.

DISCUSSION

We feel that no firm conclusions can be drawn from these data, or their analysis. We see no continuous events on any of the stack images that convince us that they are legitimate reflections, with the possible exception of an event at 25 ms on one or two of the stacks that may be the water table, and a few fragmentary reflections near the centre of some images at about 100 ms. Based on previous experience at this site, we think that the stack fold was simply too low to properly enhance possible reflections. Furthermore, the energy of the dynamite shots may have been insufficient to create much reflection energy. There is likely a problem with source repeatability, as well, because several of the casings set into the shot holes were observed to shift vertically with subsequent shots, indicating the likely incremental creation of a shot cavity with each new shot. The change in overall magnitude of the gain plots in Figures 7, 8, and 9 is progressive from Figure 7 (20 Hz vibrator signal) to Figure 9 (100 Hz vibrator signal), supporting the notion that it takes increasingly larger gain factors to least-squares match the later dynamite data to the original (dynamite-only) data. This may indicate progressively weaker source coupling with each subsequent experiment, due to cavity formation.

The original theory, as described by Quiroda-Goode (2004), assumes a very strong acoustic field in order to cause the non-linear acoustic impedance alteration. It seems unlikely that our mini-vibe source was capable of generating such a field at more than a few metres away from the baseplate, but we simply don't know; hence the experiment.

ACKNOWLEDGEMENTS

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REFERENCES

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Quiroda-Goode, G., 2004, Twin wavefield (pump-probe) exploration: CREWES presentation.