Priddis pump-probe experiment

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ABSTRACT

A novel exploration technique has been proposed, whereby the earth is continuously excited by a strong seismic signal, and concurrently 'probed' by a more transient seismic impulse. The idea is that the background field, by exciting the fluids within rock layers to vibrate with respect to the rock matrix, will significantly change the rock properties across layer boundaries, causing them to respond differently to seismic impulses than when the rocks are not perturbed by the background signal. We conducted a small-scale 3C-2D seismic survey at our Priddis test site to try to test this proposed technique, specifically targeting the water table as a prospective layer boundary. Two different 'background' surveys were conducted, as well as three 'pump-probe' experiments, all on the same profile. Our preliminary analysis of the data shows small differences between a 'background' survey and each of the 'pump-probe' surveys; but our analysis is not yet refined enough to determine the significance of these differences, if any.

INTRODUCTION

Sometimes a new idea arises that, while seemingly implausible, still begs to be tested. We describe here our first examination of one such proposal, a radical twist on conventional seismic acquisition that, if true could lead to enhanced detection and discrimination of reservoir fluids. The idea, first proposed to us by Gerardo Quiroga-Goode (2004), involves the simultaneous activation of two seismic sources, one of long temporal duration and the other impulsive. The proposed effect, which will be nonlinear if it exists, posits that the long-duration source will cause fluid movement in rock pore spaces, which will subsequently slightly alter the effective reflectivity of the porous rock. The short-duration source is then activated with the intent that its leading pulse will sample the reservoir while the other source is still affecting it. The resulting seismic record would then be compared with a record acquired with only the short duration source. Certainly the proposed effect is nonlinear, since it argues that the seismic record from the combined sources is different from the sum of records taken with each source independently. Quiroga-Goode (2004) referred to this concept as the twin wavefield, or pump-probe method.

Having known of the idea since 2004, we found ourselves, in the summer of 2008, in a position to undertake a small field evaluation at the University of Calgary Priddis test site. Being unaware of either any previous field experiment or of any relevant theoretical work we were forced to make a number of rather arbitrary decisions. We decided to simply look for an effect at the top of the water table, which is thought to be a shallow reflector at about 20-40 ms. The U of C's mini-vibe was chosen for the long duration source while small explosives were selected for the impulsive source. Blasting caps, with boosters, equivalent to 60 g of dynamite were acquired and were placed at the bottom of water-filled, 2 m steel pipes that were pushed into drilled holes. This complicated arrangement was chosen since previous experience has found such explosive sources are reasonably repeatable. It was decided to use the Vibrator with a monochromatic sweep to attempt to set up a standing wave in the near surface and then fire the dynamite while this wave was in process.

EXPERIMENTAL LAYOUT

Since the intent of this experiment was to test an effect which was expected to be quite subtle, the field test was designed as a high resolution survey whose parameters were selected to focus only on the shallowest possible reflections, hopefully including the water table. The survey was laid out south of and parallel to the Rothney Observatory access road and was only 200 m in length, but sampled every metre with a 3C geophone. The location map for the source points and receiver line is shown in Figure 1. Figure 2 shows the corresponding elevation map. Note that the source points appear about 2 m beneath the receiver line, since the sources were small dynamite charges placed in 1.8 m deep boreholes, cased with steel and tamped with water for every shot.

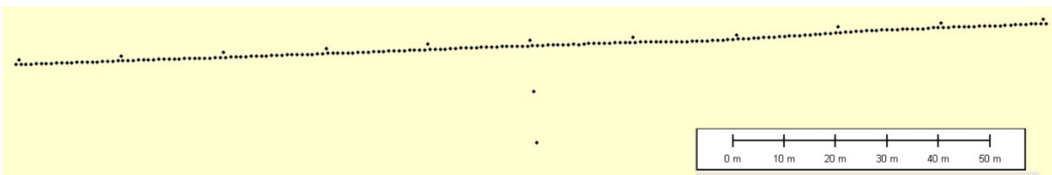


FIG. 1. Source and receiver location map (North is up). Multicomponent geophones were planted at 1 m spacing, with station numbers increasing to the east. Shot holes nominally 1.8 m deep were drilled and cased every 20 m, offset 1 m to the north of the receiver line. Centred on the receiver line, but offset 10 m to the south we have the test borehole location with a single 3C clamping geophone at 75 m depth. A single shot hole was located a further 10 m south of the borehole.

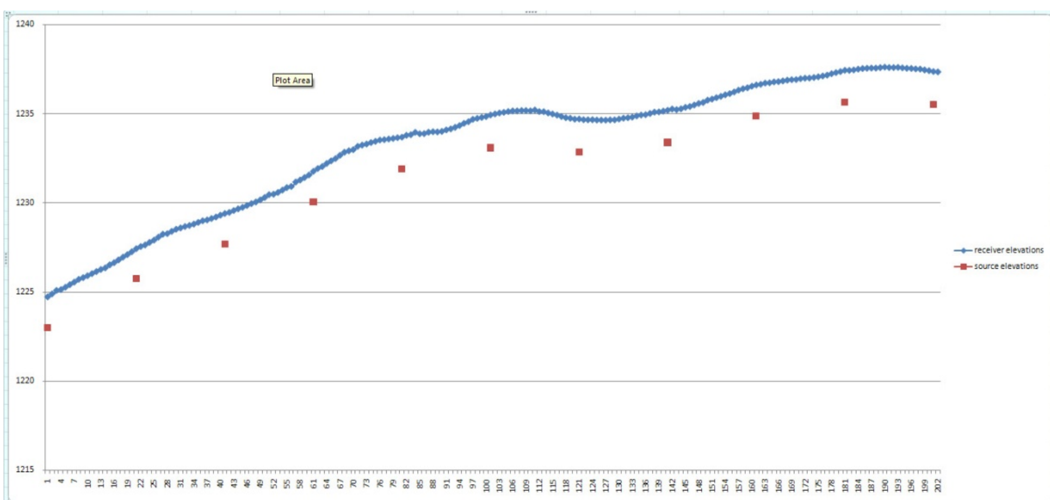


FIG. 2. Elevation profile (receivers in blue, sources in red).

PROCEDURE

Two hundred SM-24 3C geophones in nail-type cases were planted at one meter station spacing along a 200 meter east-west receiver line, ten meters north of and roughly centred on the borehole at the University of Calgary's Priddis geophysical test site. A single 3C clamping geophone was emplaced in the borehole at 75 meters depth. Shot holes were drilled every 20 m (for a total of eleven shot locations) about 1 meter north of the receiver line. An additional shot hole was drilled ~20 meters south of the receiver line (10 meters south of the borehole location. The shot holes were nominally 1.8 meters deep, and were cased with 1.3 cm (0.5") thick, 20 cm (8") diameter steel pipe. The purpose of the casing was to improve repeatability of the shots. Furthermore, it was decided to position the vibrator in a fixed position displaced 50 meters offline at the center of the line. The monochromatic sweeps were 25 seconds long and the dynamite charges were fired with manual trigger at approximately the 15 second point.

The survey was shot five times: 1) Mini-vibe only, offset north of the shot holes, 2) dynamite only (60 g booster caps tamped with water), 3) dynamite with a 20 Hz monochromatic background field provided by the mini-vibe, offset about 50 m south of the center of the receiver line, 4) dynamite with a 50 Hz background and 5) dynamite with a 100 Hz background field. The Vibroseis only shots had a 10-210 Hz linear sweep. The procedure for the dynamite+vibe shots was as follows: Manually trigger a 30 s mono-frequency sweep and fire the dynamite at the 15 s mark based on the second-hand of the clock display on the recorder's computer.

The entire acquisition phase, as well as equipment pick-up was easily performed during one day, with few problems encountered. The cased shot holes seemed to perform adequately, although it was noticed that several of the casings began to sink further into the boreholes after two or three successive shots. This probably means that a significant shot cavity was being formed by the successive shots, and that the casing was simply sinking into the cavity. This is of some concern when considering the repeatability of the sources.

Figures 3 through 12 depict various aspects of the survey during setup and active data acquisition. Figure 3 shows the test site with Highway 22 in the background, while Figures 4 and 5 show the initial phases of the survey layout. Figure 6 shows a typical 3C geophone placement, and Figure 7 shows one group of the various boxes and batteries necessary for 3C recording. Figures 8 and 9 show, respectively, the small charges used for the dynamite shots, and the casing being inserted into a shot hole, prior to being water-filled and loaded. A view inside the doghouse during acquisition is shown in Figure 10, while Figure 11 shows the U of C mini-vibrator used as the secondary or "pump" source for the experiment. Finally, Figure 12 captures one of the shots immediately after being fired. The geyser of water and mud, though undesirable, was unavoidable, since the charges were water-tamped so that the shot holes could be re-used. The water and mud falling back onto the surface does show up on the records as secondary sources, but they generally occur well over a second down the record and thus do not affect the data of interest.

FIG. 3. The site for the Priddis pump-probe experiment

FIG. 4. Preparing the receiver line

FIG. 5. Planting the 3C geophones

FIG. 6. A perfect plant!

FIG. 7. The complexities of 3C acquisition layout.

FIG. 8. Enough bang for the buck?

FIG. 9. Casing the shot holes.

FIG. 10. In the doghouse.

FIG. 11. The background or “pump” source.

FIG. 12. The “primary” source (dynamite) in action.

PROCESSING AND ANALYSIS

Since the ‘pump-probe’ experiment was somewhat unique in its conception and design, the decision was made to process the data in two different ways. First, Han-xing Lu processed the data in the accepted ‘conventional’ manner, using two different techniques to remove the monochromatic Vibroseis background signal from the three different ‘pump-probe’ runs (one each for 20 Hz, 50 Hz, and 100 Hz Vibroseis signals). She applied minimum phase spectral whitening to the ‘cleaned’ shots, then performed velocity analysis and CDP stacking of all data sets, using the same velocity function for all five runs (Vibroseis only, dynamite only, dynamite plus 20 Hz, dynamite plus 50 Hz, and dynamite plus 100 Hz). Secondly, Dave Henley applied a somewhat different ‘unconventional’ processing approach, using a non-linear technique for removal of the monochromatic Vibroseis signals, then applying coherent noise attenuation and Gabor deconvolution to the shot gathers, before stacking them. We present both sets of results here, with the proviso that both are preliminary. There are other methods for comparing results that we will explore for future reports on the topic. Furthermore, we show results mostly for the vertical component of the 3C data set, and will examine the other components at a later date.

Han-xing’s results

The first method used by Han-xing to remove the monochromatic Vibroseis signal from the three data sets constituting the actual ‘pump-probe’ part of the experiment was to apply a simple notch filter for the known frequency of the vibrator. This proved effective at removing the stated frequency itself, but not its harmonics. Figures 13 and 14 show typical raw shot gathers for the ‘control’ surveys of the line; the ‘Vibroseis only’ and ‘dynamite only’ surveys respectively. Both of these gathers are dominated by coherent noise generated by the source; and the dynamite record shows 60 Hz contamination, as well. Figures 15, 16, and 17 show raw records for the three ‘pump-probe’ surveys; 20 Hz, 50 Hz, and 100 Hz, respectively. In Figures 15 and 16, the Vibroseis mono-frequency clearly dominates the record, while in Figure 17 (possibly due to the display bandpass) the shot-generated coherent noise dominates. Figure 18 shows the result of applying a 20 Hz notch filter to the record in Figure 15. As can be seen, there is still lots of Vibroseis signal on this record. Figure 19 shows why: The 40 Hz and 60 Hz harmonics of the 20 Hz Vibroseis signal are also prominent in the record, and the 20 Hz notch filter does not address these components at all. Figures 20 and 21 show the results of applying 50 Hz and 100 Hz notch filters to the pump-probe records from Figures 16 and 17, respectively. Lots of residual Vibroseis signal can be seen in each record, although less in the 100 Hz experiment, because of the display bandpass.

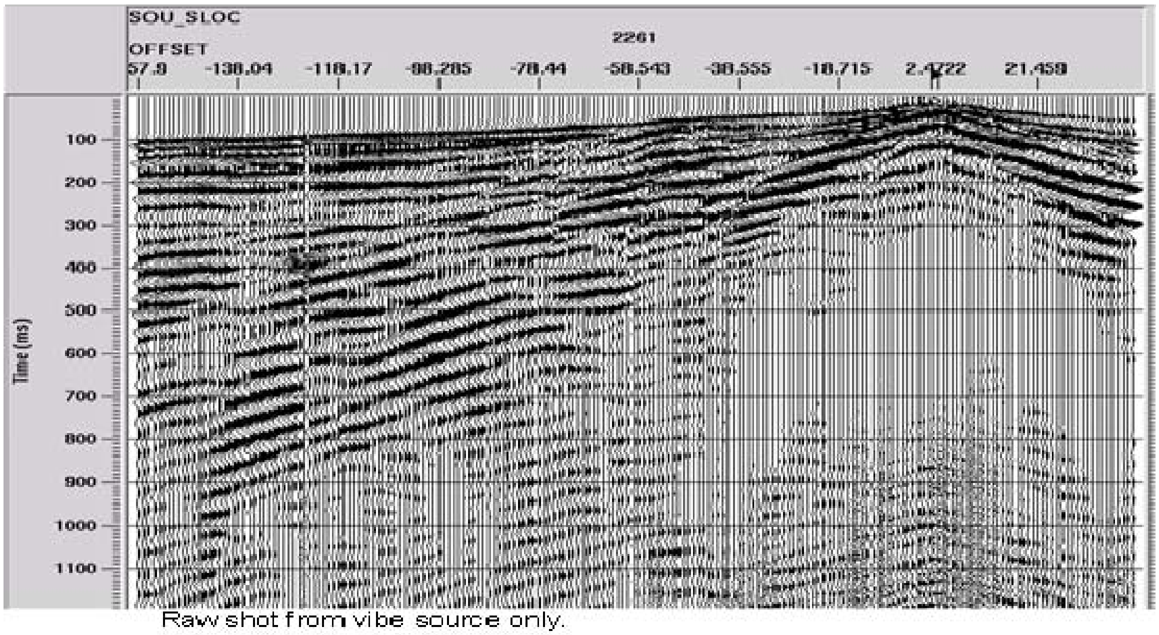


FIG. 13. Typical raw shot gather from 'Vibroseis only' survey. Coherent noise dominates the record.

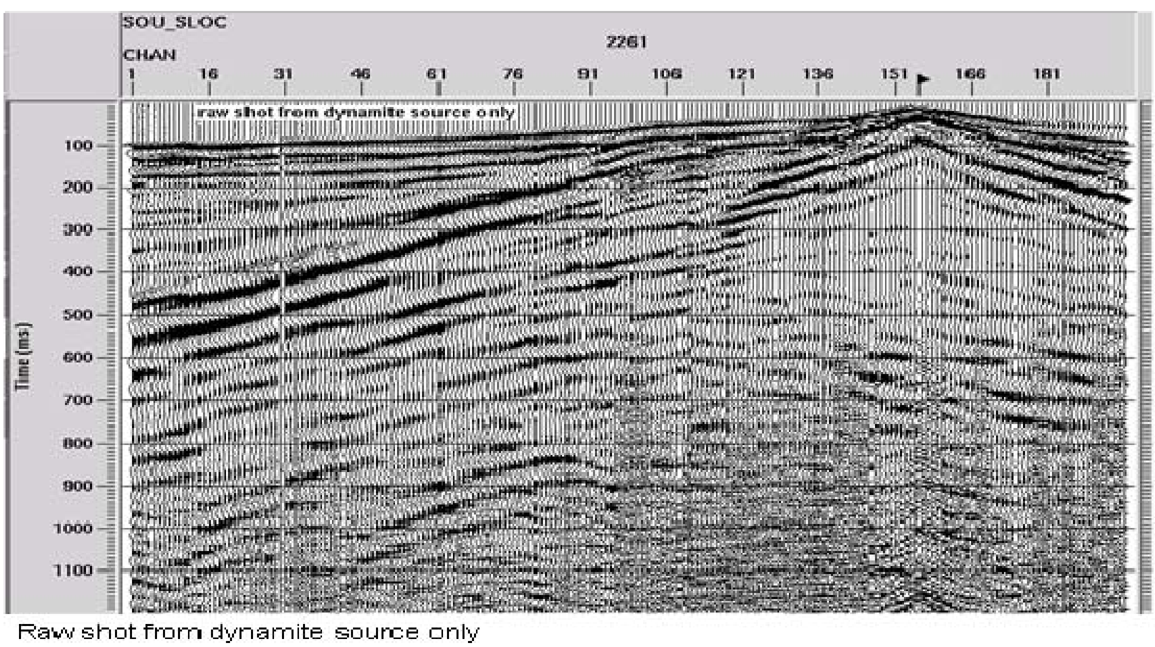


FIG. 14. Typical raw shot gather from 'dynamite only' survey. This gather is dominated by coherent noise and 60 Hz power line noise.

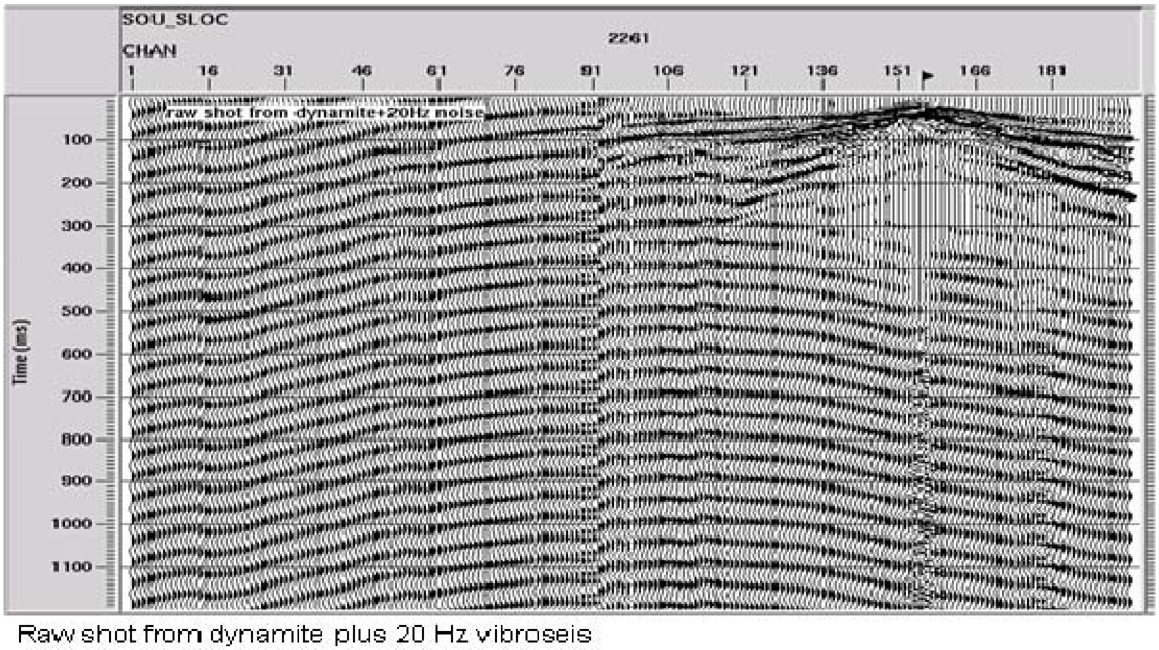


FIG. 15. Typical raw gather from pump-probe experiment with 20 Hz Vibroseis signal. The Vibroseis signal dominates the record.

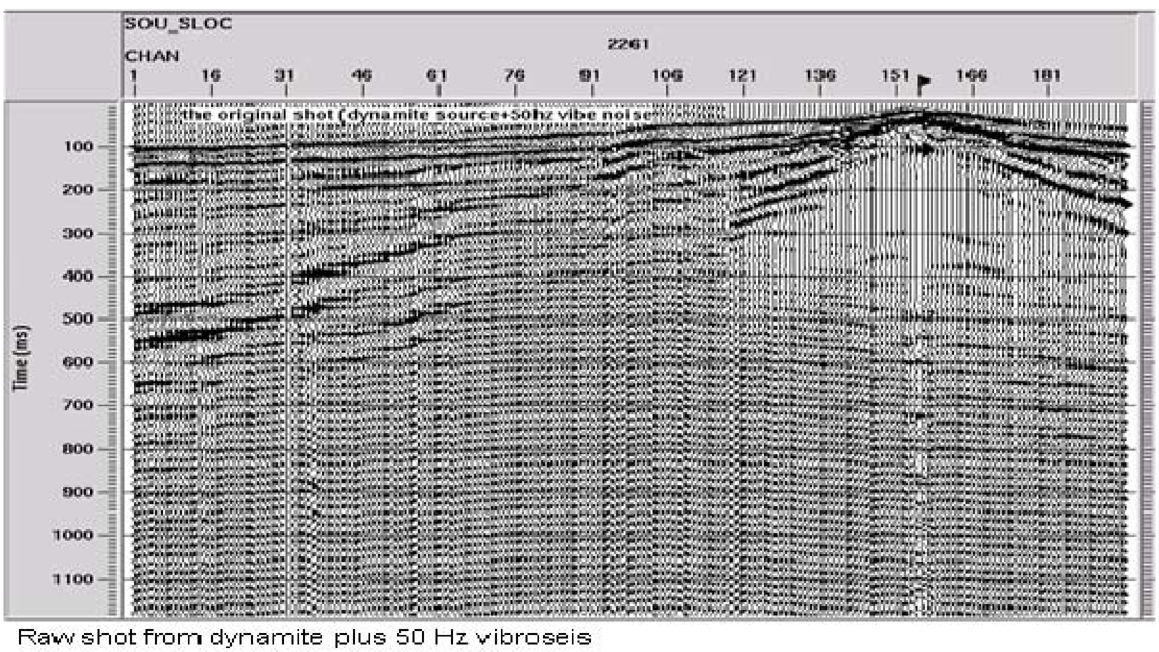
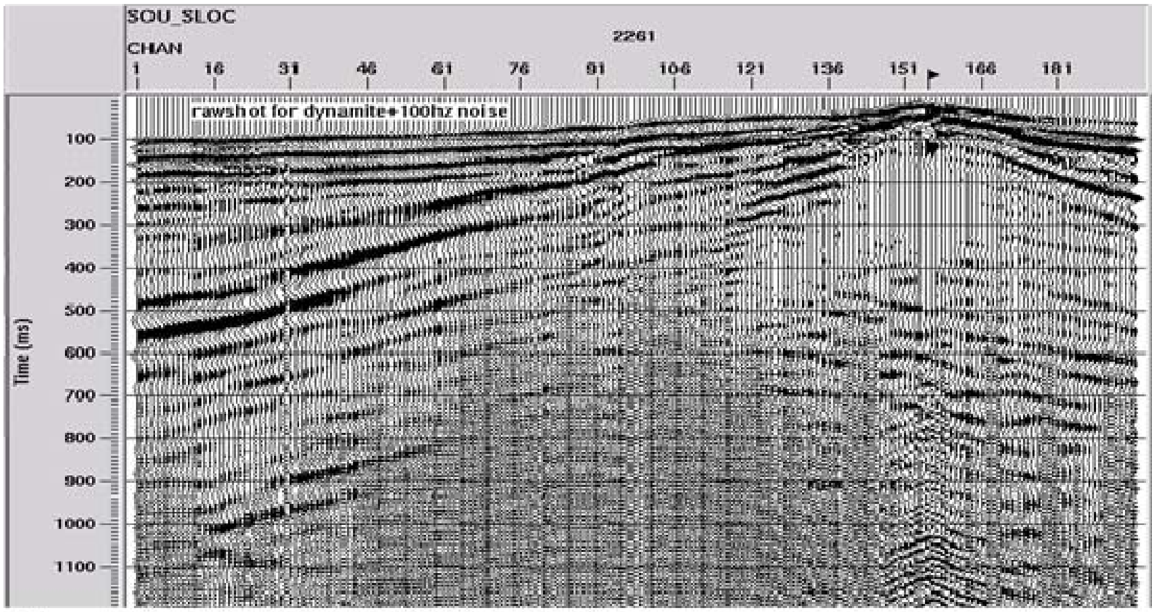
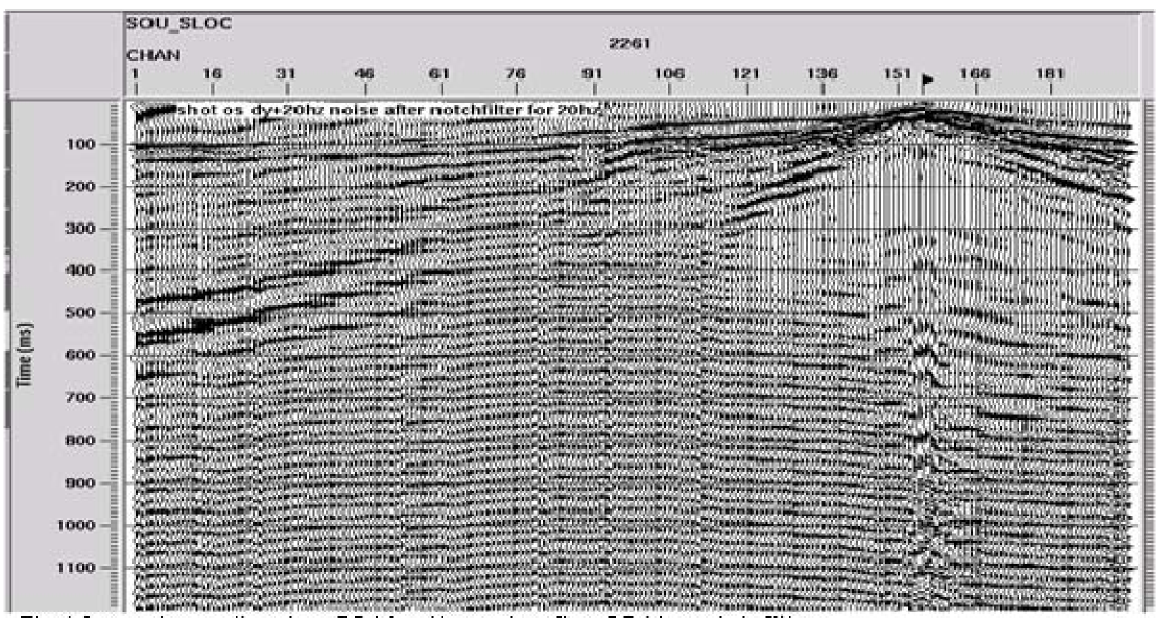


FIG. 16. Typical raw shot gather from pump-probe experiment with 50 Hz Vibroseis signal. The record is dominated by the Vibroseis signal.



Raw shot from dynamite plus 100 Hz vibroseis

FIG. 17. Typical shot gather from pump-probe experiment with 100 Hz Vibroseis signal. The record shows more coherent noise than Vibroseis signal.



Shot from dynamite plus 20 Hz vibroseis after 20 Hz notch filter

FIG. 18. Pump-probe gather from Figure 15 after application of 20 Hz notch filter. There is lots of Vibroseis signal left in this gather.

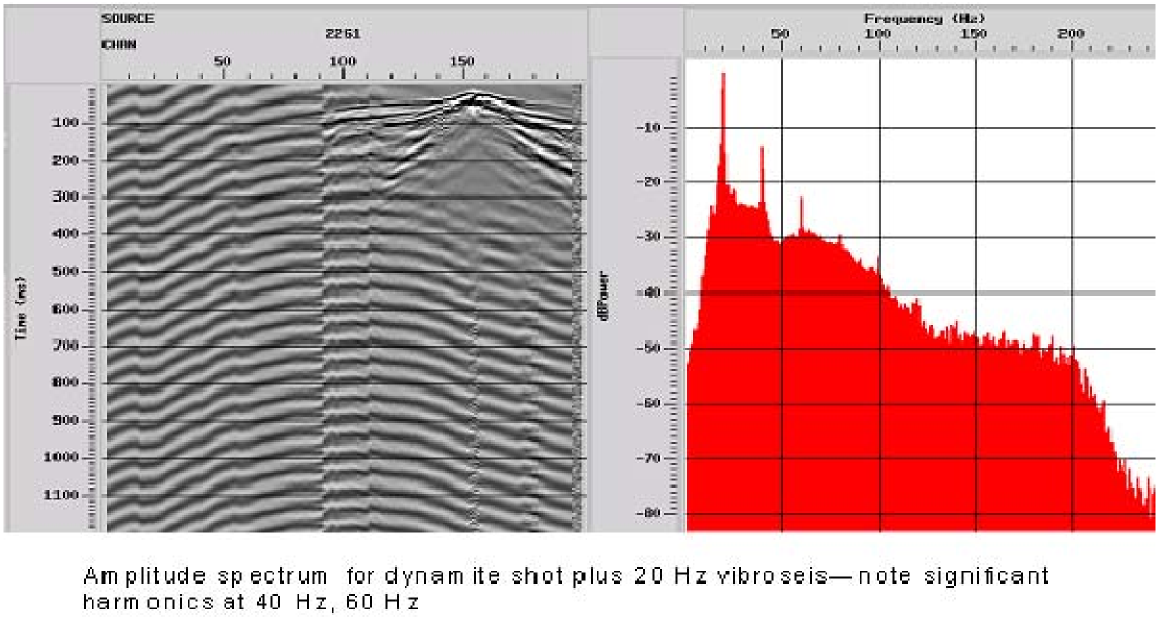


FIG. 19. The 20 Hz Vibroseis signal is accompanied by significant harmonics at 40 Hz and 60 Hz, which are not attenuated by the 20 Hz notch filter.

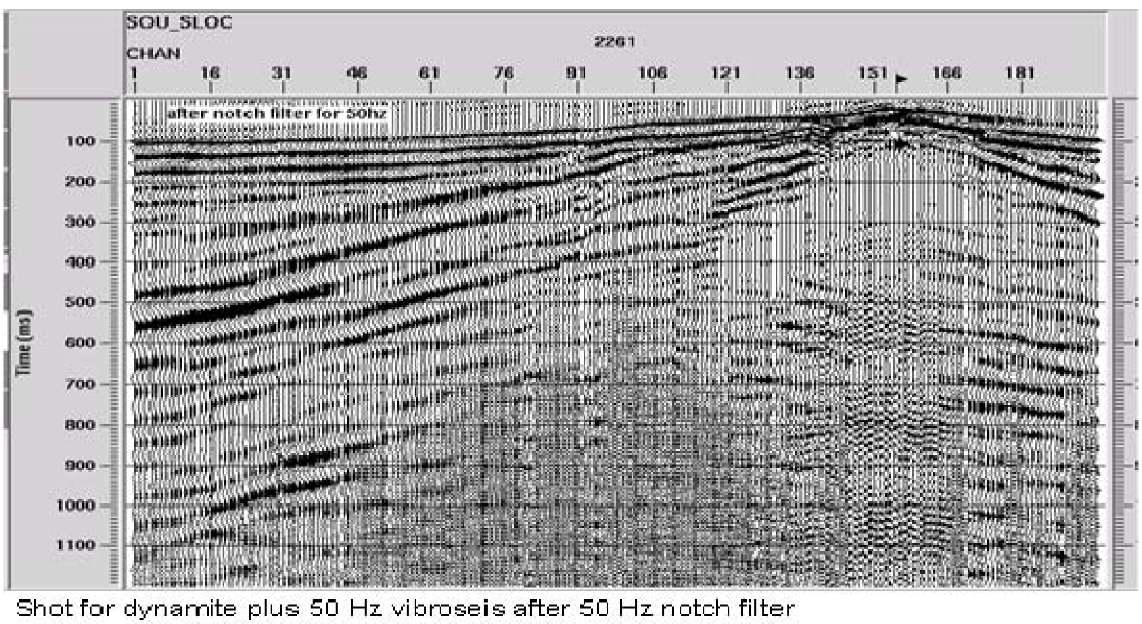
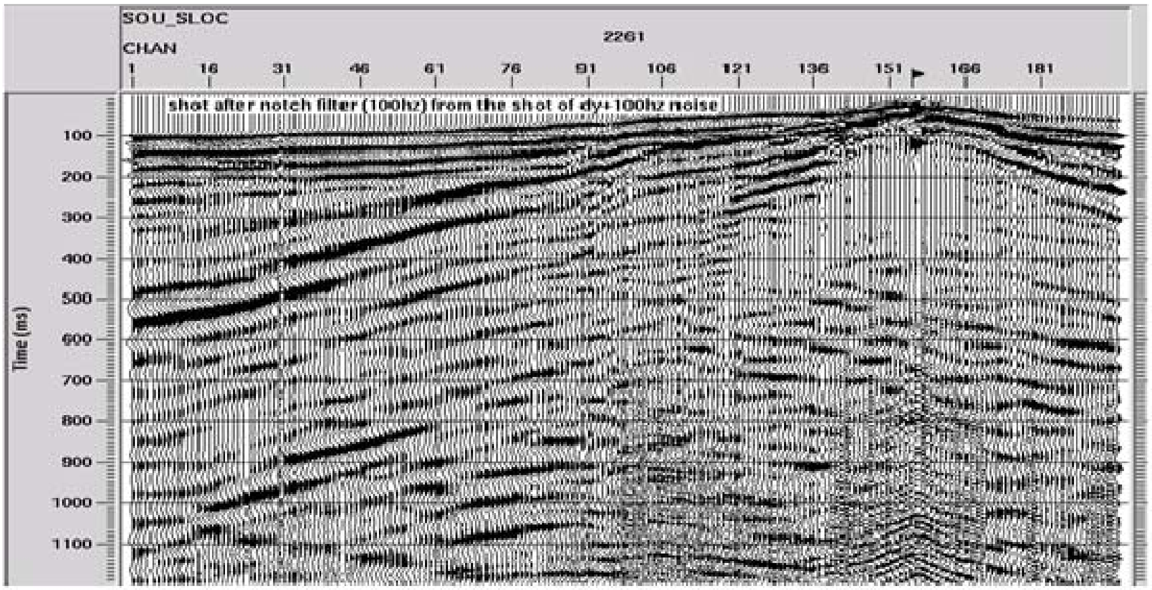


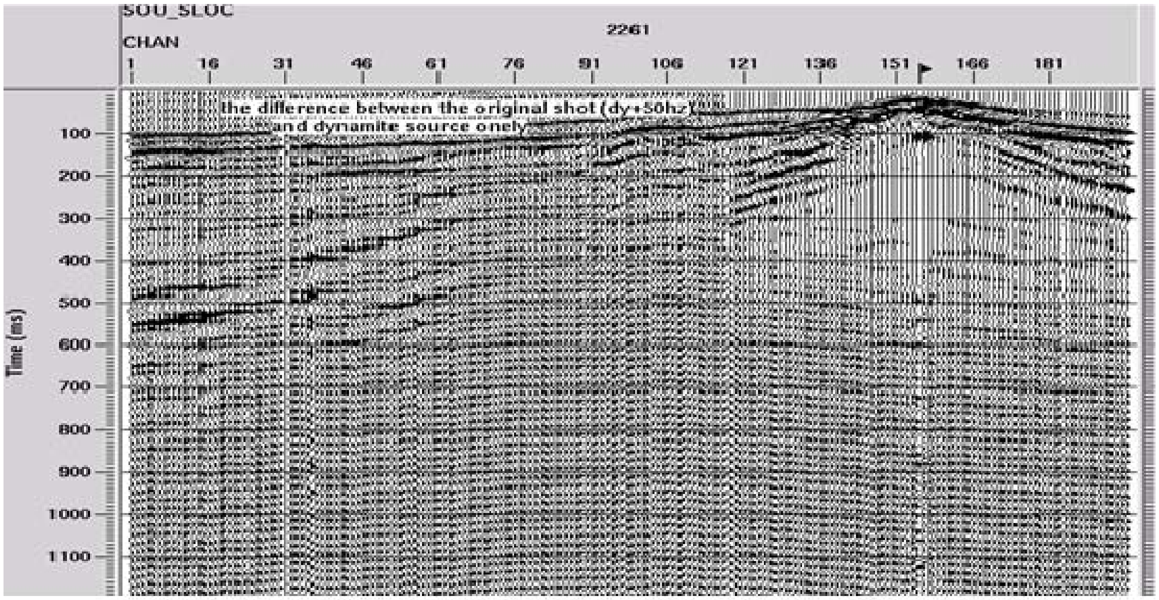
FIG. 20. 50 Hz pump-probe shot with 50 Hz notch filter applied. There is lots of residual Vibroseis signal.



Shot for dynamite plus 100 Hz vibroseis after 100 Hz notch filter

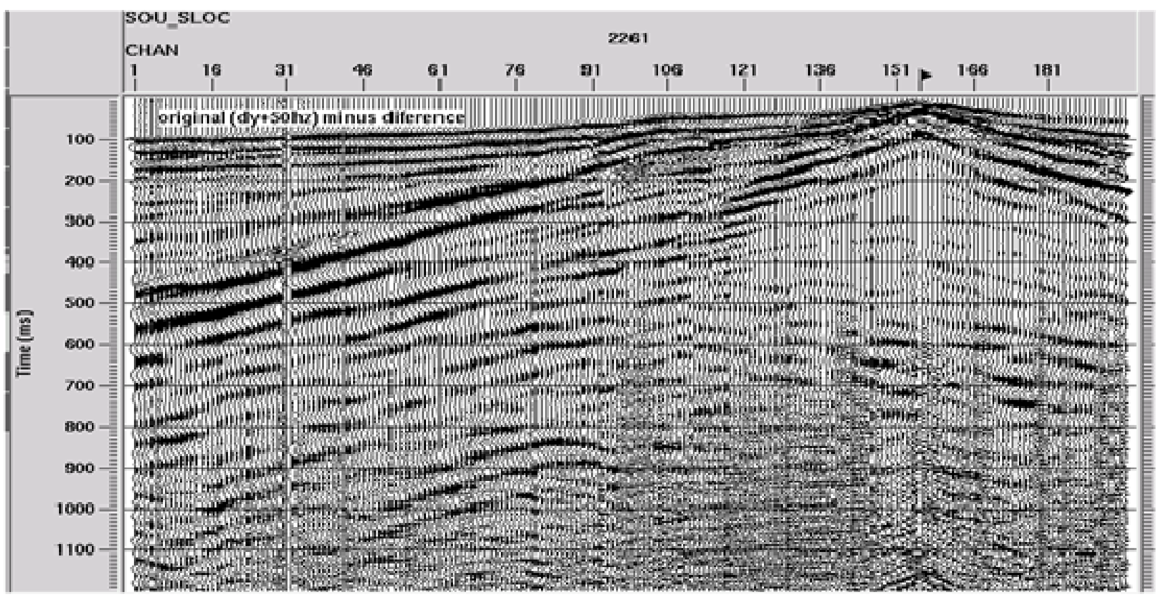
FIG. 21. 100 Hz pump-probe shot with 100 Hz notch filter applied. There is less residual noise on this gather, probably because of the display bandpass.

The second approach used by Han-xing to remove the Vibroseis components from the pump-probe records was to subtract from each pump-probe record the corresponding ‘dynamite only’ record. The result of this was a ‘difference gather’ for each pump-probe record. Each ‘difference gather’ was then subtracted from its corresponding pump-probe record to attempt to remove the Vibroseis signal overlying the dynamite record. Figure 22 shows the ‘difference gather’ for one of the 50 Hz pump-probe gathers, while Figure 23 shows the result of subtracting this panel from the raw 50 Hz pump-probe record in Figure 16.



Difference between dynamite plus 50 Hz vibroseis and dynamite only

FIG. 22. Difference gather created by subtracting the ‘dynamite only’ record for this shot from the 50 Hz pump-probe record.



Original shot for dynamite plus 50 Hz vibroseis minus difference gather

FIG. 23. Original 50 Hz pump-probe shot from Figure 16 with difference gather from Figure 22 subtracted.

Comparing Figures 23 and 20, it appears that the Vibroseis signal is significantly more reduced in Figure 23. This technique was thus adopted and used to prepare all the shot gathers for the three pump-probe surveys. Typical gathers processed in this manner for the 20 Hz and 100 Hz pump-probe surveys are shown in Figures 24 and 25, respectively.

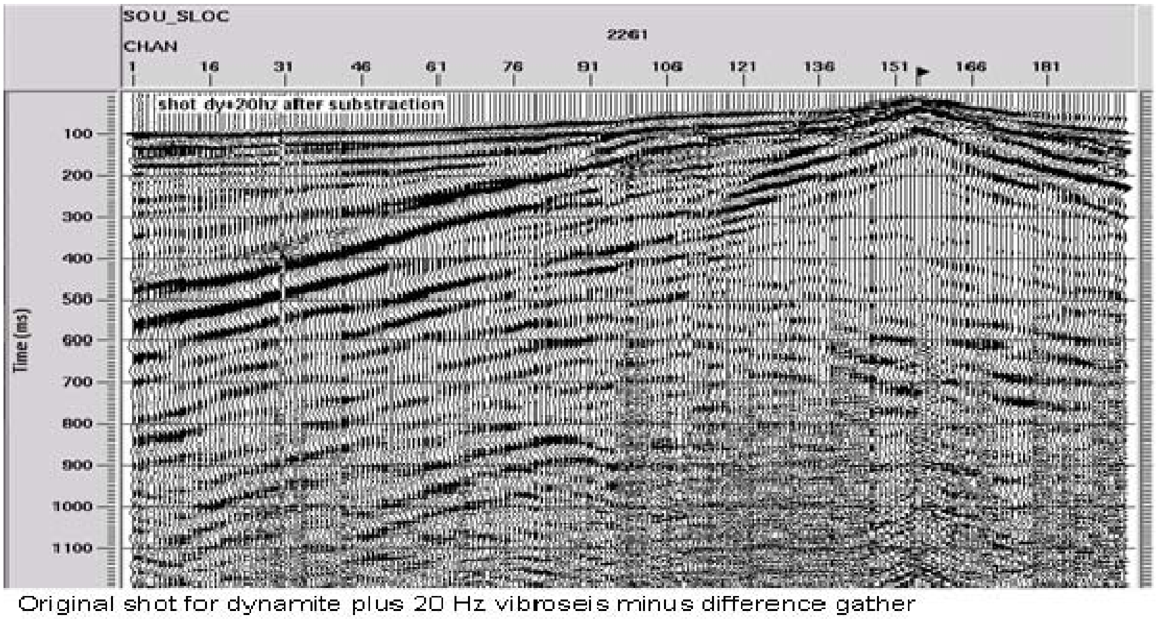


FIG. 24. Pump-probe shot from Figure 15, after subtraction of difference gather.

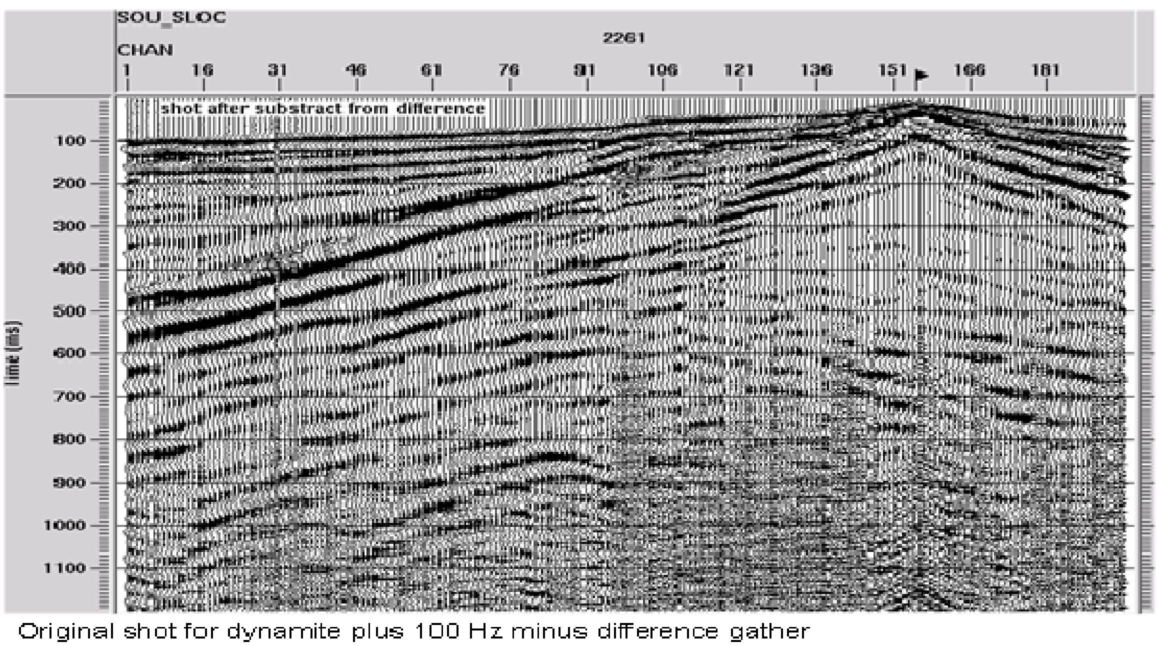


FIG. 25. Pump-probe shot from Figure 17, after subtraction of difference gather.

To see whether there are any reflections in these data, it is necessary to perform a CDP stack. The spread for these experiments was so short that moveout velocities were not critical; but a proper velocity analysis was performed nevertheless, and Figure 26 shows the stack of the ‘Vibroseis only’ control survey, while Figure 27 shows the stack of the ‘dynamite only’ control survey. While there are flat events between 600 ms and 900 ms that could possibly be reflections, this is doubtful, since reflections in this area are known to exhibit a dip to the east, and the most prominent reflections known to exist in the area, at about 250 ms and 450 ms, are either fragmentary or missing entirely from these records, probably due to low fold and low source energy. For comparison, Figures 28, 29, and 30 show the CDP stacks for the pump-probe experiments at 20 Hz, 60 Hz, and 100 Hz, respectively. Any differences between any of these stacks are difficult to see, and probably insignificant.

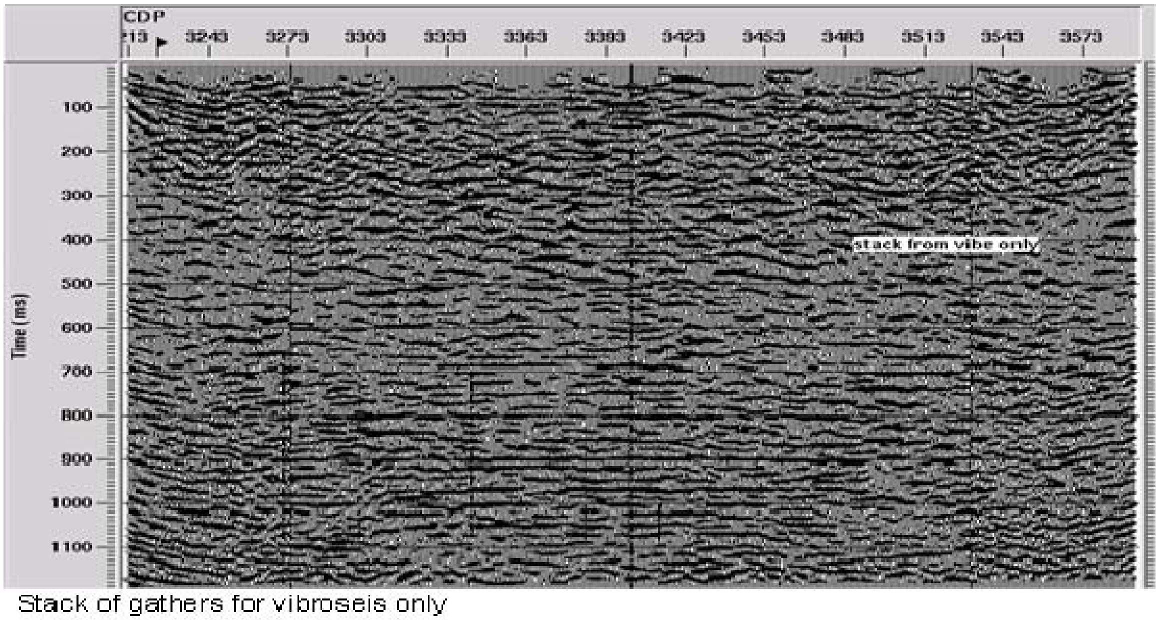


FIG. 26. CDP stack of the ‘Vibroseis only’ gathers. Coherent events between 600 ms and 900 ms may not be reflections, since we can’t reliably see known dipping reflections at 250 ms and 450 ms.

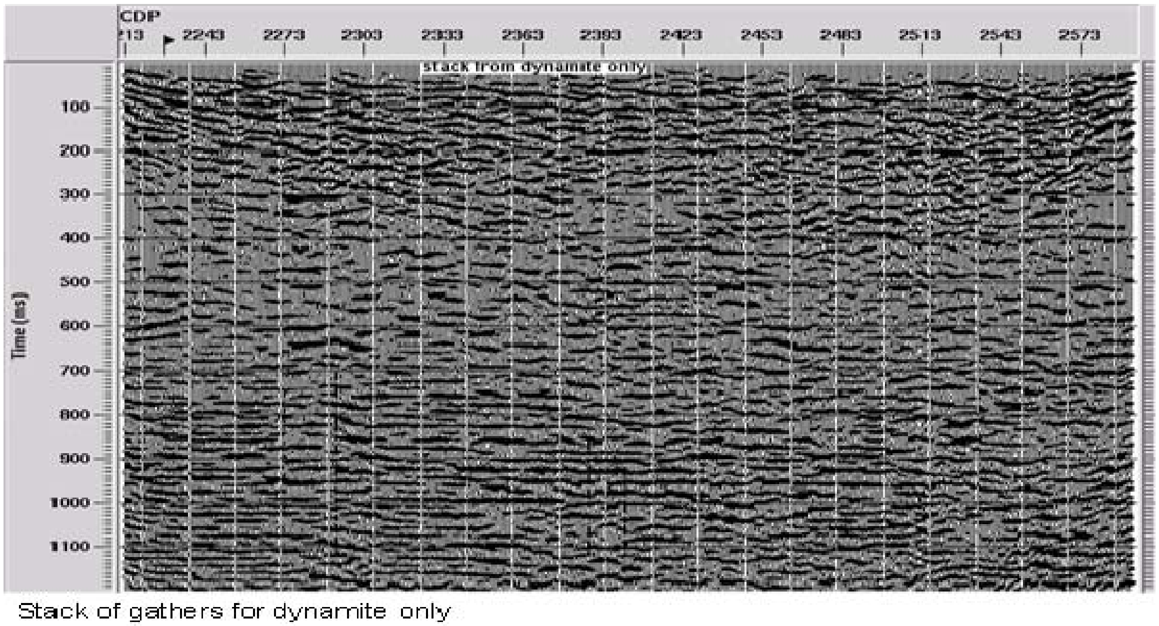


FIG. 27. CDP stack of 'dynamite only' gathers. Flat, coherent events between 600 ms and 900 ms may not be reflections, since known dipping shallow reflections are not seen on this stack.

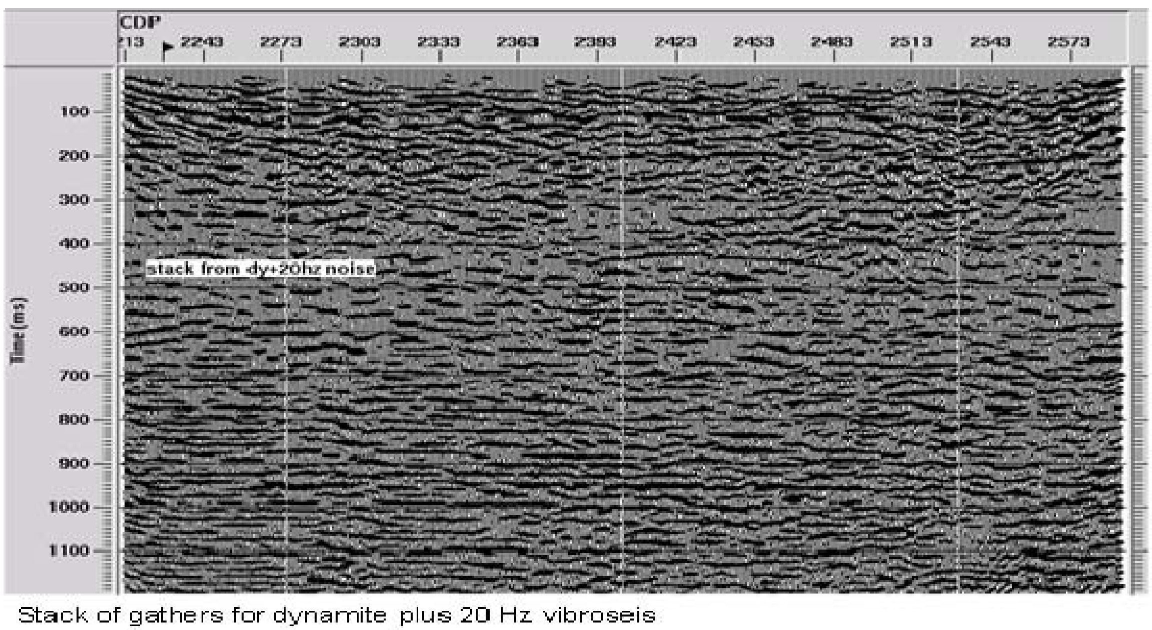


FIG. 28. CDP stack of 20 Hz pump-probe survey. Compare this with Figure 27 for any significant differences.

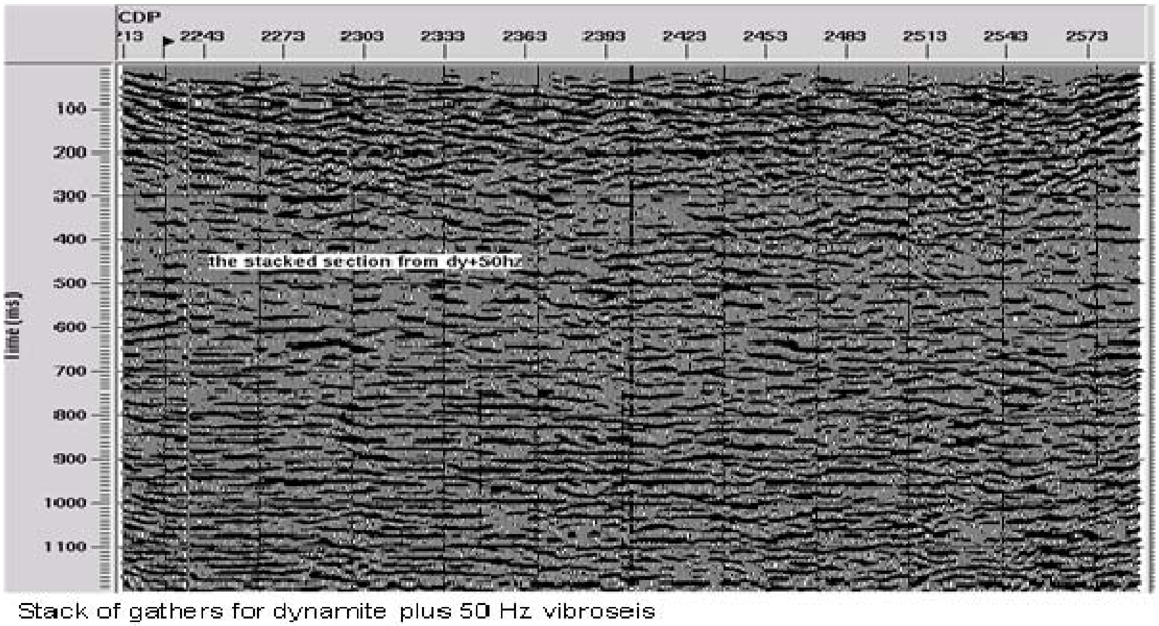


FIG. 29. CDP stack of 50 Hz pump-probe survey. Compare this with Figure 27 for any significant differences.

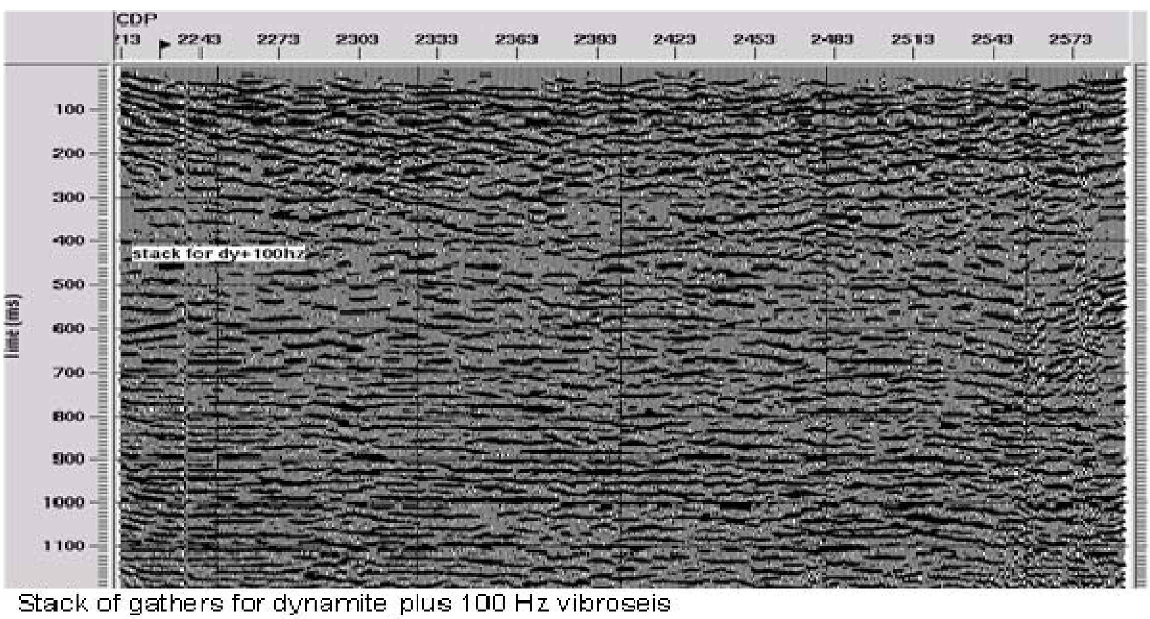


FIG. 30. CDP stack of 100 Hz pump-probe survey. Compare this with Figure 27 for any significant differences.

Dave Henley's results

A slightly different approach was taken by Dave Henley for processing and analyzing these data. Since one of the key preparation tasks for the actual pump-probe survey data is the removal of the monochromatic Vibroseis signal from the raw records, a non-linear spectral editing operation called 'spectral clipping' (Henley, 2001) was applied to the gathers from the three pump-probe surveys. This operation transforms seismic traces to the Fourier domain, locates all narrow spectral peaks which protrude more than 12 dB above the local median spectral value and replaces the peak amplitudes with their corresponding median values, while leaving the phase unchanged. Since the algorithm searches the whole of each trace spectrum independently, it is not necessary to specify target frequencies…the procedure finds them automatically. The operation is slightly more efficient if a data trace has been processed with AGC prior to spectral clipping.

The next processing step applied to all five data sets, after spectral clipping application to the pump-probe surveys, was coherent noise attenuation. Radial trace filtering (Henley, 2002) was applied to all gathers to remove all visible coherent noise; and the same filter set was used for all gathers of all five surveys.

Prior to CDP stacking the gathers, Gabor deconvolution was applied, in the single trace mode, to whiten the trace spectra. An examination of the gathers after filtering and deconvolution revealed no obvious reflections for any of the five surveys, except for a couple of very shallow events at less than 100 ms, which may well be primarily refraction events, due to the very restricted geometry of the experiment. When analyzing the gathers for moveout velocity, it appeared that these shallow events aligned equally well with either normal moveout (NMO) or linear moveout (LMO) of about 2000 m/s. Hence, we prepared *two* CDP stacks for each survey, one with NMO applied, the other with LMO applied. We refer to these displays as ‘backscatter images’ rather than reflection images, since the events we image likely consist of both reflection and refraction energy from shallow layers.

At the risk of being redundant, we show again some comparisons of raw and processed records for each of the five surveys, albeit for a different shot point. Figure 31 is a typical raw gather for the ‘Vibroseis only’ survey, and Figure 32 is its filtered and deconvolved version. Figure 33 is the raw ‘dynamite only’ record, and Figure 34 is its filtered and deconvolved version. There are no readily apparent reflections on the ‘Vibroseis only’ shot, even though we can see some fragmentary reflection-like events deeper in the ‘dynamite only’ record.

We show the effect of the additional step of spectral clipping for each of the three pump-probe surveys. Figure 35 is a typical raw record for the dynamite plus 20 Hz Vibroseis survey, while Figure 36 shows the same record after spectral clipping, and Figure 37 shows the further result of radial trace filtering and Gabor deconvolution. Figures 38, 39, and 40 are the corresponding displays for the 50 Hz pump-probe survey, while Figures 41, 42, and 43 show results for the 100 Hz pump-probe experiment.

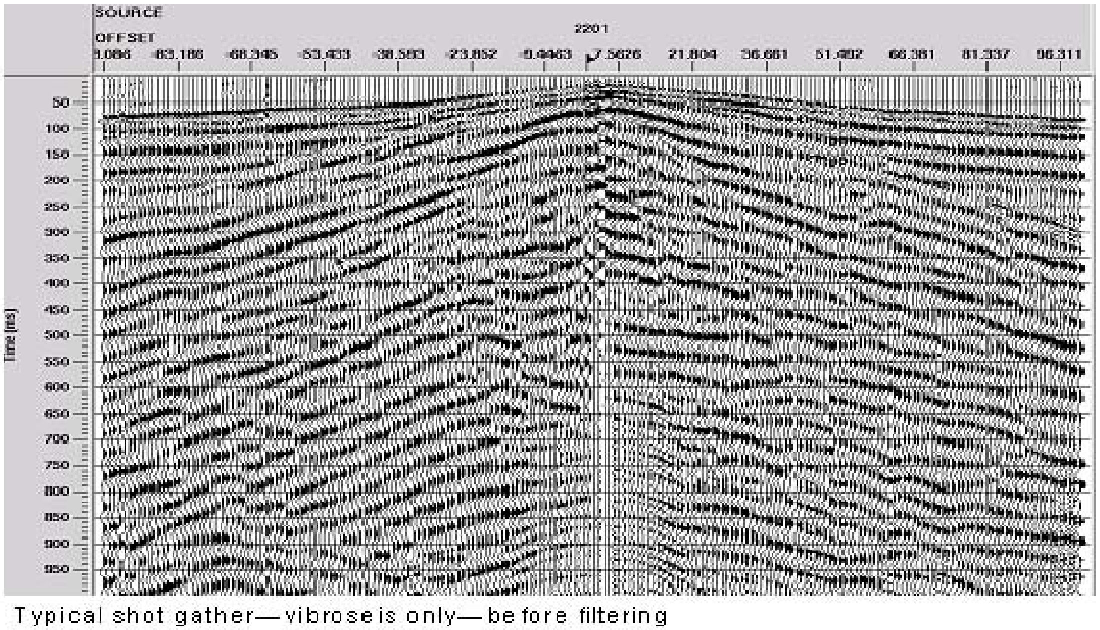


FIG. 31. Typical gather for 'Vibroseis only' survey with no filtering applied

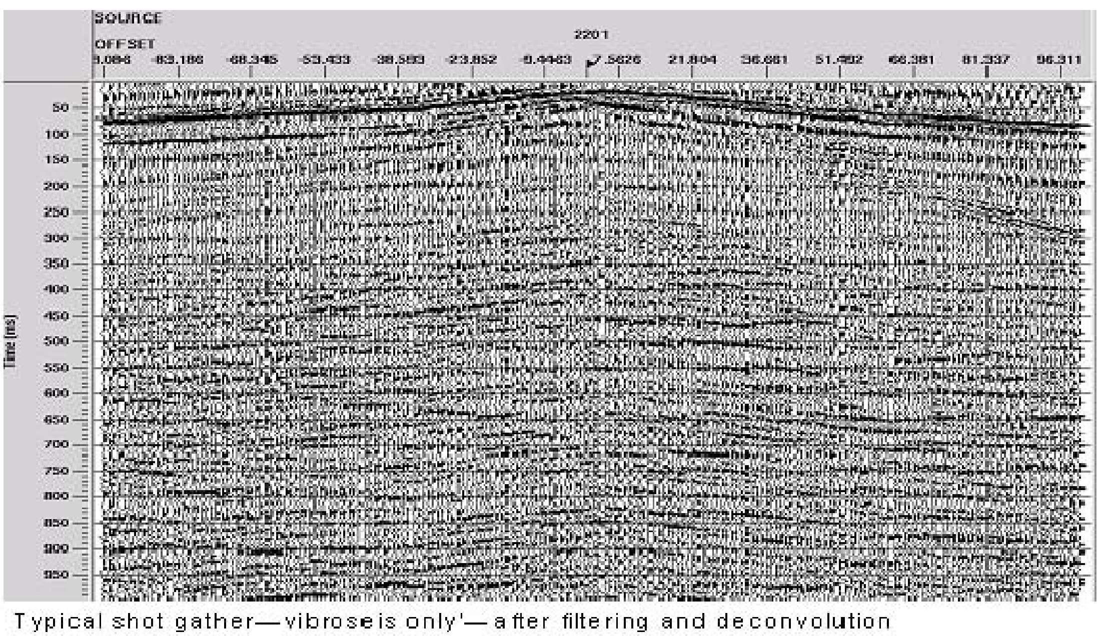


FIG. 32. Shot gather from Figure 31 after radial filtering and Gabor deconvolution. No reflections are readily apparent.

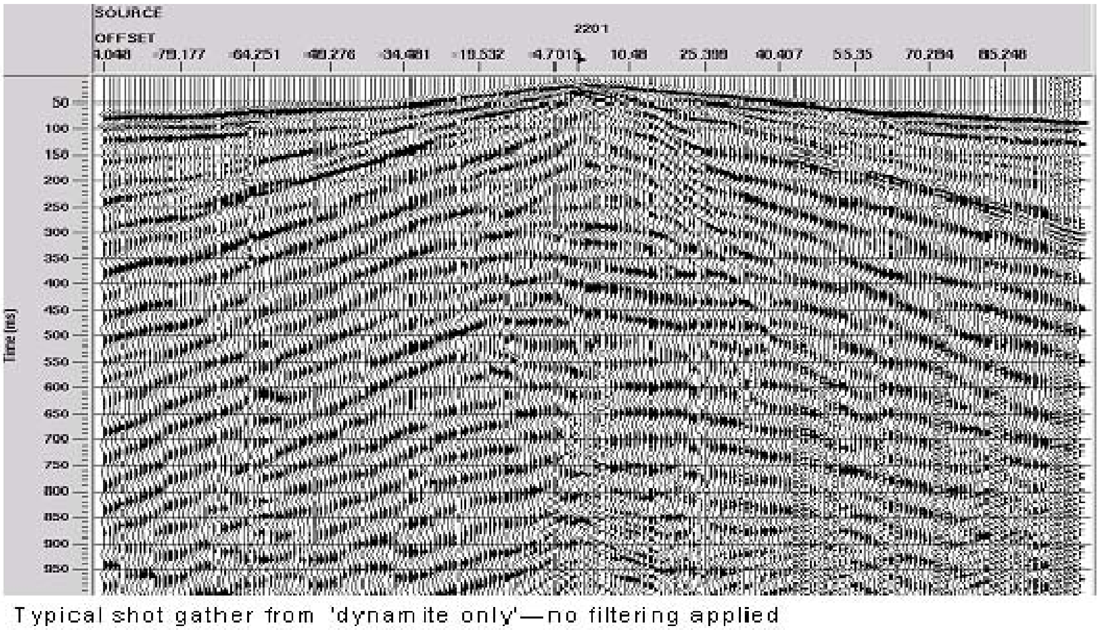


FIG. 33. Typical shot gather from ‘dynamite only’ survey with no filtering applied.

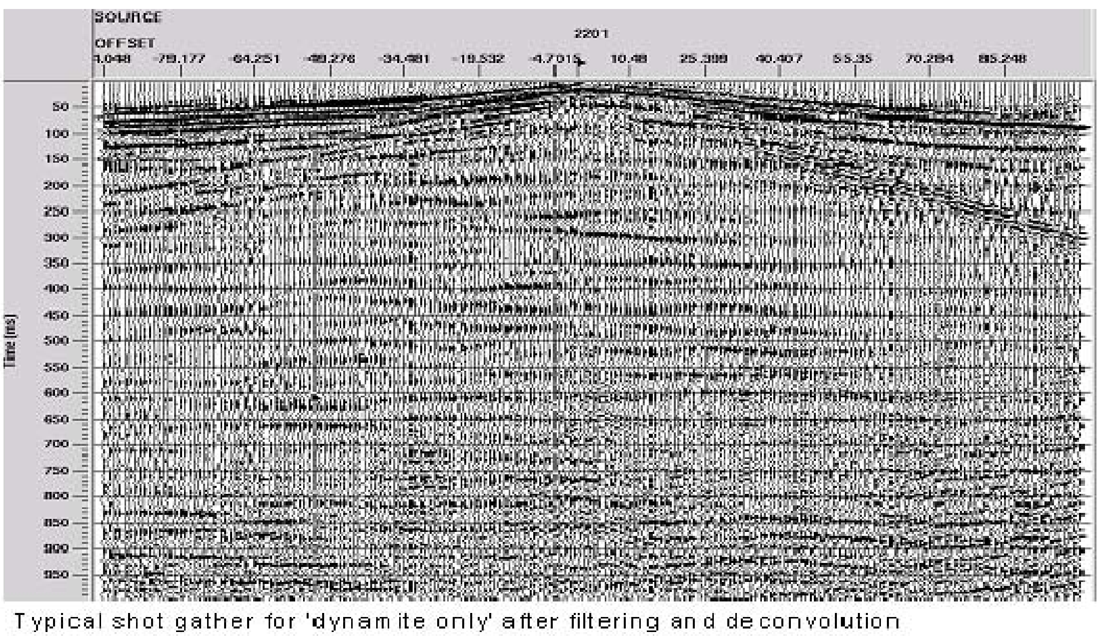


FIG. 34. Shot gather from Figure 33 after radial trace filtering and Gabor deconvolution. Horizontal reflection-like events may not be real.

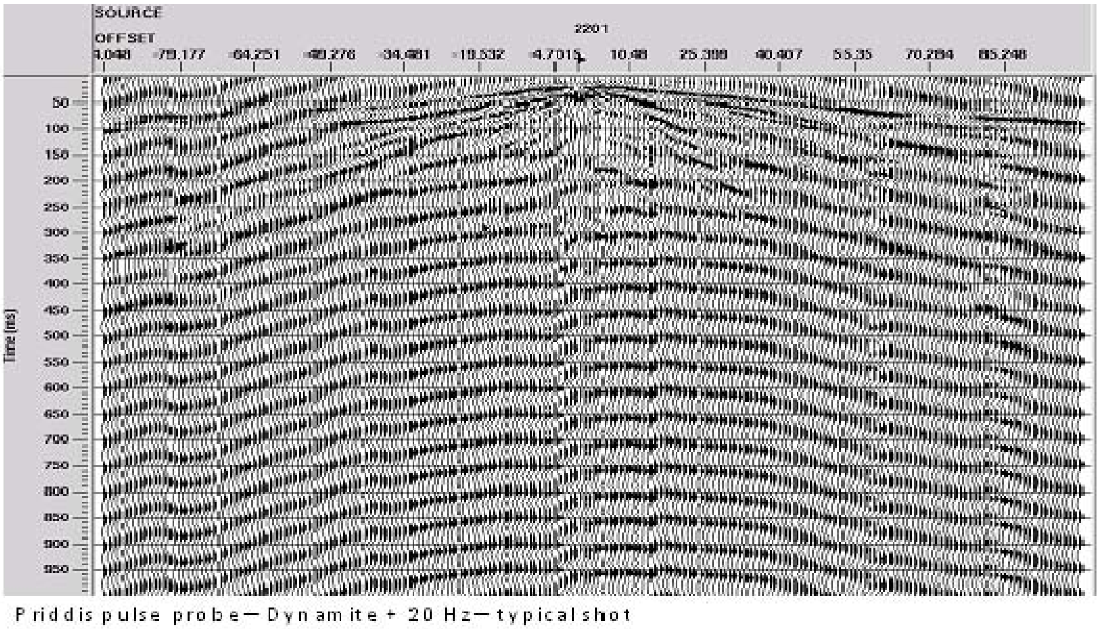


FIG. 35. Typical shot gather for 20 Hz pump-probe survey. Vibroseis signal dominates the record.

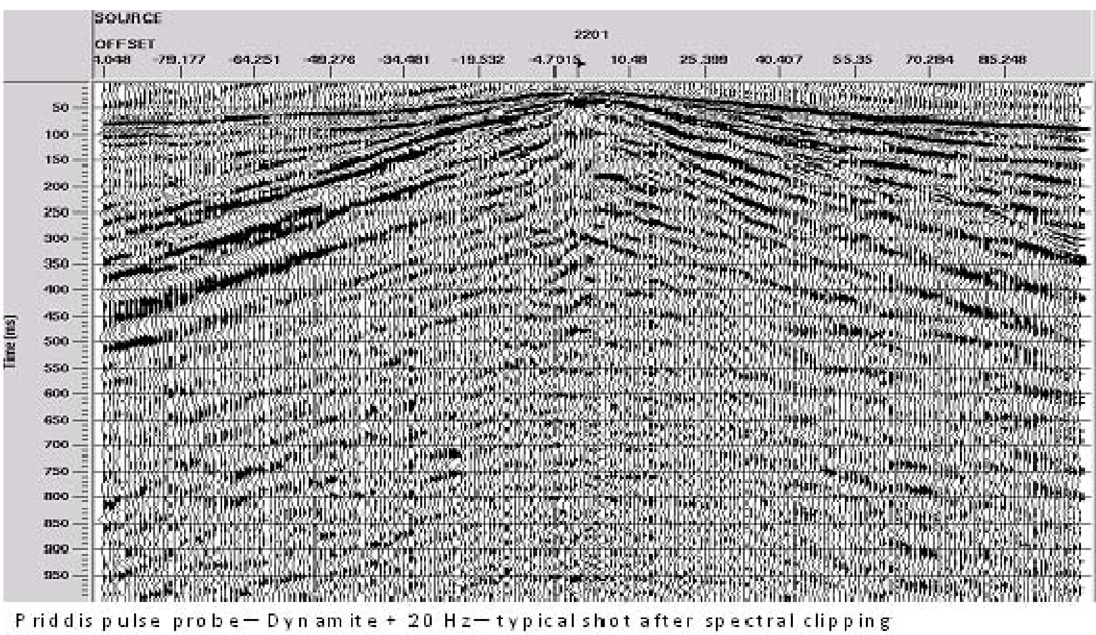


FIG. 36. Shot gather of Figure 35 after spectral clipping.

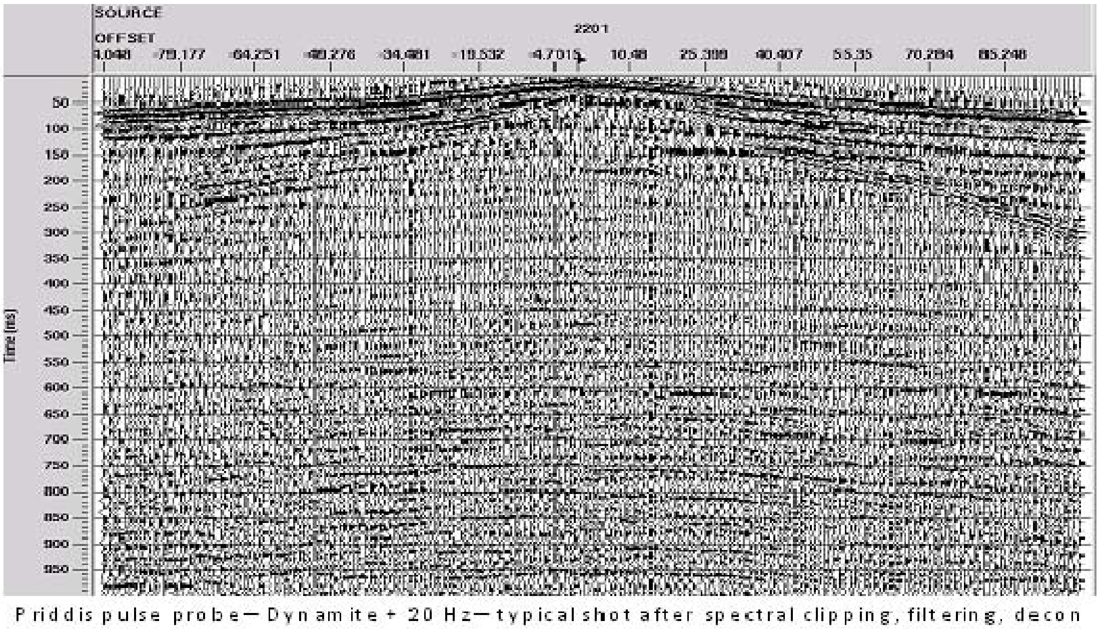


FIG. 37. Shot gather of Figure 36 after radial trace filtering and Gabor deconvolution.

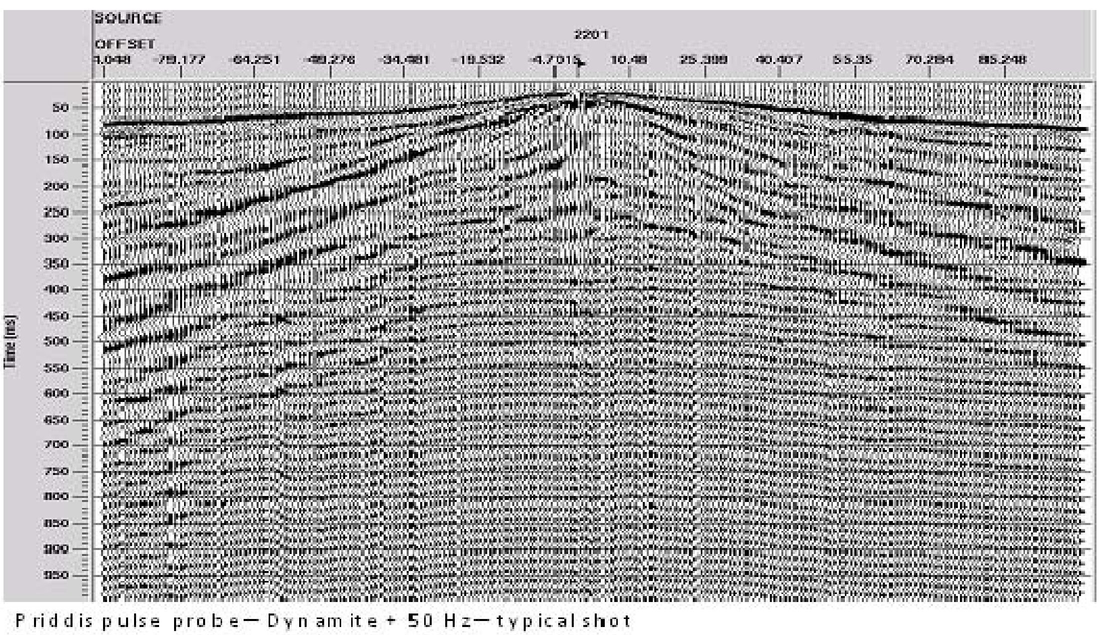


FIG. 38. Typical shot gather for 50 Hz pump-probe survey. 50 Hz Vibroseis signal dominates record.

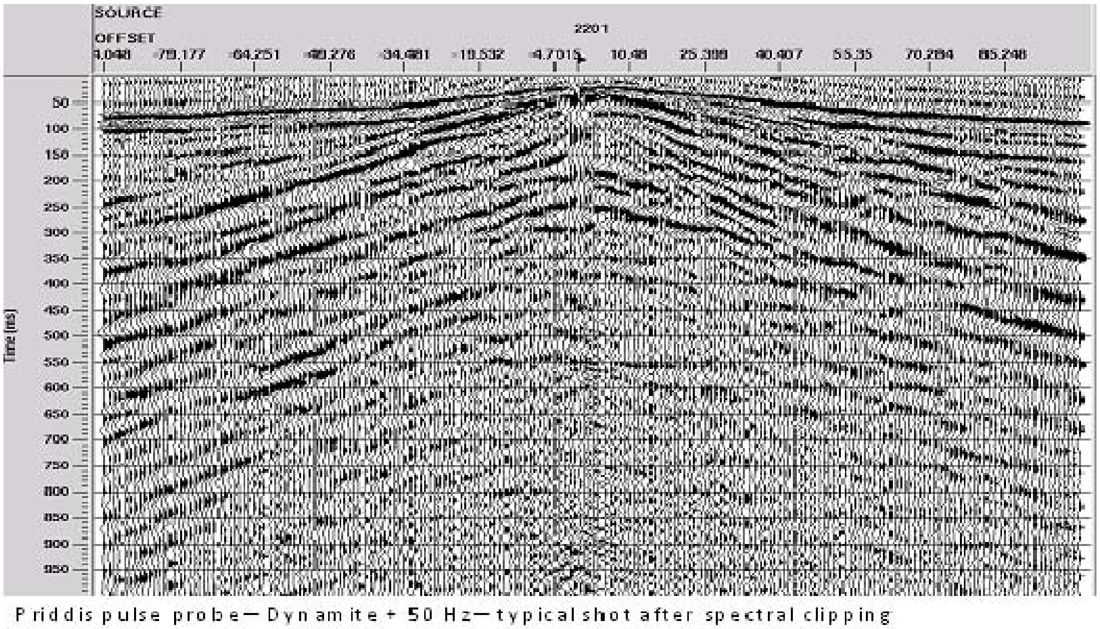


FIG. 39. Shot gather of Figure 38 after spectral clipping.

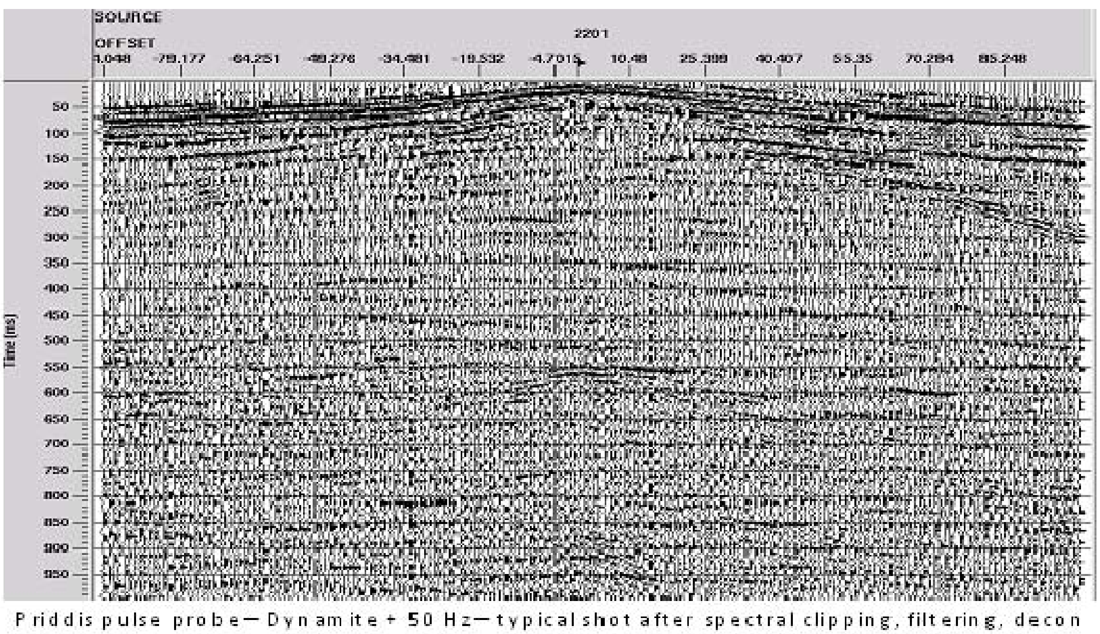


FIG. 40. Shot gather of Figure 39 after radial trace filtering and Gabor deconvolution.

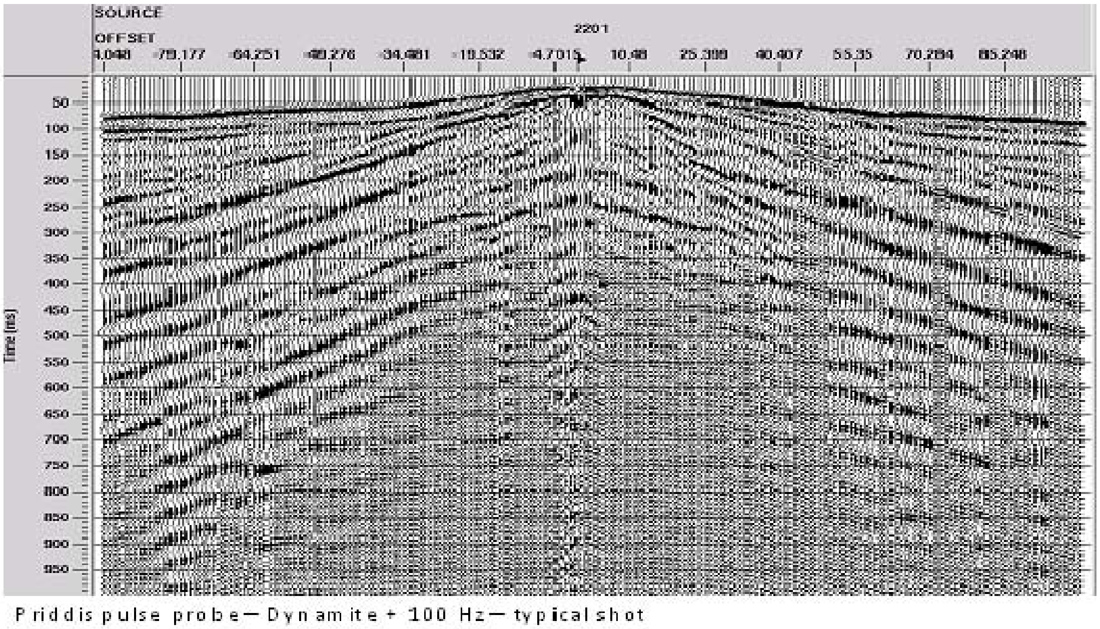


FIG. 41. Typical shot gather from 100 Hz pump-probe survey. 100 Hz Vibroseis signal is strong, but not dominant.

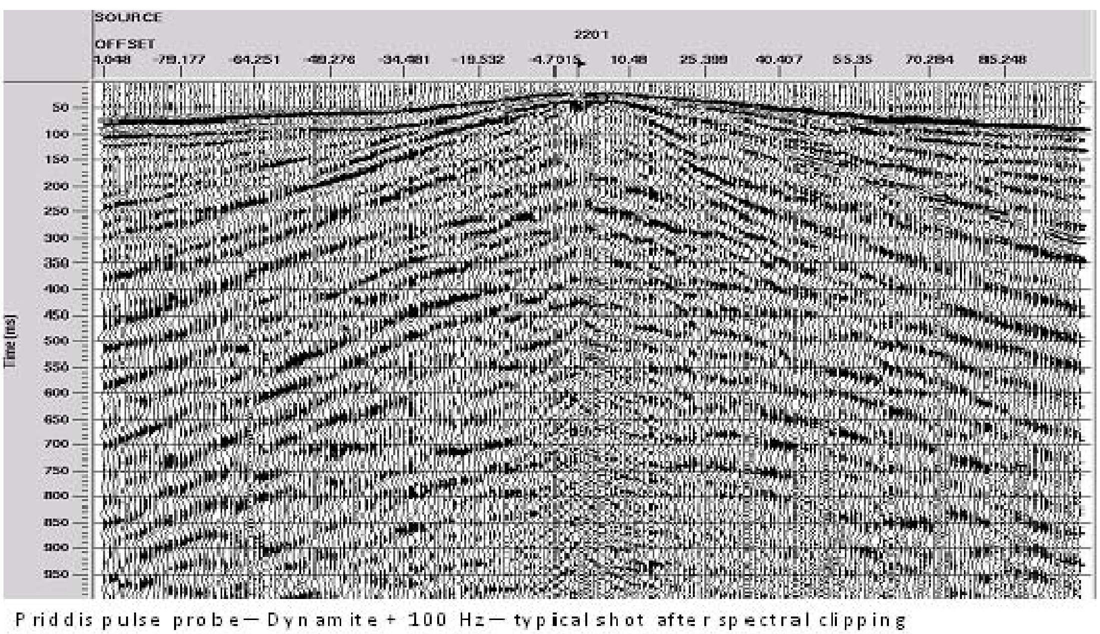


FIG. 42. Shot gather from Figure 41 after spectral clipping.

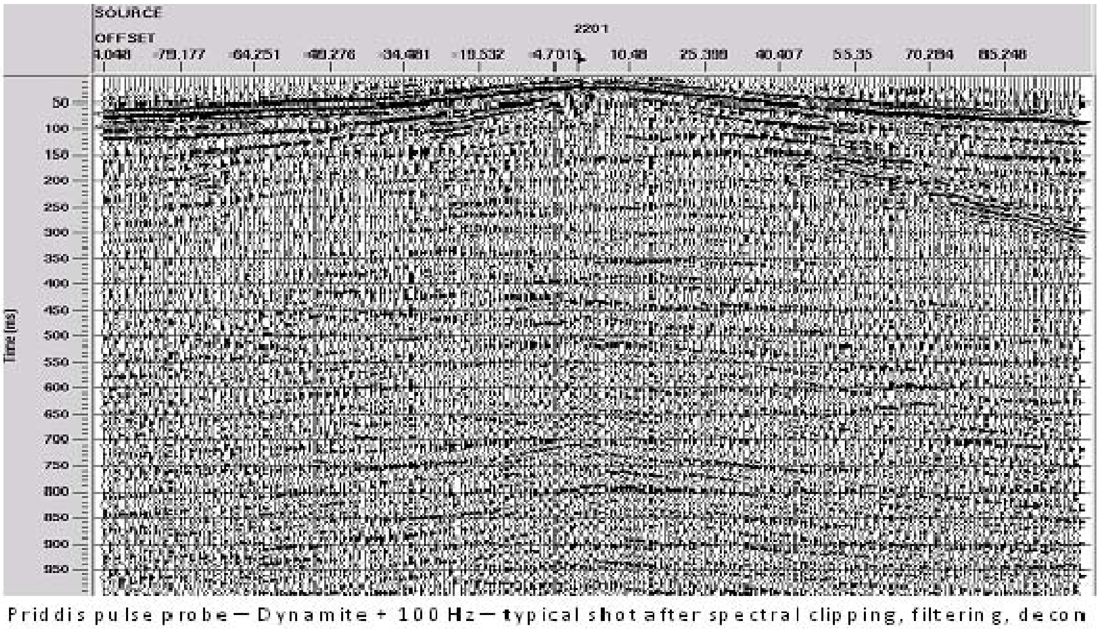


FIG. 43. Shot gather from Figure 42 after radial trace filtering and Gabor deconvolution.

The following figures show CDP stacks of the shallow portion (down to 500 ms) of the five surveys. To make them more readily comparable, we show in order first the CDP stacks after NMO correction, then the CDP stacks after LMO correction. Hence, Figures 44, 45, 46, 47, and 48, are the NMO corrected CDP stacks of the 'vibroseis only', 'dynamite only', 20 Hz pump-probe, 50 Hz pump-probe, and 100 Hz pump-probe surveys, respectively. We found that reversing the polarity of the dynamite surveys with respect to the 'vibroseis only' gave a somewhat better match of the images.

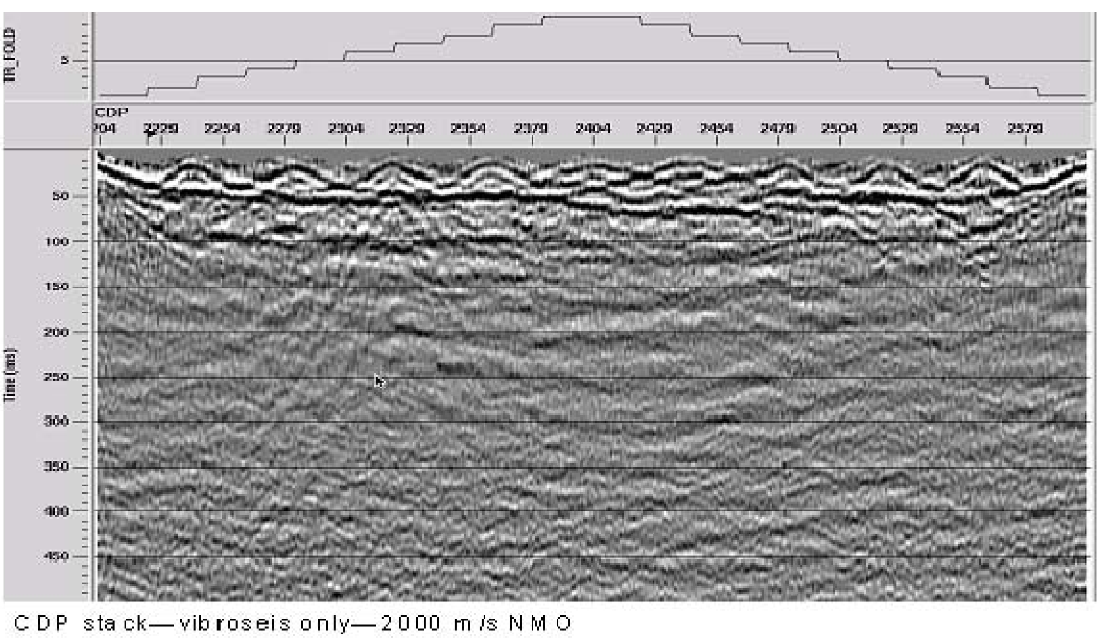


FIG. 44. CDP stack of 'Vibroseis only' survey with 2000 m/s NMO applied to shot gathers.

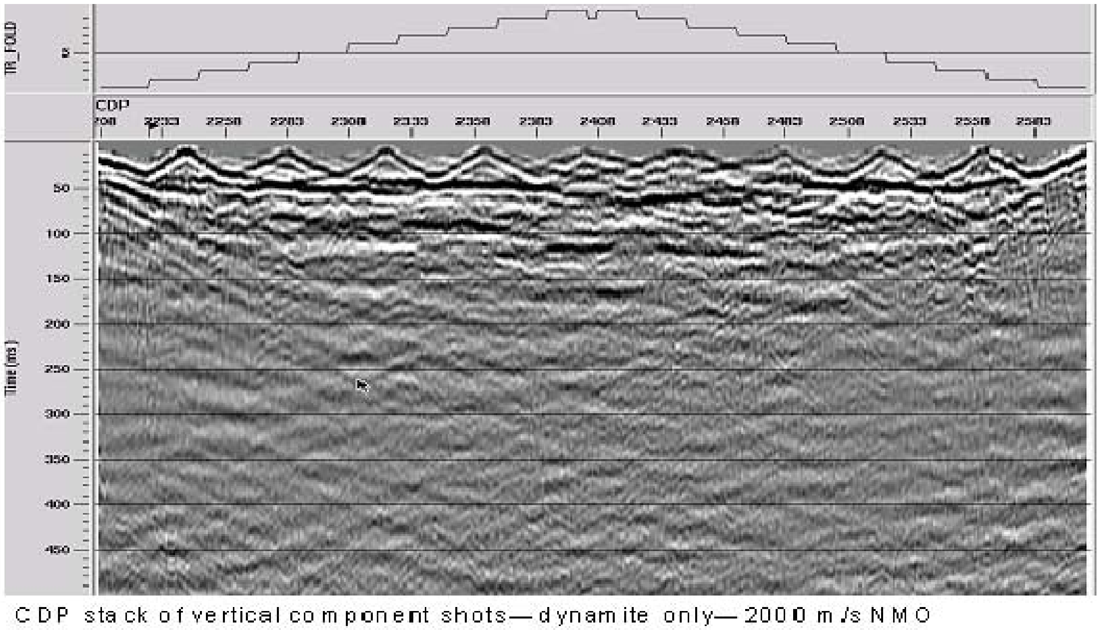


FIG. 45. CDP stack of ‘dynamite only’ survey with 2000 m/s NMO applied to shot gathers.

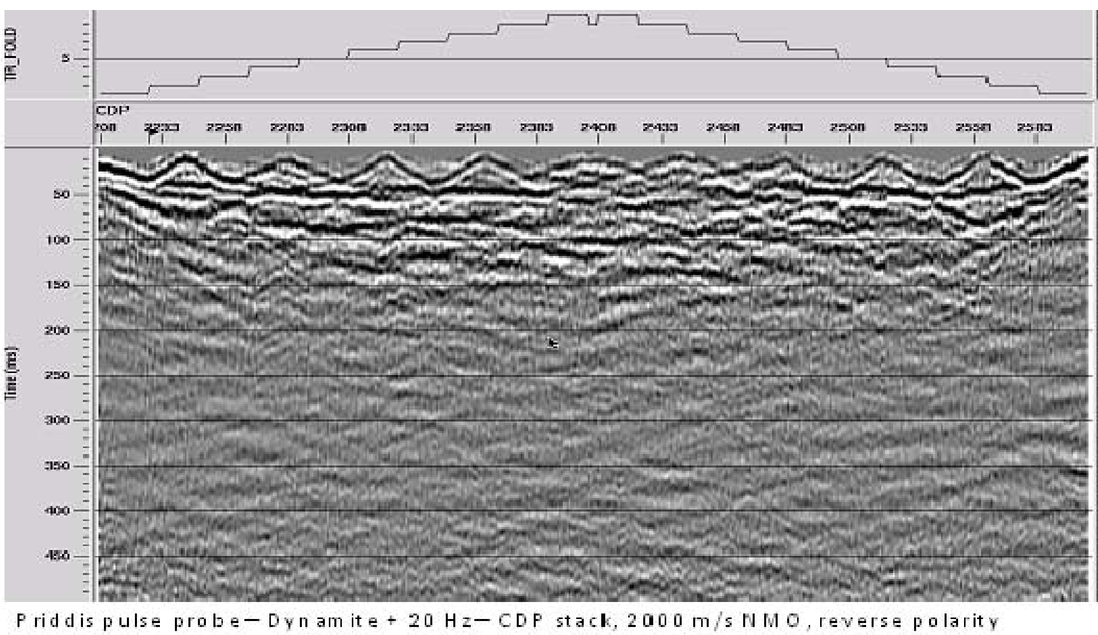


FIG. 46. CDP stack of 20 Hz pump-probe survey with 2000 m/s NMO applied to shot gathers.

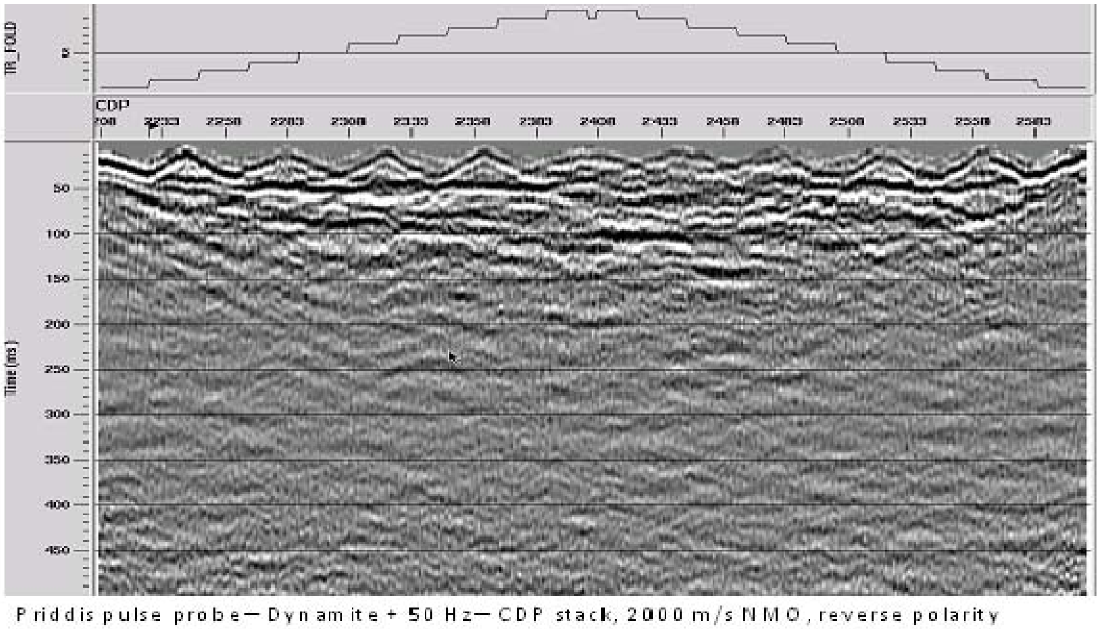


FIG. 47. CDP stack of 50 Hz pump-probe survey with 2000 m/s NMO applied to shot gathers.

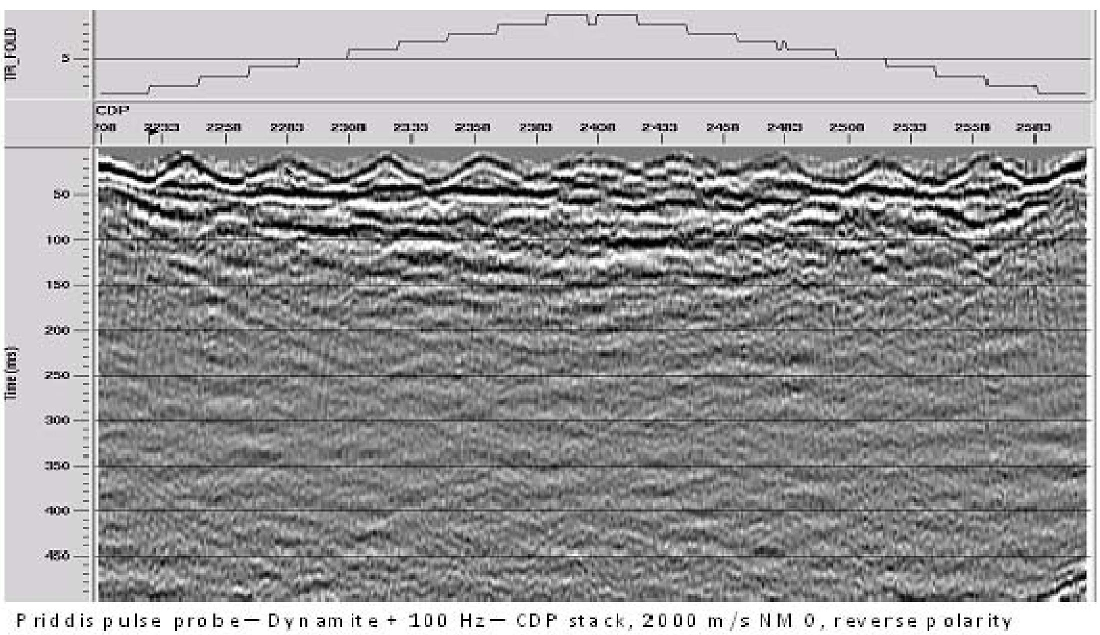


FIG. 48. CDP stack of 100 Hz pump-probe survey with 2000 m/s NMO applied to shot gathers.

While a close comparative examination of these figures shows some differences, we see nothing very compelling in any of these differences, particularly since they have no apparent lateral continuity.

Figures 49, 50, 51, 52, and 53 compare the CDP stacks of the same surveys, but this time after 2000 m/s LMO correction, to focus on refraction energy instead of reflections.

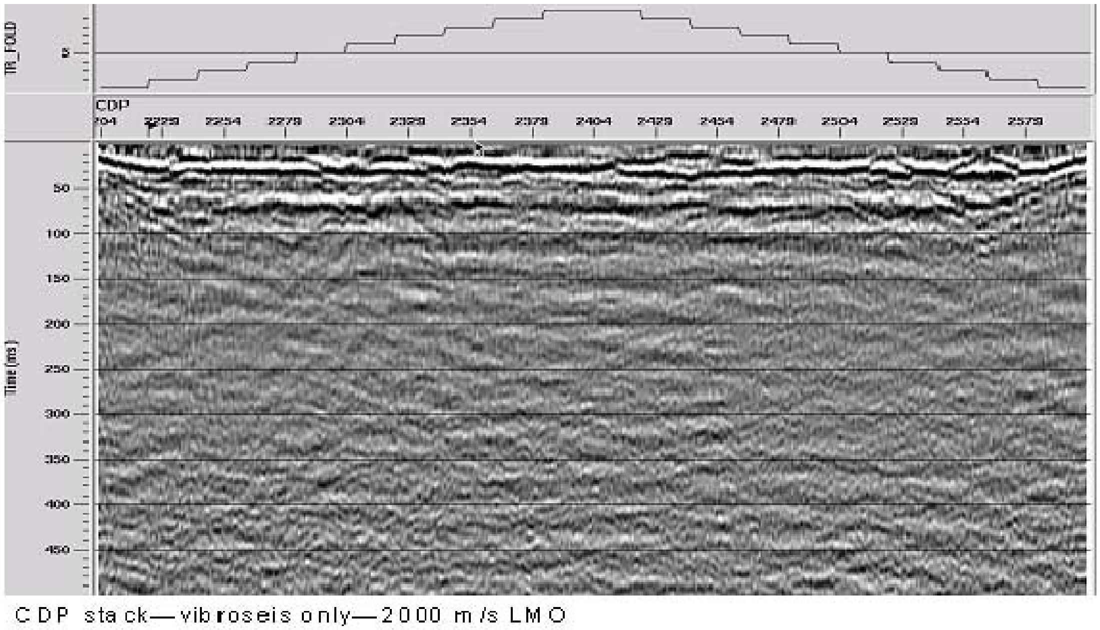


FIG. 49. CDP stack of 'vibroseis only' survey with 2000 m/s LMO applied to shot gathers.

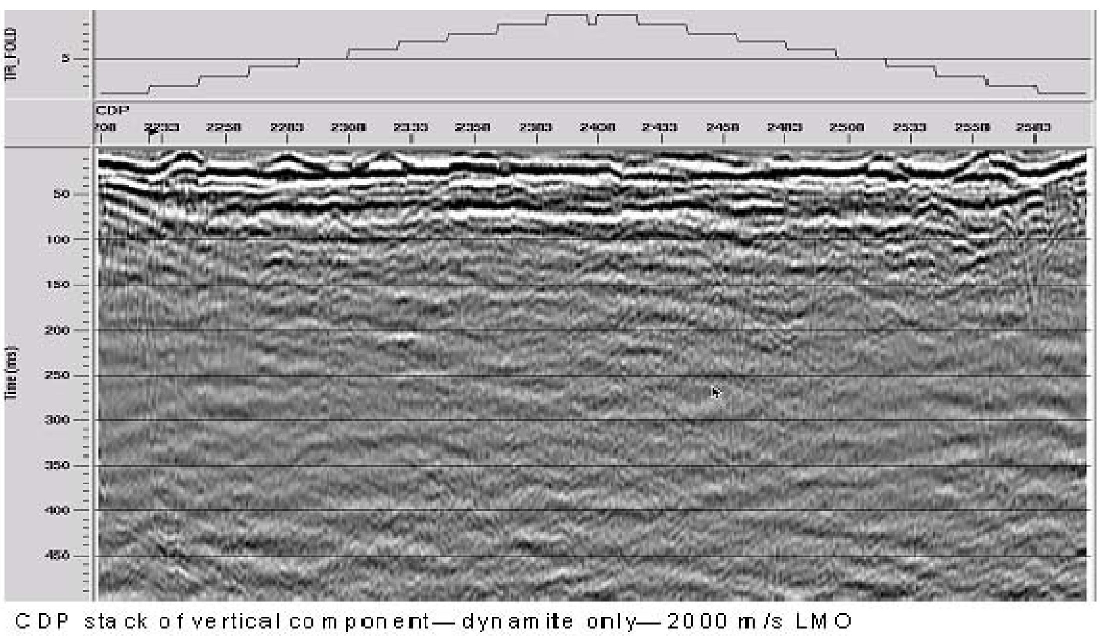


FIG. 50. CDP stack of 'dynamite only' survey with 2000 m/s LMO applied to shot gathers.

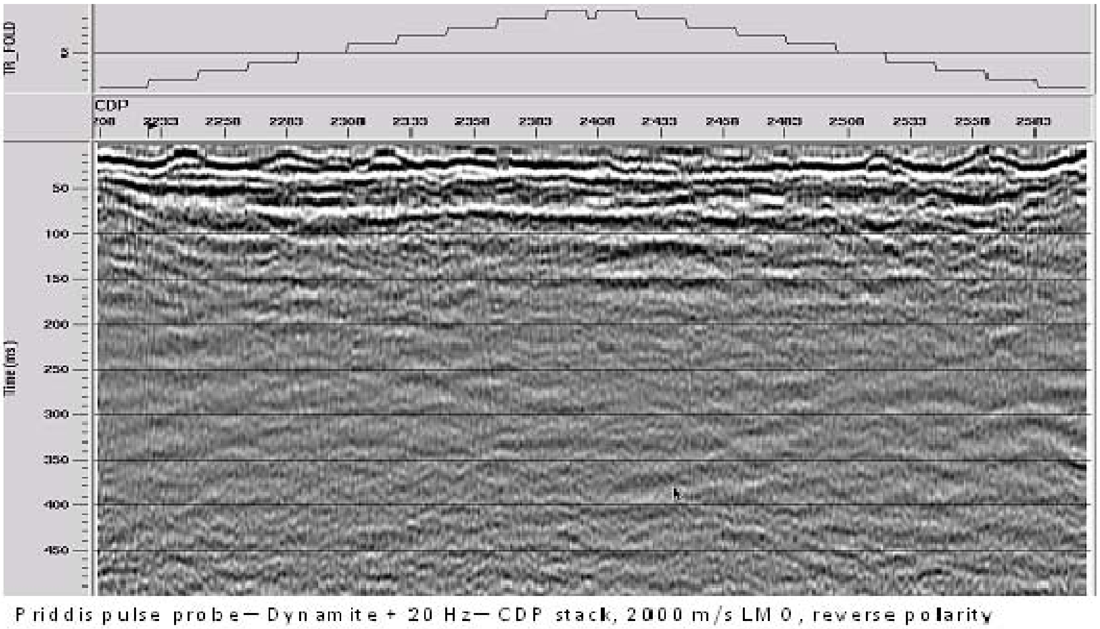


FIG. 51. CDP stack of 20 Hz pump-probe survey with 2000 m/s LMO applied to shot gathers.

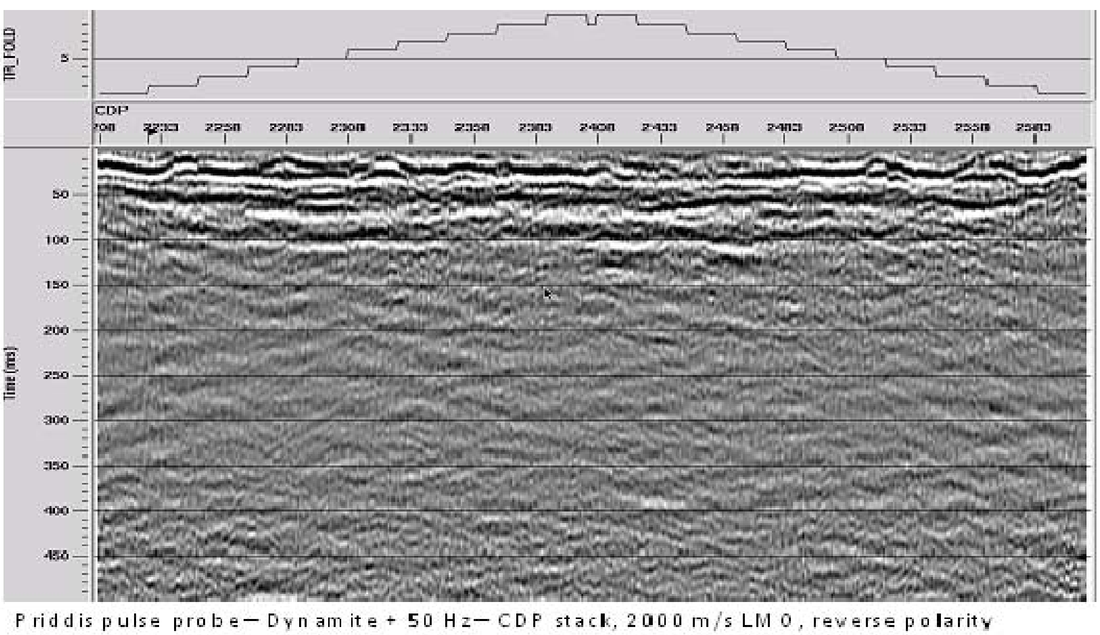


FIG. 52. CDP stack of 50 Hz pump-probe survey with 2000 m/s LMO applied to shot gathers.

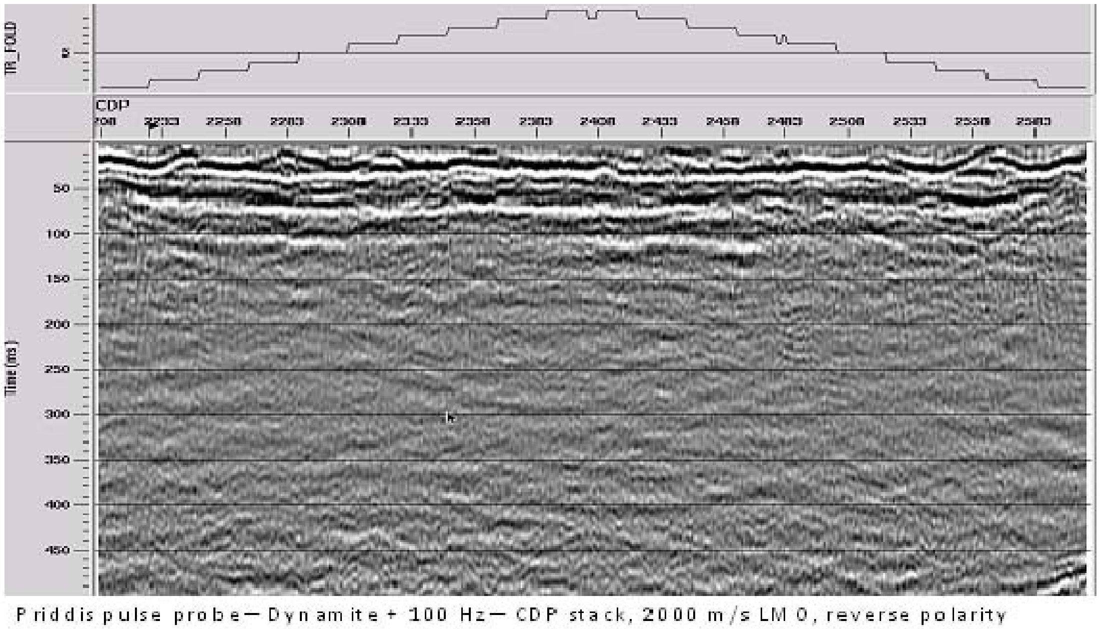


FIG. 53. CDP stack of 100 Hz pump-probe survey with 2000 m/s LMO applied to shot gathers.

Most of the coherent energy imaged in the preceding figures is almost certainly refraction energy, so our analysis of these results is somewhat uncertain and incomplete. We intend to revisit these data in the coming months, with other analysis approaches. Although these vertical component results are ambiguous, we show here two further images, in Figures 54 and 55, which are the CDP stacks of the radial and transverse components of the 'dynamite only' survey, corrected for 2000 m/s LMO. Since there is even less coherence in the shallow events on these two Figures than on the corresponding ones for the vertical component, we conclude that processing and analyzing the horizontal components of these surveys looks 'unpromising' at best.

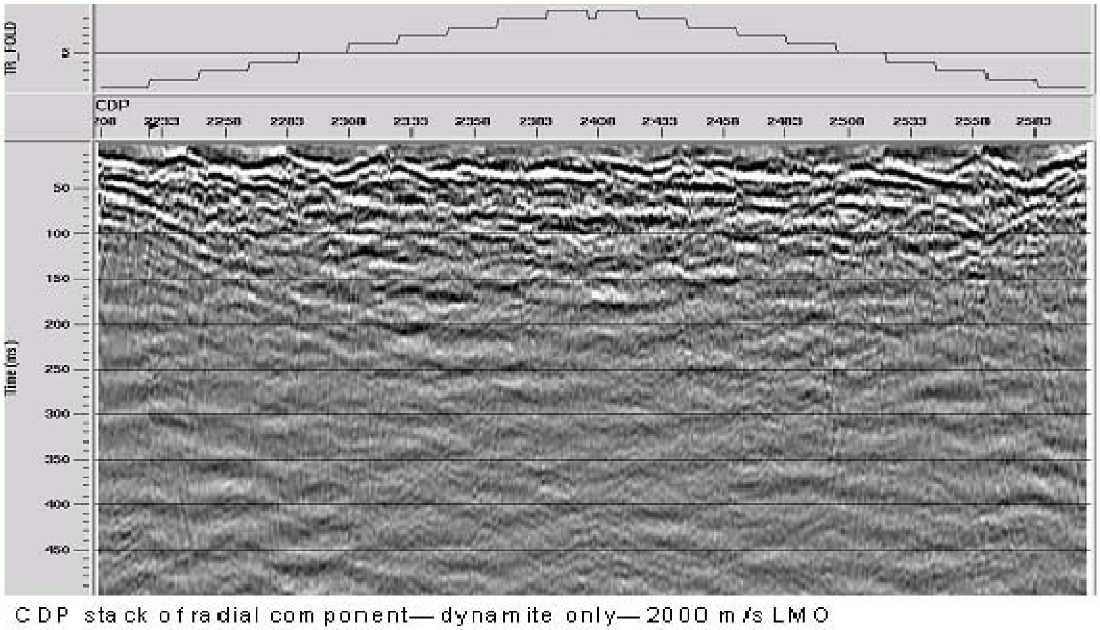


FIG. 54. CDP stack of radial component of ‘dynamite only’ survey with 2000 m/s LMO applied to shot gathers.

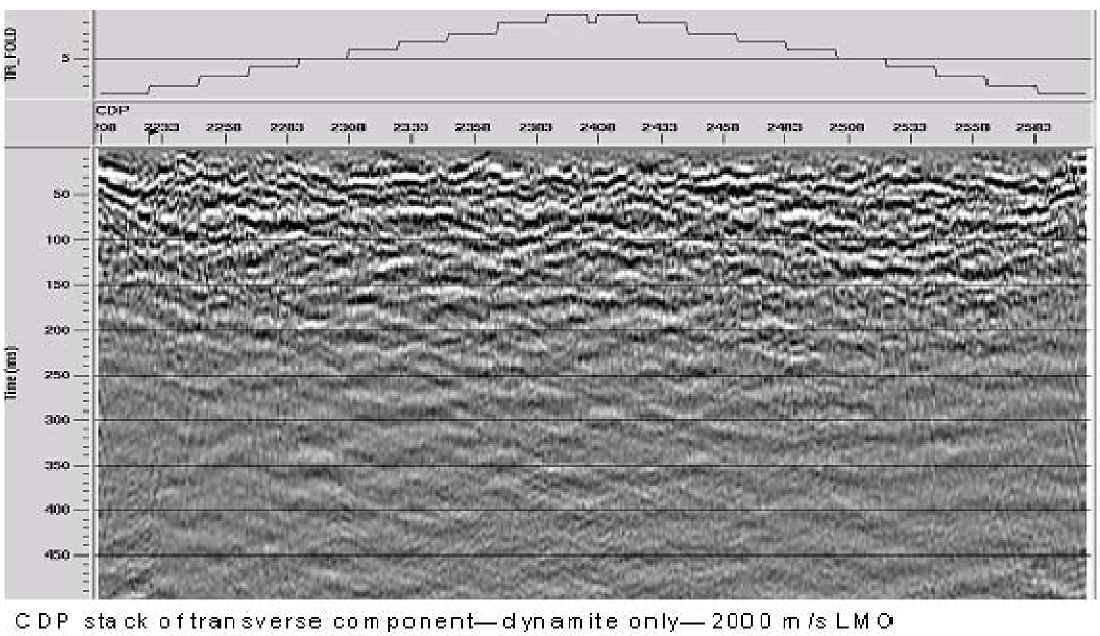


FIG. 55. CDP stack of transverse component of ‘dynamite only’ survey with 2000 m/s LMO applied to shot gathers.

Future efforts

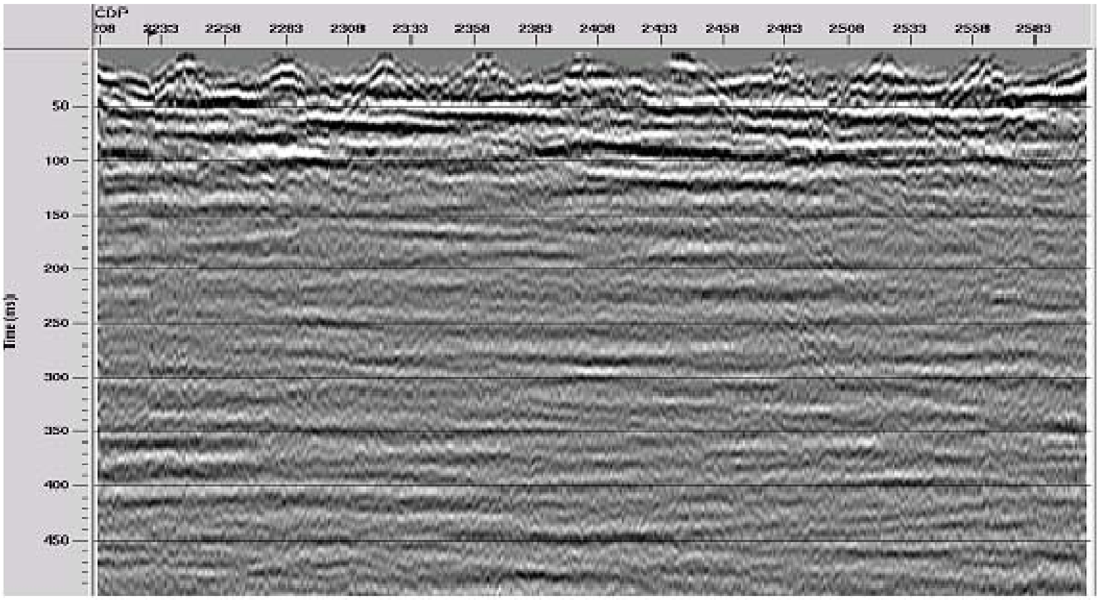
Given the nature of this experiment and the subtle results expected, there are a number of approaches we plan to try for further analysis of the data. One possible approach is to implement a least-squares subtraction algorithm, to enable us to compare shot gathers and stacked sections by computing difference panels between the ‘dynamite only’ and various ‘pump-probe’ surveys. Another possibility is to attempt to remove the slight differences in the dynamite impulse responses between comparable shots on the different surveys, using a match filter technique of some kind. This would ensure that any differences observed are due only to changes in the formation, not to differences between two dynamite shots in the same hole (repeatability is always a problem with dynamite, even with small charges and cased, reloadable holes).

LAST MINUTE RESULTS

Our ideas about the analysis and processing of these data are continuously evolving, and we attempt to test them as possible. One idea which was very recently tried by Dave Henley was to specifically target and attenuate the refraction events evident on the previously processed gathers from each of the surveys, then to refine NMO velocities for the shallowest 100 ms of the records, and to CDP stack each of the surveys for comparison. One of the features of radial trace filtering is its ability to reveal very shallow reflections by attenuating interfering refractions whose linear moveout is very similar to the NMO of the reflections. Hence, we constructed a new, harsher set of radial trace filters to apply to the raw seismic records after spectral clipping. The application of these filters revealed underlying events whose moveout appeared to be reflection-like. This enabled us to estimate NMO velocities more carefully and to construct new CDP stacks of all the surveys.

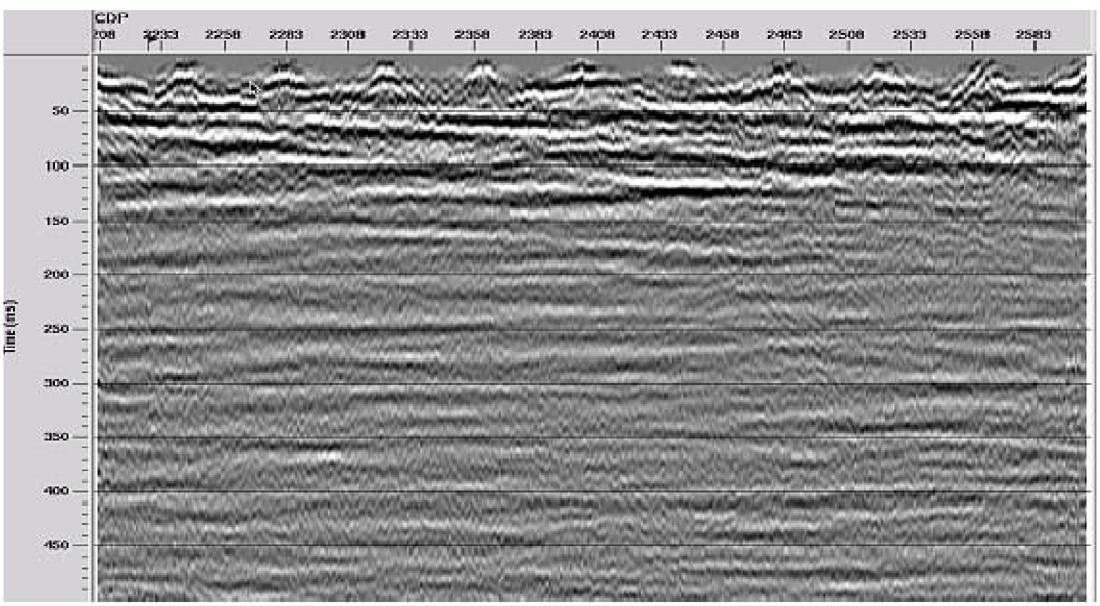
Figure 56 shows the new CDP stack for the ‘dynamite only’ survey, and Figures 57, 58, and 59 show the comparable stacks for the 20 Hz, 50 Hz, and 100 Hz pulse-probe surveys, respectively. There are obviously similarities and differences between features on these surveys. Because the processing of each survey was absolutely identical, we conclude that at least some of the apparent differences must be due to source repeatability issues for the dynamite shots.

Figure 60 results from subtracting the section in Figure 56 from that in Figure 59. This was a simple arithmetic subtraction, and we make no attempt at this point to interpret the resulting image. Ongoing research will attempt to refine these results and to try new ideas for highlighting significant differences between the surveys.



Dynamite only—refractions attenuated

FIG. 56. CDP stack for 'dynamite only' survey after attenuation of near-surface refraction events.



Dynamite plus 20 Hz—refractions attenuated

FIG. 57. CDP stack for 'dynamite plus 20 Hz' pump-probe survey after attenuation of near-surface refraction events.

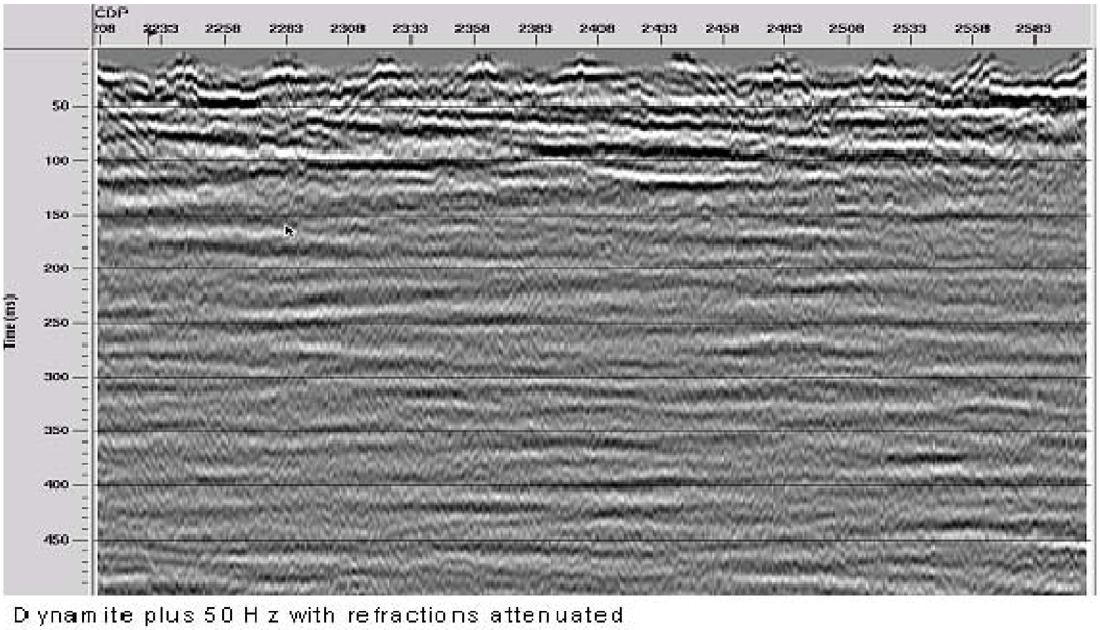


FIG. 58. CDP stack of ‘dynamite plus 50 Hz’ pump-probe survey after attenuation of near-surface refraction events.

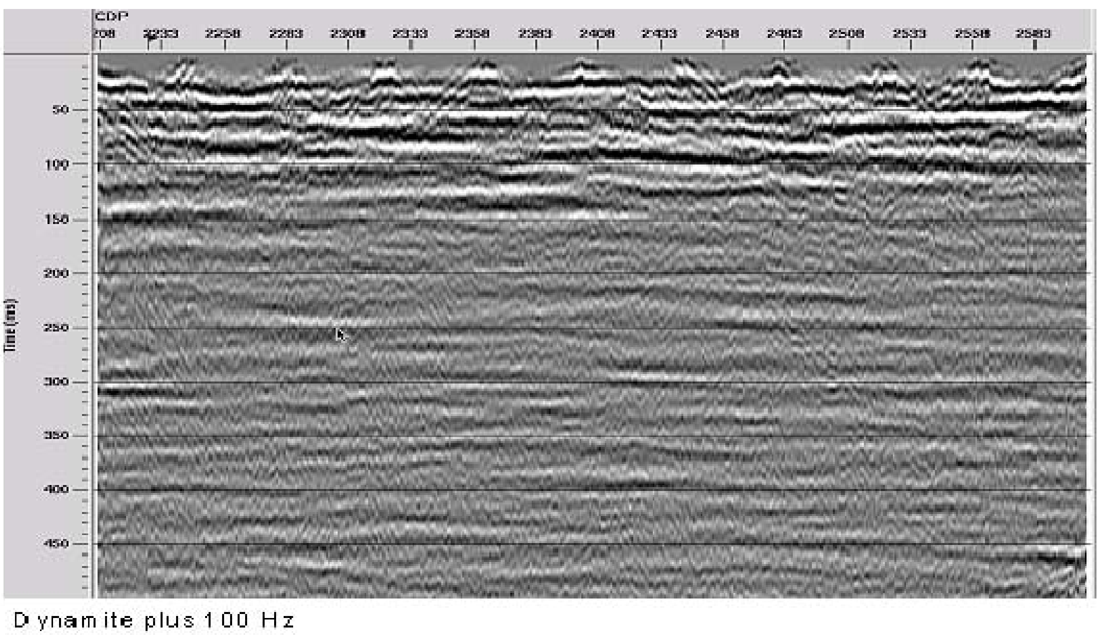
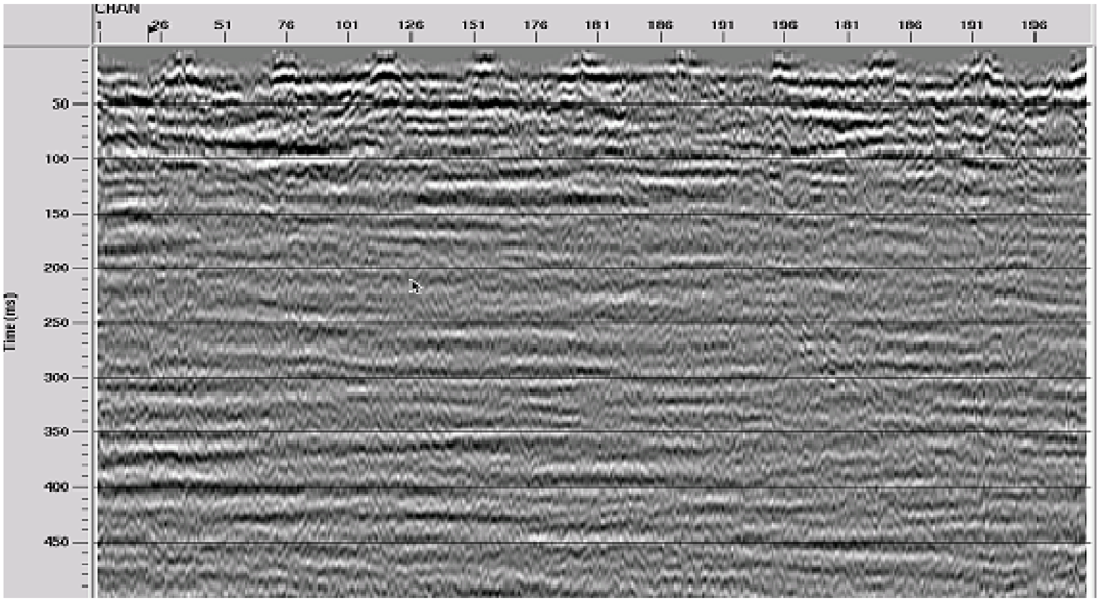


FIG. 59. CDP stack of ‘dynamite plus 100 Hz’ pulse-probe survey after attenuation of near-surface refraction events.



Dynamite plus 100 Hz minus dynamite only

FIG. 60 CDP stack of ‘dynamite plus 100 Hz’ pulse-probe survey minus CDP stack of ‘dynamite only’ survey

CONCLUSIONS

The only conclusions warranted for this experiment at this time are that we can see an event on some individual records and some stacks that may represent the water table, but unless we filter carefully most of the event we observe seems to be refraction energy. When we form CDP stacks of the various surveys using either NMO or LMO, we can see this shallow event; and there appear to be some slight differences between the images for ‘dynamite only’ and the three pump-probe surveys. Until we explore more robust ways to highlight these differences, we are hesitant to attach any significance to them. Formulating techniques for objectively comparing the data from these surveys is the next step in this ongoing research.

ACKNOWLEDGEMENTS

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