COMMON MIDPOINT SEISMIC REFLECTION DATA RECORDED WITH AUTOMATICALLY PLANTED GEOPHONES

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Abstract

Shallow-seismic reflection imaging in the 2- to 20-m depth range requires dense spatial sampling to prevent spatial aliasing. Geophones must be planted individually, by hand, along the length of the survey line at 5 to 50 cm intervals. This acquisition geometry involves intense manual labor and results in lengthy fieldwork and high costs. A more efficient method of planting geophones would minimize expenses and reduce the amount of field time needed to complete a near-surface survey. At The University of Kansas, such a geophone-planting device, which uses hydraulic cylinders, is under development. The design of the apparatus involves seventy-two geophones bolted to four pieces of rigid channel iron, with 18 geophones per bar. Two hydraulic cylinders working in tandem connect to each segment of channel iron. All eight cylinders are mounted on a trailer, which provides the platform for moving the 2-D geophone array from site to site and for data acquisition. Planting 72 vertical geophones manually typically requires that three people work for about 15 minutes. With the hydraulically powered geophone-planting apparatus, the same task can be accomplished in less than 90 seconds. When the common midpoint (CMP) data collected using the conventionally planted geophones and the CMP data acquired with the automatically planted geophones were compared, only negligible differences were found. That is, the same subsurface information could be extracted from each data set, which perhaps will lend impetus to the development of effective, automated shallow seismic reflection surveying in the near future.

Introduction

High-resolution, near-surface 2-D seismic imaging in the 2- to 20-m depth range requires receiver intervals of 5 to 50 cm because of the dense spatial sampling required to prevent spatial aliasing. This acquisition geometry, however, is prohibitively expensive and extremely time consuming for 2-D seismic data along a line of any substantial length (> 50 m). At The University of Kansas, our approach to reduce the cost of shallow-seismic reflection imaging is to decrease the time in the field by simultaneously and automatically planting many geophones (e. g., Schmeissner et al., 2001; Spikes et al., 2001; Steeples et al., 1999). These geophones are bolted rigidly to four pieces of channel iron similar to the method discussed in Schmeissner et al. (2001), with 18 geophones per bar. Instead of four or five people standing of the channel iron to plant the geophone spikes as in Schmeissner et al., (2001) and Spikes et al., (2001), hydraulic cylinders suspended vertically from a trailer frame provide the power to force the geophone spikes into the ground (Figure 1). Two hydraulic cylinders are attached to each segment of channel iron. This geophone-planting device, called the “autojuggie”, is capable of planting 72 geophones in approximately 90 seconds. The same task performed by three people planting geophones manually one at a time requires approximately 15 minutes.

Background

Schmeissner et al. (2001) demonstrated that accurate shallow seismic reflection information can be recorded with rigidly interconnected geophones. In that research, geophones were rigidly bolted to pieces of channel iron, allowing 18 geophones to be planted simultaneously. The resulting seismograms were nearly identical to the seismograms acquired using conventionally planted geophones. The success

of this research allowed Spikes et al. (2001) to record shallow CMP reflection data with rigidly interconnected geophones. Stacked sections from that work indicated that CMP data acquired with bar-mounted geophones were equivalent to data acquired with conventional spike-mounted geophones. The same geological information could be extracted from both CMP stacked sections.

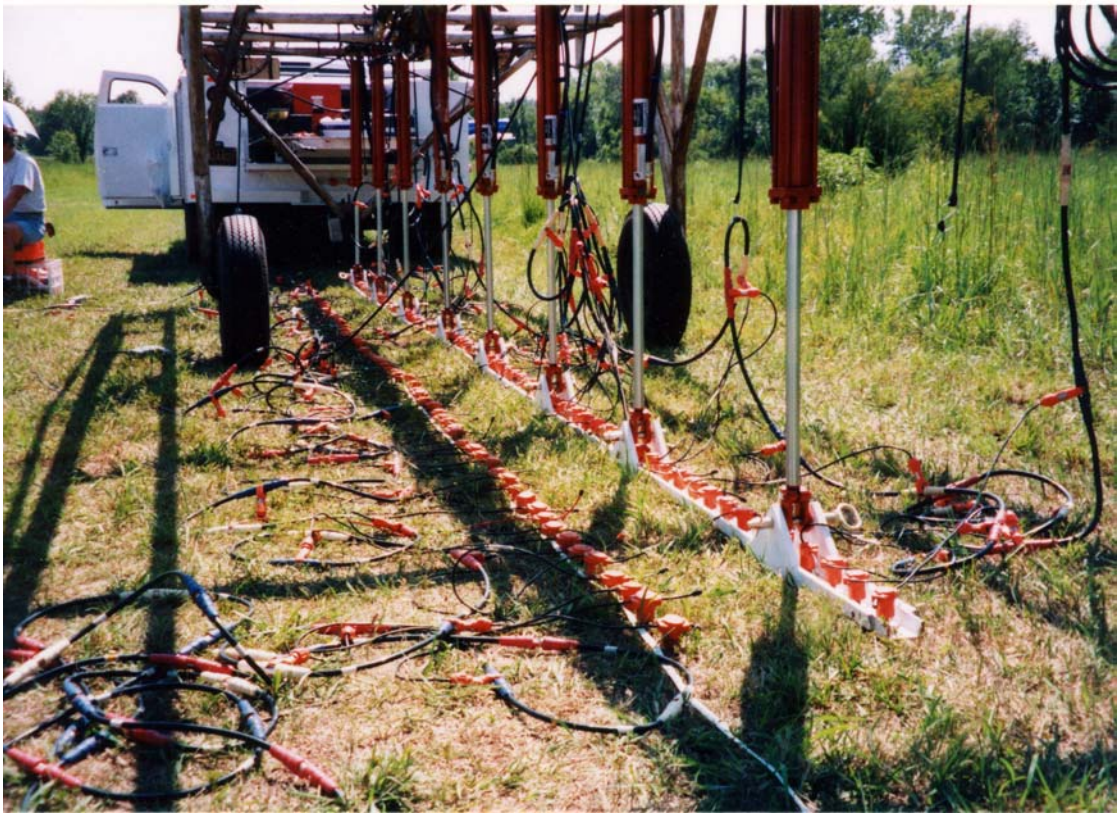

FIG. 1. A hydraulic geophone-planting device called the "autojuggie", includes four segments of channel iron, 18 geophones per bar, and two hydraulic cylinders per bar. Each of the coincident CMP surveys was conducted using an automatically planted test line (right) and a conventionally planted control line (left).

Methods

The experiments discussed in this paper were conducted on a grass-covered field located on the campus of the University of Kansas in Lawrence. The weathering layer consists of a 0.5- to 1.0-m-thick, clay-rich soil. Beneath the surface layer, at a depth of 25 m, is the Robbins Shale Member, a flat-lying limestone of the Pennsylvanian Lawrence Formation (O'Connor, 1960).

In August 2001, two coincident, parallel CMP surveys were conducted, one using automatically planted geophones and the other hand-planted geophones (Figure 1). The control line consisted of 72 geophones at 12-cm intervals, with 12.5-cm geophone spikes. The test line comprised of 72 geophones at 12-cm centers rigidly attached to four pieces of channel iron. Each segment of channel iron was 2.13 m in length, for a total aperture of 8.52 m. The 12-cm geophone spacing maximized the number of geophones that could be planted with the trailer at its present length of 8 m. An eight-valve hydraulic control bank was suspended in the center of the trailer. Each of the valves controls one hydraulic cylinder. This valve arrangement allows for each segment of channel iron to be planted individually using two cylinders in tandem. Cylinders can be operated independently to provide fine adjustment when dictated by topography.

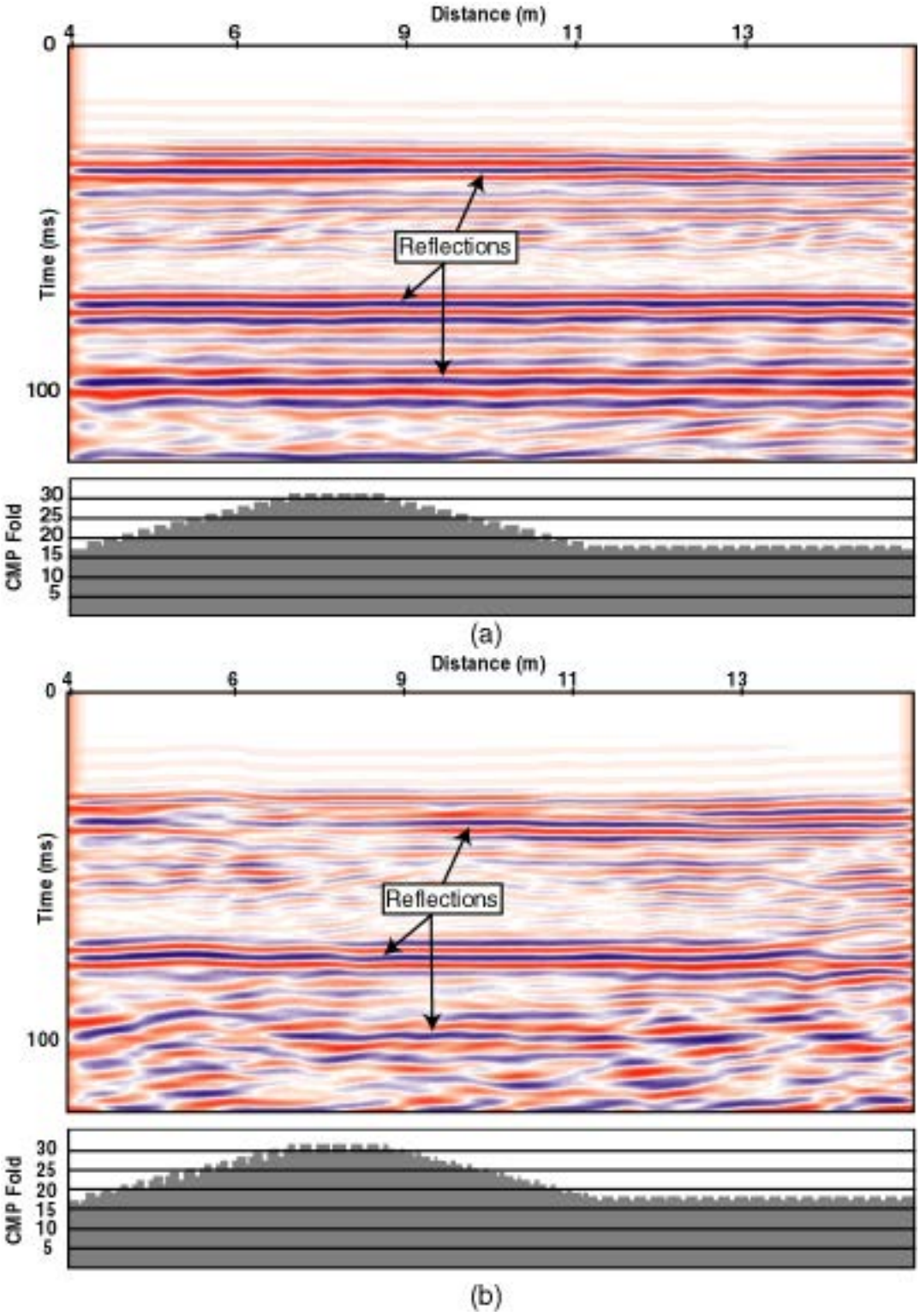

FIG 2. Stacked sections and fold diagrams from August 2001 experiments. The top section (a) is from the control line and the bottom section (b) is from the test line. Reflection coherency is much better in the control-line data than in the test-line data.

Geophone spikes 12.5 cm in length were used in the control line, whereas 7.6-cm geophone spikes were used in the test line. One concern was that that the trailer did not weigh enough to force the 12.5-cm geophone spikes into the ground a sufficiently. Otherwise, the two CMP lines were identical. A .223-caliber and a 30.06-caliber rifle were the seismic sources used in these coincident surveys. Because of a malfunction in the .223-caliber rifle midway through the survey, the 30.06-caliber rifle was used instead. The two sources were not mixed during CMP stacking, and the data displayed from this survey were acquired with the .223-caliber rifle.

During data acquisition, the cylinders remained attached to the channel iron by means of the steel hitch pins. Two unforeseen problems resulted by leaving the cylinders and channel iron connected during recording. First, when one segment of channel iron was planted, and the cylinders were left attached, the planting of the next segment caused the geophone spikes in the first segment to decouple partially from the ground. This situation introduced geophone-to-ground coupling differences between adjacent segments of channel iron and between the control line and the test line. Second, an interfering mode was present in the test-line data.

The stacked sections from August 2001 are displayed with a 250–700-Hz bandpass filter and a 30-ms AGC window (Figures 2a,b). Data processing steps included trace editing, velocity analysis, NMO correction without a stretch mute, *f-k* filtering, CMP sorting, frequency filtering, and windowed AGC, early-arrival muting, automatic residual statics, and CMP stacking. These two 18-nominal fold stacked sections, acquired with coincident shot, show differences in amplitude and frequency content in the ~35-, ~75-, and ~95-ms reflections. Reflection coherency in the test-line stacked section is clearly less than in the control-line data.

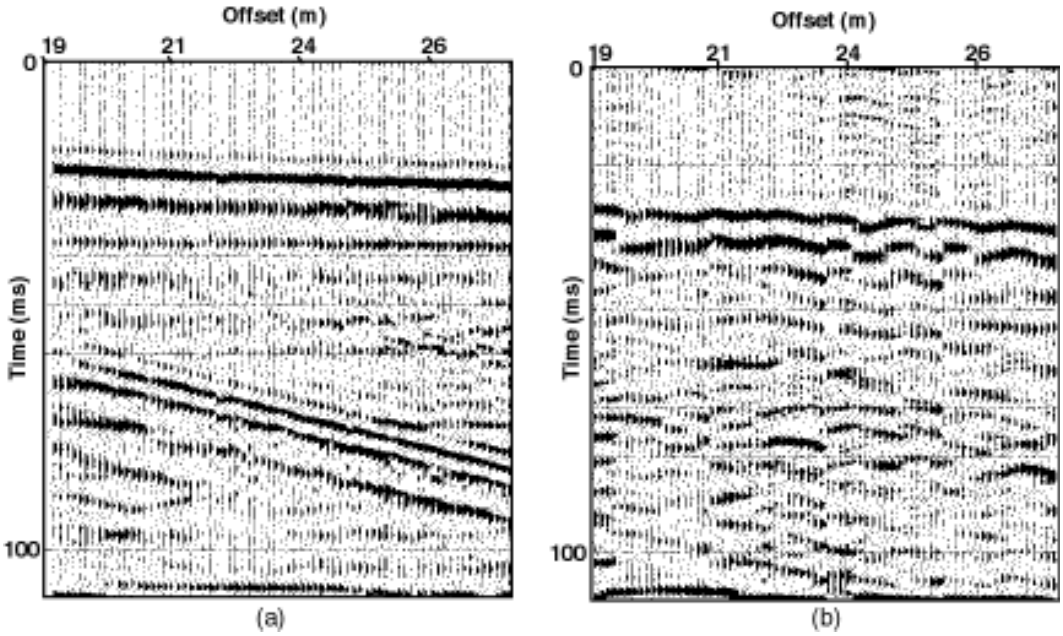

FIG. 3. August 2001 coincident field files from the control line (a) and the test line (b). Interfering modes resembling diffractions are present in the test-line data. Each of the diffractions is centered at the junction of a hydraulic cylinder and a channel-iron segment. Both field files are displayed with a 35-ms AGC window and a 300–750 Hz bandpass filter.

Analysis of the August 2001 raw test-line data showed the presence of an interfering mode with the velocity equal to that of airwave. This interfering mode appeared to be diffraction. Test-line field files indicated that these interfering events were centered where the cylinders were coupled to the channel iron by the steel hitch pins (Figures 3a,b). The difference in reflection coherency between the control-line and test-line stacks (Figure 2a,b) is due in part to this interfering mode. Another factor that was responsible for the difference in data quality was the use of 7.6-cm spikes in the test-line data and 12.5-cm spikes in the control-line data. Better coupling of the 12.5-cm spikes to the ground allowed for better

recording of higher frequencies. Lastly, the quality of the data is partially the result of relatively dry soil-moisture conditions. At test site, this factor is known to affect data quality (Jefferson, 1998).

The experiment conducted in September 2001 was designed to determine the source of the interfering mode seen in Figures 3a,b. This high-frequency energy appeared as diffractions centered at the location of each hydraulic cylinder. Based on the locations of these diffractions, two possible scenarios existed that were relatively simple to test. First, air-coupled wave within the trailer could have been transmitted through the cylinders to the channel iron-geophone systems. Second, vibrations induced by the truck may have been transmitted to the trailer, then to the cylinders, and then to the channel iron and geophones.

Two pseudo-walkaway surveys were conducted using a 30.06-caliber rifle firing downhole ~45 cm in predrilled shotholes. Ten shots were fired for each of the surveys. A test line only was set up with 72 geophones at 12-cm centers mounted on 12.5-cm spikes. The first pseudo-walkaway survey was recorded with the cylinders attached to the channel iron. After the first survey, the geophones were unplanted, and the line was moved ~0.5 m in the in-line direction. The geophones were then planted again, one channel-iron segment at a time. After each segment was planted, the cylinders attached to that segment were detached and remained detached for the second pseudo-walkaway.

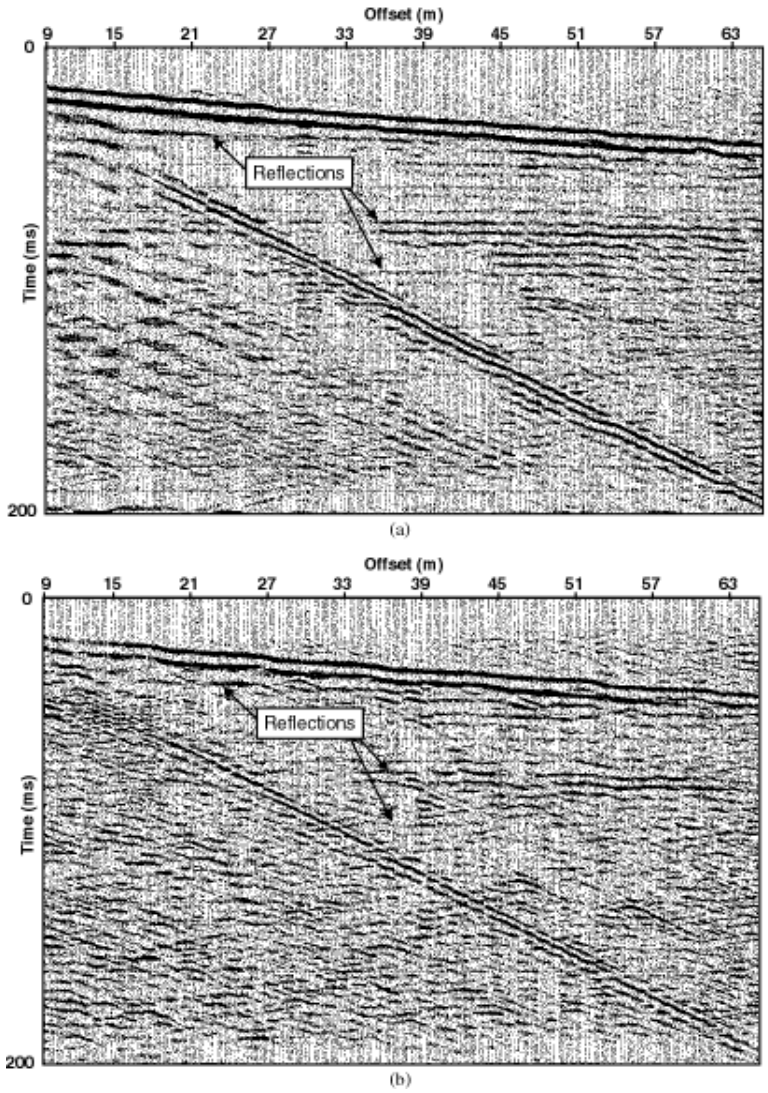

FIG. 4. The top figure (a) is the pseudo-walkaway recorded with the cylinders detached from the channel iron. The lower figure (b) was acquired while leaving the cylinders coupled to the channel iron.

The two pseudo-walkaways recorded during this experiment are displayed in Figures 4a,b, each with a 300–600 Hz bandpass filter and a 60-ms AGC window. All three reflections typically recorded at this site are present in the walkaway recorded with the channel iron detached from the cylinders (Figure 4a). The ~35-ms reflection separates from the first arrivals, and the ~75-ms reflection can be traced into inside the airwave. The deeper reflection at ~95 ms is present at the far offsets beyond the airwave, and it can be seen inside the airwave. To remove a ringing first arrival refraction, a deconvolution operator was applied to allow the 35-ms reflection to be seen (Figure 4a). The same processing steps were applied to the pseudo-walkaway recorded with the cylinders attached to the channel iron. However, none of the reflections are as coherent in figure 4b as they are in figure 4a. Overall data quality is much higher in the pseudo-walkaway recorded with the cylinders detached from the channel iron than in the data acquired with the channel iron attached to the cylinders.

Field files from the September 2001 experiment are displayed in (Figures 5a,b). Each record is shown with a 100 ms AGC window and 3-dB gain. The field file recorded with the cylinders attached to the channel iron shows the high frequency diffraction patterns centered at the location of each cylinder (Figure 5a). The corresponding field file recorded with the cylinders detached clearly shows the absence of this interfering mode. Based on this experimental data, it was conclusively decided the cylinders should be decoupled from the channel iron for all future CMP data acquisition.

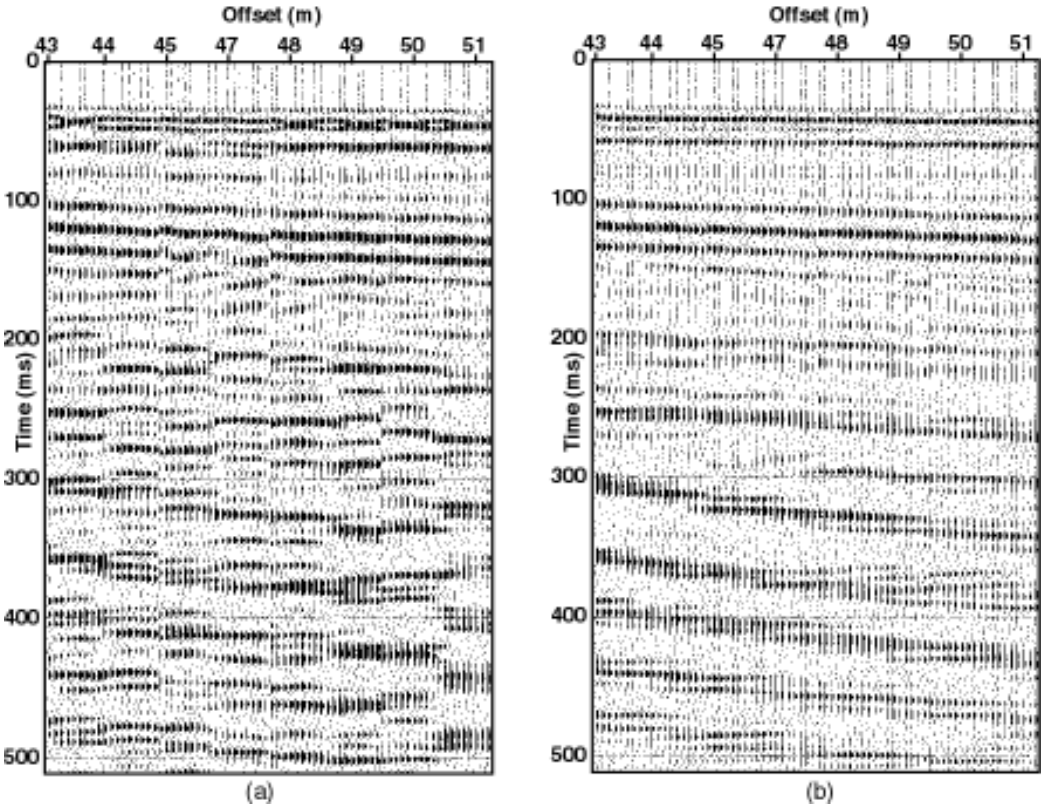

FIG. 5. Test-line data from September 2001 showing in (a) the presence of the interfering mode associated with the cylinders being attached to the channel iron during acquisition. Detaching the cylinders from the channel iron prevents that mode from being recorded as in (b).

In October 2001, two parallel coincident surveys were conducted with similar field parameters to the CMP lines from August 2001. The geophone interval was 12 cm for 72 geophones and the seismic source was a .223-caliber rifle. In both survey lines, 12.5-cm geophone spikes were used. Because of the conclusions of the September experiment, the steel hitch pins connecting the cylinders to the channel

iron were removed during recording. By detaching the cylinders from each channel-iron piece after that segment was planted, no partial decoupling of the geophones to the ground occurred.

The acquisition geometry was designed to avoid multiple receiver statics at individual receiver locations. Planting different test-line geophones at individual receiver locations may have compounded statics problems. Therefore, after collecting the set number of records with the 72 geophones remaining at fixed locations, the line was moved ahead one aperture length, where the procedure was repeated. A total of 216 receiver locations resulted from three spread lengths. The source was walked away at a constant interval out in front of the truck (Figure 1).

Stacked sections from October 2001 shown in Figures 6a,b are both displayed with a 60-ms AGC window and a 3-dB gain. Processing steps included trace editing, velocity analysis, NMO correction without a stretch mute, *f-k* filtering, CMP sorting, frequency filtering, early arrival muting automatic residual statics, and CMP stacking. Filtering in the *f-k* domain was crucial for removing airwave in both the control-line and test-line data sets. Comparing the two stacked sections reveals negligible differences. Reflection coherency is very similar in both stacked sections for the ~35-, ~75-, and ~95-ms reflections. However, amplitude and phase characteristics of the two sections differ slightly.

Discussion

August 2001 data (Figures 2a,b) clearly show that the control-line stacked data is of much higher quality than the test-line stacked data. The stacked sections from October 2001, however, are very similar to each other. Detaching the cylinders from the channel iron after each segment was planted allowed for improved data quality and higher signal-to-noise ratio (S/N) in the test-line data from October compared to the test-line data from August. This simple field procedure prevented the interfering mode in figures 3b and 5a from being recorded in the test-line data.

The advantages of using the automatic geophone-planting device include planting 72 pre-connected geophones in one and one-half minutes. Few personnel are needed because one person operating the hydraulic controls plants all the geophones, which eliminates the need for a large crew. Seismic cables can be permanently attached to the geophones, reducing the time to setup initially the survey equipment. Because of the preset geophone interval on the bars, that interval is preserved exactly throughout the survey. This factor may help to minimize field geometry errors. Potentially, better and more uniform geophone coupling to the ground may result from planting the geophones with the hydraulic cylinders.

Although the device reduces time, costs, and labor demands, it does have its disadvantages. For example, the locations where this could be used do not include areas of topography and trees. The hydraulic cylinders can be adjusted independently from one another, which allows for some fine adjustment to compensate for slight ground undulations. However, static shifts may result due to ground undulations smaller than the length of a piece of channel iron. Lastly, rocky soil conditions would result in bending the geophone spikes.

Summary

This research introduces a quick and efficient way to plant geophones for near-surface 2-D CMP seismic data acquisition. The reasons for planting many geophones quickly are to reduce the cost, time in the field, and manual labor for shallow CMP surveys. By rigidly bolting geophones to segments of channel iron and attaching those pieces of channel iron to hydraulic cylinders, it is possible to plant 72 geophones in approximately 90 s. This is approximately an order of magnitude reduction in the time required to plant 72 geophones relative to the time required for three people to perform the same task.

After detaching the cylinders from the channel iron, our data clearly indicate that accurate CMP data can be recorded with geophones planted with a hydraulically powered device. Additional data sets have been collected in different geological conditions, but as of present, they have not been analyzed and processed completely. Initial examination of those data indicates similar results to those shown in the October 2001 data set. Therefore, we are confident that this data acquisition method will allow the same geological information to be extracted from the subsurface that would be obtained from conventionally acquired data.

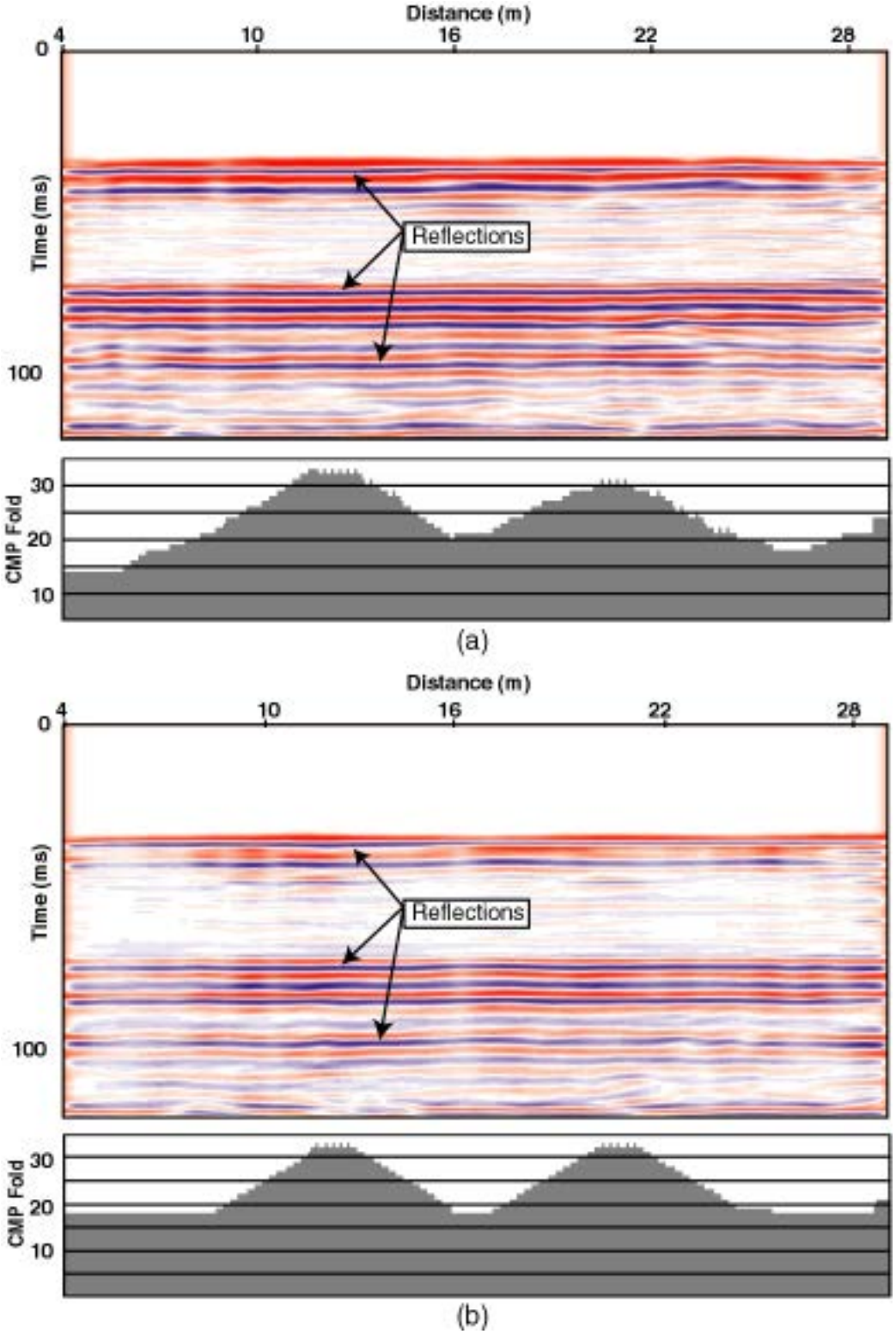

FIG. 6. October 2001 control-line (a) and test-line (b) stacked sections. The three reflections typically recorded at this site were imaged successfully in both the data sets. The fold diagrams differ because of different trace and record editing in each data set.

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