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Geophones on a board

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ABSTRACT

We examined the feasibility of using seismic reflections to image the upper 10 m of the earth's surface quickly and effectively by rigidly attaching geophones to a wooden board at 5-cm intervals. The shallow seismic reflection information obtained was equivalent to control-test data gathered using classic, single-geophone plants with identical 5-cm intervals. Tests were conducted using both a .22-caliber rifle source and a 30.06-rifle source. In both cases, the results were unexpected: in response to our use of small, high-resolution seismic sources at offsets of a few meters, we found little intergeophone interference that could be attributed to the presence of the board. Furthermore, we noted very little difference in a 60-ms intra-alluvial reflection obtained using standard geophone plants versus that obtained using board-mounted geophones. For both sources, amplitude spectra were nearly identical for data gathered with and without the board. With the 30.06 source, filtering at high-frequency passbands revealed a wave mode of unknown origin that appears to be related to the presence of the board; however, this mode did not interfere with the usefulness of the shallow-reflection data. The results of these experiments suggest that deploying large numbers of closely spaced geophones simultaneously—perhaps even automatically—is possible. Should this method of planting geophones prove practical after further testing, the cost-effectiveness of very shallow seismic reflection imaging may be enhanced. The technique also may be useful at greater reflector depths in situations employing bunched geophones. However, this approach may not be applicable in all circumstances because larger energy sources may induce interference between the geophones and produce undesirable modes of motion within the medium holding the geophones.

INTRODUCTION

Seismic reflection methods can be useful when analyzing very-near-surface geology at depths of less than 15 m (Pakiser and Warrick, 1956; Birkelo et al., 1987; Miller et al., 1989). However, the expense of shallow subsurface seismic imaging may be prohibitive when shotpoint and geophone intervals of only a few centimeters are required to maintain the coherency and distinctness of recorded shallow reflections (Baker et al., 1999).

Hence, in an effort to develop a fast and cost-effective method of deploying large numbers of closely spaced geophones for use in seismic reflection imaging, we conducted experiments in which 12 geophones were attached firmly to a wooden board at 5-cm intervals, as discussed in the field-experiments section [see Figure 1(a)]. The presence of the board did not cause the geophones to interfere with each other extensively or distort useful seismic signals substantially. As a result, we were able to obtain shallow seismic reflections that were comparable to control-test data gathered using conventional, single geophones planted at identical 5-cm intervals.

Recent experiments using a land streamer (van der Veen and Green, 1998) were motivated also by a desire to decrease the cost of shallow reflection surveys. A similar land streamer equipped with gimbal-mounted geophones has been in use in the southwestern United States for several years by C. B. Reynolds Associates. The land-streamer approach, however, fails to develop strong geophone coupling to the ground, which is essential for recording high frequencies.

To some degree, the relative amplitude of a reflection from any depth is a function of geophone coupling to the ground, which in turn determines how well geophones are able to measure actual ground motion (Krohn, 1984). In most circumstances, the best coupling is obtained when geophones are mounted on long spikes and planted firmly in the earth (see, e.g., Hoover and O'Brien, 1980; Krohn, 1984).

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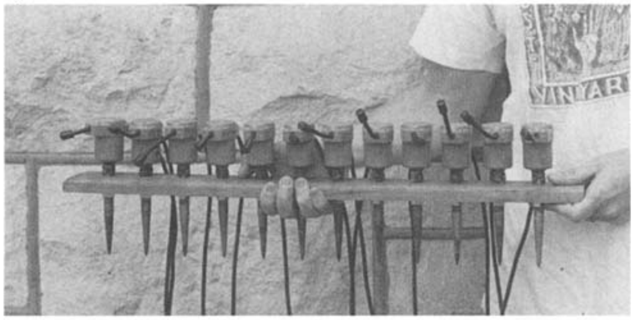
In a practical sense, because of the size of the case enclosing the geophone, the lower limit of the geophone interval is about 4 cm. Such small spacings may be advantageous when imaging the shallow subsurface or generating models for experiments involving sand boxes of the type used in laboratory settings, for example. If a cost-effective apparatus capable of rapidly deploying dozens of closely spaced geophones were to be devised, shallow seismic reflection techniques might become more valuable as a complement to ground-penetrating radar (GPR), particularly in situations in which GPR does not work well, such as those involving clay-rich soils, or when a broader range of depths is to be imaged.

The experiments we describe were designed to determine whether numerous geophones could be deployed quickly, at the same time, while maintaining good coupling to the ground and ensuring negligible interference between geophones. Experimental data were collected at two sites near Lawrence, Kansas. Thin soil overlies shale bedrock at the first site, and the seismic data recorded there using board-mounted geophones were nearly identical to data recorded using single geophones and standard deployment techniques. To make certain that these results were not site specific, we conducted more extensive experiments at a second site. Because the experiments at the second location were more comprehensive than those at the first, we include here data gathered from the second site only; however, results from the two sites were comparable.

a)



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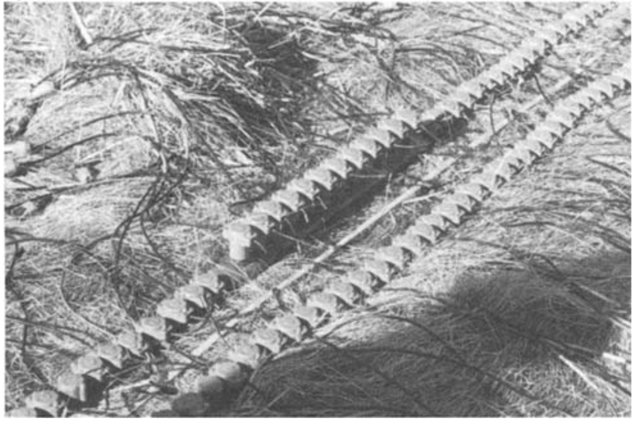

FIG. 1. Photographs of (a) 12 conventional geophones mounted on a board about 67 cm long and (b) the 12 board-mounted geophones, visible near the center of the left-hand geophone line, following deployment at the test site.

FIELD EXPERIMENTS

The second test area was in the alluvial valley of the Kansas River near Lawrence, Kansas. The valley floor is composed of 20 m of clay and sand alluvium overlying Pennsylvanian bedrock (Figure 2). Based on previous borehole-checkshot experiments conducted at this site (Steeples, 1979), the two-way traveltime for a reflection from bedrock was determined to be 82 ms. Even shallower intra-alluvial reflections have been detected at this location (Steeples and Knapp, 1982).

Two parallel lines 20 cm apart consisting of 48 geophones each were emplaced [Figure 1(b)]. The line in which no board-mounted geophones were used served as an experimental control to ascertain what effects, if any, the board might have on the geophone plants and thus on the recorded data.

On both lines, Mark Products L-40A, 100-Hz geophones were positioned at intervals of 5 cm and equipped with 12.5-cm-long spikes, except on the board itself, where 8 cm spikes were used. A solid-birch board 5.5 cm wide, 2.0 cm thick, and 66.7 cm long was used. Twelve geophones were attached to the board at intervals of 5 cm [Figure 1(a)]. The line of geophones was aligned parallel to the grain of the wood. First, the geophones were screwed into 9.5-mm (3/8-in) NF-threaded nuts welded to the heads of 9.5-mm NF-threaded bolts 4 cm long. Next, the bolts were inserted downward into the board through 10 mm drillholes and fastened snugly with 9.5 mm NF-threaded nuts. Geophone spikes 8 cm long were then screwed onto the ends of the bolts.

Our first experiment with the board-mounted geophones underscored the difficulty of simultaneously pushing twelve, 12.5-cm-long geophone spikes into firm ground. Therefore, in the second experiment, we used spikes only 8 cm long on the board. Overall deployment became much easier, and the effect of the board itself remained negligible. However, the combination of higher geophone elevations and shorter spikes produced receiver statics of +0.5 ms relative to the geophones that were not mounted on the board.

EXPERIMENTAL DATA

Two walkaway noise tests were performed on each line. The geophone configuration depicted in Figure 1(b) remained fixed

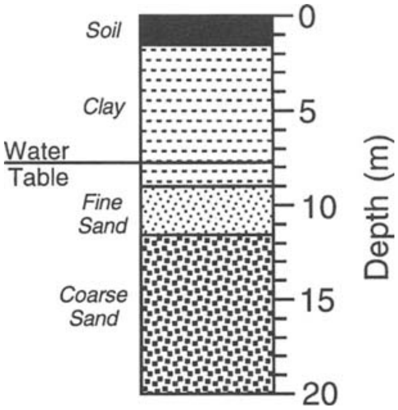

FIG. 2. Geologic section based on two boreholes drilled about 10 m and 60 m from the line location. One borehole encountered bedrock at 20.1 m, the other at 19.8 m.

as each source was moved away progressively, in 2.4-m increments, from one end of the receiver lines. Data were recorded simultaneously on both lines to remove source variation from our data comparisons. The seismic source used to generate the data given in Figures 3 and 4 was a .22-caliber rifle, with the tip of the rifle barrel placed about 10 cm below the surface of the ground. The source used for Figures 5–8 was a 30.06 rifle with the tip of the barrel placed about 20 cm below the surface. The use of the 30.06 rifle as a source is further described in Miller et al. (1992). The .22-caliber-rifle source was a bolt-action, single-shot hunting rifle available commercially. On the closest offsets, subsonic .22-caliber short ammunition was used to avoid data clipping. At offsets of 3 m or larger, supersonic .22-caliber long-rifle ammunition was used to increase the signal-to-noise (S/N) ratio.

Band-pass-filtered, .22-caliber-rifle data recorded from the line on which board-mounted geophones were not used show that a prominent intra-alluvial reflection is visible at about 60 ms (Figure 3). The reflection is from either the water table at about 8 m or a clay-sand interface at about 9 m. The .22-caliber-rifle data recorded using board-mounted geophones can be seen in Figure 4, using the same band-pass filter as that in Figure 3. A slight phase variation can be seen in the arrivals at the geophones attached to the board, which is consistent with the static delay discussed previously.

Figure 5 is unfiltered 30.06-rifle data collected from the geophone line without the board, whereas Figure 6 is equivalent data gathered from the line in which 12 of the geophones were board mounted. In the unfiltered data, the effect of the board is barely visible except where a static shift attributable to the higher geophone elevations and the shorter geophone spikes caused a slight phase delay. Figure 7 shows the 30.06-rifle data from the line without the board after a digital band-pass frequency filter from 200 to 300 Hz with 12 dB/octave slopes was applied. Figure 8 is equivalent data gathered from the line with the board. In both figures, the same prominent reflection noted at about 60 ms on the .22-caliber-rifle data is visible.

To provide a more detailed 1:1 comparison of the data, we plotted the 12 traces obtained from the board-mounted geophones and the comparable 12 traces obtained from standard geophone plants (Figures 9 and 10). Figure 9 presents the data comparison for the .22-rifle source, using shot-to-geophone offsets of 6.65 to 7.25 m and four different passband filters. The significant question is whether the reflection data are comparable. Specifically, the reflection seen at about 60 ms is essentially identical for the two data sets, regardless of the filter passband used. Some minor differences in ground roll occur, particularly with the higher frequency passbands. However, because we were not concerned with ground roll in our research, we did not examine those differences closely.

In Figure 10, the 30.06 data are displayed using the same parameters as those used in Figure 9. Again, we see very little difference between data obtained from the geophones planted in the standard manner and those mounted on the board. The principal difference between the reflections visible in Figures 9 and 10 is the emergence of some minor receiver statics for the board-mounted geophones. When examining ground roll, as discussed later, we observed that the board-mounted geophones generated what we refer to as the "board mode," visible in the higher frequency passband displays. Again, we were not concerned with ground roll, so we did not examine that aspect of the data in detail.

We stated previously that we found very little difference in the time domain between the 60-ms reflection data obtained from the standard geophone plants and the data obtained from the board-mounted geophones. Nonetheless, variation in geophone plants can affect frequency responses as well as data amplitude. Figure 11 presents amplitude spectra for the data provided in Figures 9 and 10 (the 12 comparable traces of data for both sources, with and without the board). Note that frequency variations in the data, for both the .22-caliber and the 30.06-rifle sources, are negligible for the board-mounted geophones as well as for the standard-plant geophones.

Figure 12 is a large-scale plot of near-source, 30.06-rifle data to which a much higher band pass (600–900 Hz, with

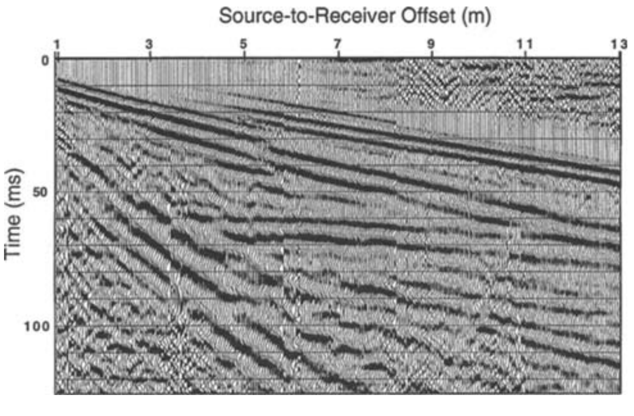

FIG. 3. Pseudowalkaway field file for the .22-rifle source, without board-mounted geophones, displayed with a 25-ms automatic gain control (AGC) window and a band-pass filter from 300 to 400 Hz with 12 dB/octave slopes. The receiver interval is 5 cm. The prominent reflection at 60 ms is from either a clay-sand interface at a depth of about 9 m or the water table within the clay at about 8 m. The bedrock reflection at this site exhibits a very strong amplitude–variation with–offset effect; as a result, the bedrock reflection often is not obvious on field records at offsets of less than 15 m.

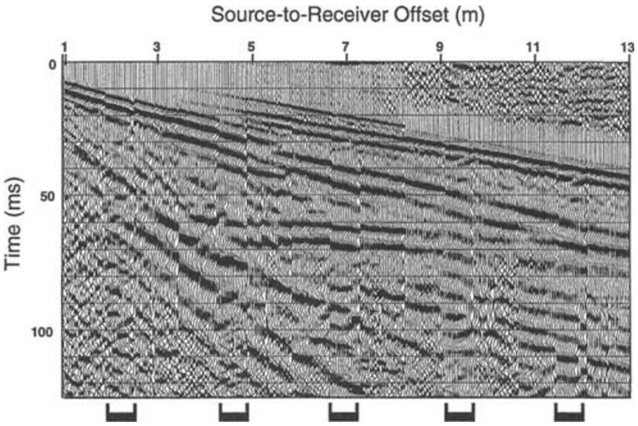

FIG. 4. Pseudowalkaway field file for the .22-rifle source, using board-mounted geophones, displayed with a 25-ms AGC window and a band-pass filter from 300 to 400 Hz with 12 dB/octave slopes. The traces produced by the board-mounted geophones are denoted by brackets. Note that the static shifts at these locations are a function of the higher elevation and the shorter (8-cm) spikes used with the board-mounted geophones.

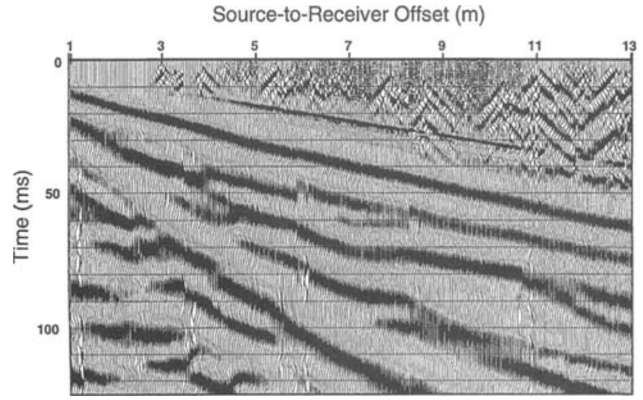

FIG. 5. Pseudowalkaway field file for the 30.06-rifle source, without board-mounted geophones, displayed with a 25-ms AGC window but without a band-pass filter. Noise prior to the first arrival on this and subsequent field files was generated by the grazing of sheep nearby.

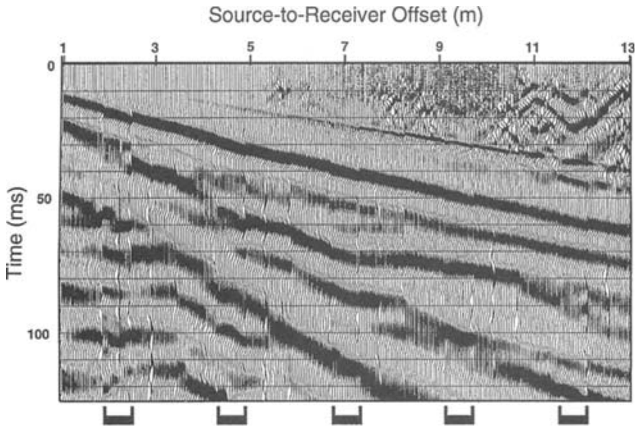

FIG. 6. Pseudowalkaway field file for the 30.06-rifle source, using board-mounted geophones, displayed with a 25-ms AGC window but without band-pass filtering. Traces produced by the board-mounted geophones are denoted by brackets. The coherent noise prior to the first arrivals is caused by sheep grazing nearby.

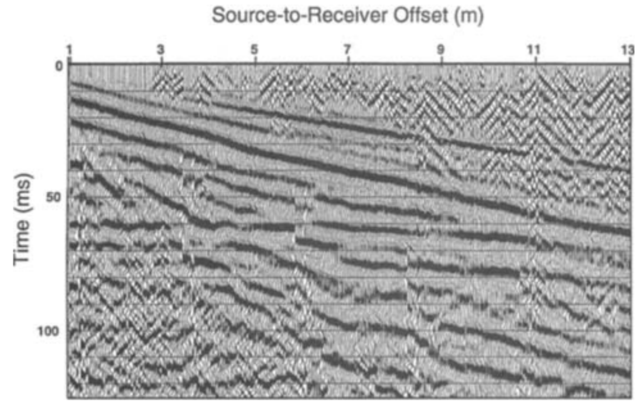

FIG. 7. Pseudowalkaway field file generated by the 30.06-rifle source, without board-mounted geophones, displayed with a 25-ms AGC window and a band-pass filter from 200 to 300 Hz with 12 dB/octave slopes. The prominent reflection at 60 ms is from a clay-sand interface about 9 m deep or from the water table within the clay at a depth of about 8 m.

12 dB/octave slopes) was applied. The board mode, with a velocity of about 150 m/s, is visible in the data recorded for the board-mounted geophones. This mode appears as a prominent zigzag pattern at times between 14 and 35 ms and at geophone-offset distances between 1.75 and 2.35 m. Although the source of this mode is unknown, it has a phase velocity very near that of ground roll. Its velocity is at least an order of magnitude too small to be a P-wave traveling horizontally (in the form of multiple reflections) within the board. It could be a "rocking" motion of the board in response to ground roll. Whatever the source of the board mode may be, it may not necessarily preclude the use of board-mounted geophones. The mode, if present, can be separated from the reflections fairly simply because it has a phase velocity that is substantially different from that of the desired reflection signal.

DISCUSSION

Conventional wisdom—or myth—suggests that the 12 board-mounted geophones used in these experiments would interfere with each other or be swamped by board-mode energy as a result of their firm connection to the board. This was not generally the case, as shown in the experimental results presented here.

The ramifications of these results may be significant to those interested in performing shallow reflection seismology in which very small geophone intervals are needed. For example, an apparatus capable of deploying large numbers of geophones very quickly might be devised, and if geophones were affixed permanently to a board or other rigid medium, then electrical wiring could be attached permanently as well. Thus, instead of connecting each geophone to a master cable equipped with standard takeouts, geophones outfitted with individual pairs of wires could be attached several at a time to a master cable. A small, all-terrain vehicle equipped with hydraulically controlled geophone "planters" might even be envisioned. On such a vehicle, geophones could be wired permanently to a cable connected to an onboard seismograph. A significant decrease

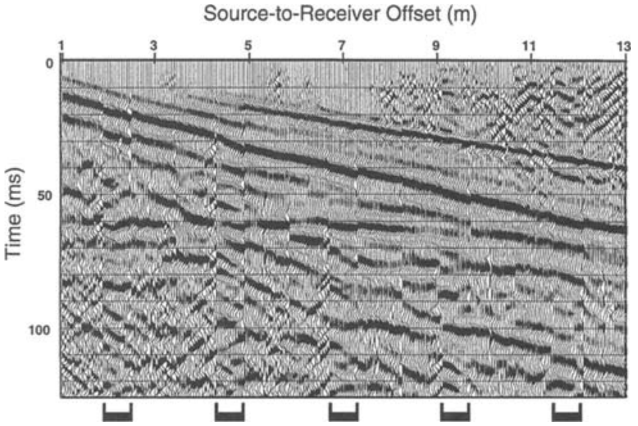

FIG. 8. Pseudowalkaway field file produced by the 30.06-rifle source, with board-mounted geophones, displayed with a 25-ms AGC window and a band-pass filter from 200 to 300 Hz with 12 dB/octave slopes. The traces generated by the board-mounted geophones are denoted by brackets. Note that the static shifts at these locations are a function of the higher elevation and the shorter (8-cm) spikes used with the board-mounted geophones.

in the time required to deploy receivers would result, greatly increasing the cost-effectiveness of shallow seismic surveying.

CONCLUSIONS

We examined the feasibility of using seismic reflections to image the upper 10 m of the earth's surface quickly and effectively by attaching geophones to a wooden board at 5-cm intervals. The results were surprising: in response to our use of small, high-resolution seismic sources at small offsets, we found little intergeophone interference attributable to the rigid coupling of the geophones to the board. Furthermore, the board did not affect the performance of the geophones as individual detectors of shallow seismic reflections. These findings were consistent with unpublished data we obtained previously at a separate, geologically different test site.

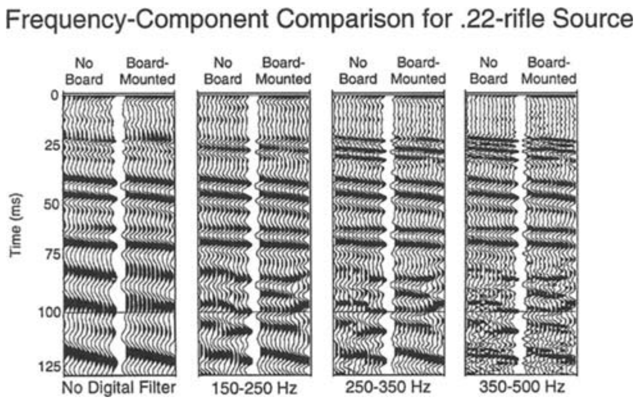

FIG. 9. Response comparison of standard-plant versus board-mounted geophones at different frequency ranges for the .22-rifle source. Traces from the 12 unmounted and 12 board-mounted geophones are from source-to-receiver offsets of 6.65 to 7.25 m. The doublet event arriving at 60 ms is the intra-alluvial reflection from the water table or a clay-sand interface at a depth of about 8–9 m.

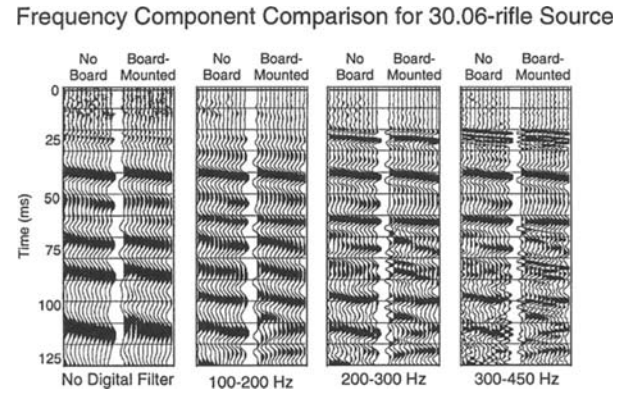

FIG. 10. Response comparison of standard-plant versus board-mounted geophones at different frequency ranges, for the 30.06-rifle source. Traces from the 12 unmounted and 12 board-mounted geophones are from source-to-receiver offsets of 6.65 to 7.25 m. The doublet event arriving at 60 ms is the intra-alluvial reflection from the water table or a clay-sand interface at a depth of about 8–9 m. The high-frequency board mode can be seen in the right half of the 300- to 450-Hz filtered data at times greater than 65 ms. This high-frequency mode has small amplitudes that are not obvious on the spectrum in Figure 11; the mode can only be seen when short AGC windows are used to produce the display.

Shallow seismic reflection information gathered using board-mounted geophones was found to be comparable to control-test data collected using classic, single-geophone plants with identical, 5-cm intervals. The results suggest that planting large numbers of closely spaced geophones simultaneously—even automatically—may be possible. Should an automatic method of deploying geophones prove practical after further testing, interest in ultrashallow seismic reflection profiling

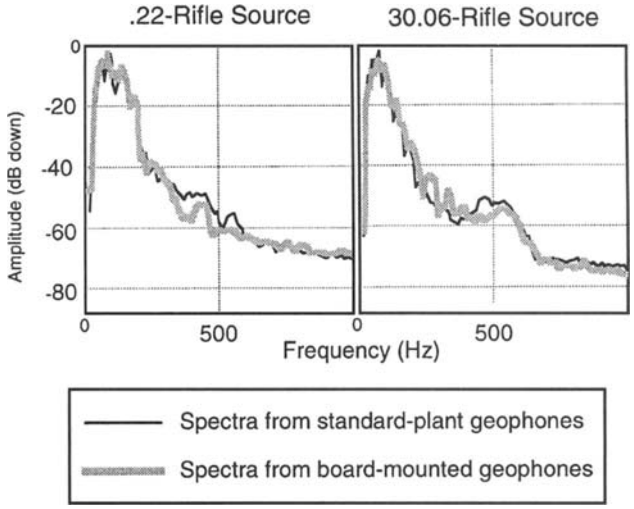

FIG. 11. Comparison of frequency spectra for the .22- and 30.06-rifle sources for board-mounted versus standard-plant geophones. In each case, the spectra were averaged over the 12 traces shown in Figures 9 and 10.

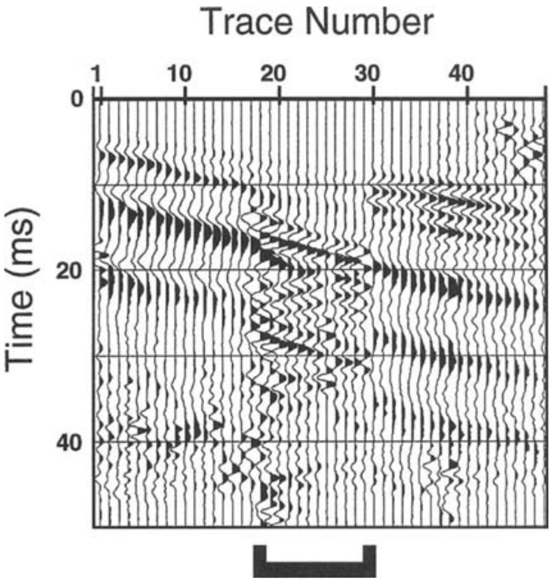

FIG. 12. Zoomed view of a pseudowalkaway field file produced by the 30.06-rifle source when board-mounted geophones were used. Display is without AGC but with a band-pass filter from 600 to 900 Hz with 12 dB/octave slopes. The traces generated by the board-mounted geophones are denoted by a bracket. Note the "board mode," which has a phase velocity approximately equal to ground roll. When using the 30.06-rifle source and a high-frequency band-pass filter, this phase is dominant only at the near offsets.

might increase accordingly, with new environmental and other geophysical applications being developed as a result.

In terms of usefulness, the technique may be effective at greater depths and in broader applications such as petroleum exploration. Also, board-mounted geophones or similar devices could be used for 2-D and 3-D surveying, as bunched geophones could be deployed more quickly when grouped together on a rigid medium than when deployed singly. Additionally, the possibility of automatically attaching large numbers of geophones to the ocean bottom constitutes an attractive goal relative to improving off-shore reservoir imaging.

The geophones-on-a-board approach may not be applicable to all sites or situations, however, because the use of larger energy sources may induce interference between the geophones and could produce undesirable modes of motion within the rigid medium.

ACKNOWLEDGMENTS

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