YEARLY PROGRESS REPORT

Project Title:	Automating Shallow Seismic Imaging
Covering Period:	June 14, 2002 through June 15, 2003
Date of Report:	June 15, 2003
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Subcontractors:	None
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PROJECT OBJECTIVES:

Our primary research focus during the current three-year period of funding has been to develop and demonstrate an automated method of conducting two-dimensional (2D) shallow-seismic surveys with the goal of saving time, effort, and money. Recent tests involving the second generation of the hydraulic geophone-planting device dubbed the “Autojuggie” have shown that large numbers of geophones can be placed quickly and automatically and can acquire high-quality data, although not under all conditions (please see the *Status* and *Results of Experiments* sections for details). In some easy-access environments, this device is expected to make shallow seismic surveying considerably more efficient and less expensive.

Another element of our research plan involved monitoring the cone of depression around a pumping well, with the well serving as a proxy location for fluid-flow at a contaminated DOE site. To try to achieve that goal, we collected data from a well site at which drawdown equilibrium had been reached and at another site during a pumping test. Data analysis disclosed that although we were successful in imaging the water table using seismic reflection techniques (Johnson, 2003), we were not able to explicitly delineate the cone of depression (see *Status* and *Results of Experiments*).

BACKGROUND

Thousands of chemically contaminated sites exist in the United States, including at least 3,700 at Department of Energy (DOE) facilities and numerous others at Department of Defense (DOD) installations worldwide. Establishing the spatial extent of the contamination, along with the fate of the contaminants and their transport-flow directions, is essential to the development of effective cleanup strategies. Among the most significant problems facing hydrologists today is the delineation of preferential permeability paths in sufficient detail to make a quantitative analysis possible. Aquifer systems dominated by fracture flow have a reputation of being particularly difficult to characterize and model.

Imaging technologies such as SSR and ground-penetrating radar (GPR) sometimes are capable of identifying geologic conditions that might indicate preferential flow paths. However, no single sensing technique is able to detect and image all of the various geological and soil conditions to be found across the country. Historically, SSR has been used very little at depths shallower than 30 m, and even more rarely at depths of 10 m or less. Conversely, GPR is rarely useful at depths greater than 10 m, especially in areas where clay or other electrically conductive materials are present near the surface.

In recent years, however, SSR methods have been applied to near-surface geological inquiries at depths of 10 m or less (e. g., Baker et al., 1999). At these depths, the wavefield must be sampled densely, usually at a spatial interval in the range of 5–50 cm. Thus, the cost per line km of planting the required number of geophones becomes a significant factor. When a 2D array of geophones is used to execute a 3D seismic reflection survey, the cost goes up even more.

If a cost-effective apparatus such as the Autojuggie--which is capable of emplacing large numbers of closely spaced geophones rapidly and automatically in a 2D array--were to be developed for use in 3D surveys, SSR techniques could be used more often at depths of less than 10 m as a complement to or instead of ground-penetrating radar. This would be especially appropriate in settings in which the GPR signal is likely to be attenuated, e. g., when near-surface soils have a high clay content or when a larger range of depths is to be imaged.

We have found also that the Autojuggie is capable of collecting data for use in surface-wave studies (Tian et al., 2003a;Tian et al., 2003b, in press)) and in seismic refraction work. Conceivably, work by Tian et al. (2003) could be developed further to perform, for example, seismic surface-wave studies using robotic methods in areas where human safety is a major issue. This might include DOE sites at which human occupancy is not feasible because of radiation or other hazardous-materials issues. With further research into the difficulties identified by Ralston (2003), the Autojuggie also could be used for three-component (3C) seismic surveys in both two and three dimensions.

STATUS

The most notable research results stemming from the first three years of our EMSP funding (1997-2000) are summarized in several refereed scientific papers documenting the procedures used to achieve seismic imaging at ultrashallow (< 3 m) depths [see *Refereed Papers in Review, in Press, and Published (1997-2003)].* Progress in this area has been attributable largely to an improved ability to measure the near-source wavefield. To accomplish this, we collected data using very small energy sources and single, 100-Hz geophone-group intervals of 5 cm. In contrast, typical "shallow" seismic surveys often use geophone-group intervals of 1 m or more. Because we increased the spatial density of the geophones by a factor of at least 20, we were able to delineate and improve the coherence of the ultrashallow reflections relative to other interfering phases. Increasing the spatial density of the geophones, however, comes at a price in time and effort. It is this aspect of the work that we have attempted to alleviate during the second three-year period of funding by concentrating on the development of the automated geophone-planting device (the Autojuggie).

In the current three-year period of funding (2000-2003), we have built and field-tested first- and second-generation versions of the Autojuggie and attempted to monitor the cone of depression of two pumping wells. Research results have been reported in three University of Kansas M. Sc. theses (Spikes, 2002; Blair, 2003; Johnson, 2003), a Ph. D. dissertation (Ralston, 2002), and published in refereed scientific journals (Schmeissner et al., 2001; Spikes et al., 2001a,b; Tian et al., 2003) and conference proceedings (Spikes et al., 2000, 2001; Ralston et al., 2001, 2002). Additional manuscripts are either in review or in press. Descriptions of the experiments and their outcomes are presented in the *Results of Experiments* section of this report.

Over the last three years we have confirmed that a task-specific mechanical device can be used to plant large numbers of vertical geophones both quickly and effectively. We have also discovered that three-component geophones can be planted in a similar way. However, wave modes in the rigid medium used to connect the geophones complicated the analysis of shear- and Love waves in data acquired with three-component geophones planted automatically. Despite these difficulties, we have made progress in understanding and implementing ultrashallow 3C seismic methods (Ralston et al., 2002; Ralston, 2003).

In addition to demonstrating the feasibility of the Autojuggie concept as outlined above, we have taken the following variables into consideration:

(1) the cross-sectional shape of the rigid medium to which the geophones are attached,

(2) the optimum spike-length of geophones planted automatically,

(3) the amount of downward force to be applied and maintained on the rigid medium both during geophone planting and as data are acquired, and

(4) whether, for each shot, the structural frame of the Autojuggie (and thus its added mass) should be detached temporarily from the rigid medium used to hold the geophones during data acquisition.

Work in progress (Blair, 2003) demonstrates that we can improve data collection by mounting geophones on lengths of 12.5-cm-square steel tubing rather than on channel iron. We have been able to reproduce these results at the same site on different days and at different sites; additional experiments will be performed during the 2003 summer field season.

Experiments incorporating different shapes of steel geophone-holding media are part of the EMSP proposal under which we are currently funded, and the results of these experiments have been one of the surprises to emerge from our EMSP research. We do not yet understand why square tubing appears to be superior to channel iron or to the other media shapes with which we have experimented. Furthermore, the square tubing seems to yield seismic data superior to data collected with geophones planted by conventional means.

Our working hypothesis is that we may be encountering a phenomenon in which the data are being amplified in much the same way that an organ pipe amplifies sound. As a result of this thinking, we will be testing round pipes and square tubing (with closed as well as open ends) during the coming field season. Note that in addition to potential benefits with respect to seismic data collection, round pipes and square tubing offer the advantage of enclosure, i. e., they provide increased robustness in the field because both the geophones and their cables are protected from weather, entanglement, and damage.

With respect to the other variables listed, the following investigations were undertaken. Blair (2003) conducted experiments with variable geophone spike lengths, using spikes up to 27-cm long. These tests were conducted at one site to determine the effects of geophone spike length on time- and frequency-domain seismic data recorded by geophones rigidly attached to channel iron and planted automatically using the hydraulic device (*also* Blair et al., 2003, in review). At the selected test site, spike length did not appear to be a significant factor in terms of data quality.

Spikes et al. (2001) showed that effective geophone mass (i. e., downward force) does not have a significant effect on data quality. The present Autojuggie weighs about 3200 lbs., which provides a downward pressure of only about 44 lbs. for each of the 72 geophones. Given the present configuration of the Autojuggie, the available downward force is not sufficient to push the geophones firmly into extremely hard ground. Constructing a heavier next-generation Autojuggie would solve this difficulty.

We have noted that the structural frame of the Autojuggie presents a dilemma. After the test-line geophones are pressed into the ground by the hydraulic mechanism, we have found it necessary to detach the frame of the Autojuggie from the steel medium to which the geophones are fastened. However, by removing a single steel connecting pin from the clevis of each hydraulic cylinder, we have been able to detach the frame quickly and easily from the rigid connecting medium. When we are ready to move the geophones to their next position, we then reconnect the hydraulic cylinders to the rigid medium by reinserting the pins. Alternatively, the development of digital filtering could solve the noise problem induced in the geophones by the vibration of the frame of the Autojuggie (Ralston, 2003), which would allow fieldwork to progress even faster.

Results of Experiments

Initially, experimental common-midpoint (CMP) reflection data were collected using the Autojuggie at three test sites with varying near-surface geology near Lawrence, Kansas (Spikes, 2002). Two parallel lines, referred to here as the test line and the comparison or control line, were positioned about 0.5 m apart. Each line consisted of 72 geophones with intervals of 12 cm. Using the Autojuggie (Fig. 1) on the test line, all of the geophones were planted mechanically by two people within approximately one minute.

The planting rate is limited currently by the hydraulic-pump capacity of the seismic recording truck. In these experiments, geophones were bolted rigidly to the channel iron (Fig. 2), which was then connected via steel pins to hydraulic cylinders attached to the frame of the Autojuggie. Comparison-line data were collected using traditional methods in which 72 geophones were planted by hand in a line parallel to the test line, a process that took four people approximately 15 minutes. The comparison line served as an experimental control whose purpose was to disclose any effects on the recorded data produced by bolting the geophones to a long, rigid medium.

On each of the geophone lines, Mark Products L-40A, 100-Hz geophones were positioned at intervals of 12 cm and equipped with spikes 12.5 cm long. Data on both lines were recorded with 72-channel Geometrics Strataview seismographs. Both seismographs have 24-bit analog-to-digital (A/D) conversion, and both seismographs recorded data from each shot to remove source variability from the comparison aspects of the experiments.

The method of attachment of the test-line geophones is detailed in Figure 2(a). Each of the 72 geophones was screwed into a 9.5-mm (3/8-in) NF-threaded nut welded to the head of an NF-threaded bolt 3 cm long and 9.5 mm in diameter. The bolts were inserted into the channel iron through 9.5-mm holes and fastened with 9.5-mm NF-threaded nuts. Geophone spikes 12.5 cm long were screwed onto the ends of the bolts. Pairs of hydraulic cylinders attached to each 2.8-m-long section were used to force the channel iron downward.

In addition, Blair (2003) conducted experiments at one of our test sites to determine the effect of geophone spike length on time- and frequency-domain seismic data. Geophones were rigidly attached to channel iron and then planted automatically (Blair et al., 2003, in review). The spikes tested were 27 cm, 21 cm, 12.6 cm, and 7.6 cm long. Based on an analysis of the resulting test- and control data, the longer geophone spike lengths yielded an advantage of only about 3 dB at frequencies <140 Hz. Although the effect of geophone spike length on the spectral characteristics of the vertical-component seismic data was not considered a major factor at this site under existing soil-moisture conditions, an unexpected result of the experiments was a possible link between spike length and airwave coherency. In fact, the pseudowalkaway records for bar-mounted geophones fitted with the shorter spike lengths exhibited the least coherent airwave.

The original Autojuggie was fabricated on a modified trailer previously used to transport agricultural implements, with the geophones mounted under the trailer. We performed a series of experiments on the test- and comparison geophone lines simultaneously to compare the recorded wave fields for the two lines. Figure 3 shows common-midpoint stacked sections from the KU West Campus test site from Spikes (2002). The two data sets are virtually equivalent, although the data from the Autojuggie-planted line appear to be less ringy. A field experiment at another test site indicated that data collected by the Autojuggie were superior to data collected using conventional geophone plants on a day when sustained winds of about 30 mph were noted (Fig. 4). The attenuation of wind-generated noise was an unexpected benefit of the Autojuggie.

Over the past three years, we have concentrated our experiments on channel iron as the connecting medium for the geophones. However, one of the goals of our current funding has been to determine whether channel iron is the best material for the job.

Recent results (Blair, 2003; Blair et al., 2003, in review) indicate that our data-collection system can be improved by modifying the design to include steel media with other cross-sectional shapes (Fig. 5). Blair conducted experiments using rigid media with varying cross-sectional shapes at two sites and replicated the experiments at each site to verify the experimental repeatability of the results. The seismic sources tested for these experiments included a .223-caliber rifle, a 30.06 rifle (further descried in Miller et al., 1986) and a sledgehammer. Prior to firing, the muzzle of each rifle was placed in a pre-punched hole about 25 cm deep. Figure 6 is a pseudowalkaway wave test of .223 rifle data for individual shots with source-to-geophone offsets ranging from 2 to 74 m.

The reflection data from the square tubing in Figure 6 are clearly superior to the data from the conventional geophone plants. Specifically, the reflection event at 80 ms is more coherent in the square-tubing data than it is in the conventional-plant data, especially at shot-to-geophone offsets from 3- to 30 m. In addition, the airwave effects are more severe in the conventional-plant data than they are in the square-tubing data, which is another significant and unexpected benefit of Autojuggie use. Usable surface-wave information also has been retained in the square-tubing data, although this may not be evident in the figure because of the 200- to 500-Hz passband filter applied to the data. We have also used the Autojuggie to collect surface-wave imaging data (Tian et al., 2003) by applying the multichannel analysis of surface waves (MASW) technique (Park et al., 1999; Xia et al., 1998).

The Autojuggie is useful for Rayleigh-wave analyses of data collected with vertical geophones, but the analysis of horizontal-component *S*-waves and Love waves is proving to be more challenging. In addition to the *P*-wave and other vertical-component work described above, we have been examining the total-vector wavefield to better understand how we might improve both vertical and three-component automated seismic data recording. Our 3C geophones employ the Galperin configuration, in which the three geophones are positioned orthogonally with respect to each other but are mounted at an angle of 35.3 degrees with respect to the ground (Galperin 1974; Goff and O'Brien, 1981).

The Galperin geophone configuration and the map view of the field layout for the 3C experiments discussed are depicted in Figure 7. Three sets of 3C geophones were used for this experiment: one with conventional plants (control line); one set bolted to the channel iron and connected to a spike (test line); and one set bolted to the edge of the channel iron but without a spike attached (bar-motion line). The goal of the experiment was to measure the seismic-vector response of the channel-iron bar in relation to the motion of the ground and to see how the resulting data compared to the test- and control-line data.

Records of the full-vector seismic wavefield acquired with the field configuration shown in Figure 7 reveal multicomponent crosstalk. The crosstalk results from the rigid-body bulk excitation of the channel iron by seismic ground motion. Figure 8 illustrates the nature of the crosstalk between two arrays of eight rigidly interconnected 3C receivers relative to a spatially coincident control-line of eight manually planted, spike-mounted 3C receivers. The first channel of radial-component motion on the test-line array and the bar-motion array attached to the channel iron appears to have been replicated on the neighboring seven channels. That is, the radial component of seismic ground motion recorded by the receiver nearest the source on each of the receiver arrays appears to interfere with the neighboring channels in the array. The transverse-component seismograms acquired with the test-line array and the bar-motion array are distorted in both amplitude and phase. However, the nature of the crosstalk among the transverse-component seismograms is not as apparent visually as it is in the corresponding radial-component seismograms. Vertical-component seismograms acquired with the test-line array and the bar-motion array are equivalent to those acquired with the control line (Spikes et al., 2001; Ralston et al., 2001).

Snapshots of the radial-, transverse-, and vertical components of motion recorded by each of the three receiver spreads during Rayleigh-wave arrival illustrate the nature of the crosstalk. The snapshots of radial-component motion (Figure 9) show clearly that the test-line receivers respond rigidly to the motion of the bar (as seen by the bar-motion array) rather than to the seismically induced motion of the ground. The snapshots of transverse-component motion (Fig. 10) show that the test-line receivers respond to flexural modes in the channel-iron induced by seismic ground motion. The snapshots of vertical-component motion (Fig. 11) show first that the test-line receivers respond in-phase to the vertical component of seismic ground motion and, second, that the channel iron itself appears to be flexible enough in the vertical direction to allow the vertical component of seismic ground motion to be acquired with near-perfect fidelity on the bar-motion receivers. Figures 9–11 illustrate why the Autojuggie concept works well for *P*-wave surveys but poses a challenge yet to be conquered in 3C surveys.

Crosstalk among the radial- and transverse-component seismograms may be removed by modeling the array of rigidly interconnected receivers as a linear system and deriving a time- or frequency-domain estimate of the system's response. An estimate of the system response of the channel-iron in the form of a time- or frequency-domain filter would provide a means to remove the crosstalk from seismic field files through the process of inverse filtering. However, variations in the effective ground coupling of a receiver array have a direct impact on the response of the array (Fig. 11). The implications of this finding are (1) that a sole shaping filter cannot be computed from a small subset of calibration data and subsequently used throughout an entire seismic survey, and (2) that a unique shaping filter is required for each placement of the receiver array during the course of the survey. Consequently, using the Autojuggie for 3C data collection will require either inventive inverse filtering or the use of a different medium to interconnect the geophones. We do not think that this is a permanent obstacle to Autojuggie-based 3C data collection; rather, it represents a conundrum that we hope to solve.

Along with its overall portability, another benefit of the Autojuggie is that the electronic connector cables remain attached to the geophones and to the seismograph when the planting device is moved from one location to another. The use of square tubing or round pipe would offer the additional advantage of protecting the geophones and cables from weather, vandalism, and tangling during the planting process. Also, both geophones and cabling would be less susceptible to damage by physical impacts or abrasion. These benefits, combined with the automatic geophone-planting capability, would make a significant difference in the number of person-hours required to execute a seismic survey. Furthermore, with the Autojuggie, the operator runs a hydraulic lever while seated in a motorized apparatus as opposed to having to stoop repeatedly, as is required when geophones are planted and retrieved manually.

Another of the objectives of the first three years of EMSP funding was to image a cone of depression around a pumping well using both seismic data and GPR. Although we were successful in imaging the same geologic interfaces with both *P*-wave seismic reflection and GPR methods (Baker et al., 1999, 2001) as well as imaging the water table, we have not been able explicitly to delineate the cone of depression around a pumping well (Johnson, 2003). We believe this is due partly to the depositional complexity of the alluvial aquifers at the test sites (Fig. 12) and partly to the gradational nature of the capillary fringe found immediately above the water table. Based on these experiments, we have concluded that to obtain a useful geophysical image (1) the aquifer in which the pumping occurs must be in direct communication with the water table, (2) the aquifer must be either unconfined or semiconfined, and (3) sediment must be capable of dewatering during pumping.

PLANS FOR THE REMAINDER OF THE GRANT PERIOD:

We continue to refine the Autojuggie concept as a means of planting geophones automatically and effectively. In experiments with various media shapes, Blair (2003) showed that square tubing is superior to channel iron as a geophone-mounting medium. At two of our test sites, geophones rigidly connected to square tubing yielded seismic data superior to data acquired from geophones planted by hand. We plan to repeat these experiments at other test sites during the coming field season to clarify why the square-tubing data are better than the data from conventionally planted geophones. In addition, Jennifer Powers is initiating M. Sc. thesis research to examine this question further. Her working hypothesis is that vibrations in the square tubing are being amplified much as sound waves inside a pipe organ are amplified. Powers' experiments will include square tubing (with open as well as closed ends) and circular pipes. The remainder of the third year of funding will be used to compose and refine manuscripts for publication and to prepare a demonstration of the Autojuggie device.

MILESTONE STATUS TABLE

Task Number	Task Description	Planned Completion Date	Actual Completion Date	Comments
Year 1-1	Type of medium	2001	Continuing	
Year 1-2	Geophone spike length	2001	2002	
Year 1-3	Downward force	2001	2001	
Year 2-1	Portability	2002	2001	
Year 2-2	Level of automation	2002	Continuing	
Year 2-3	Use in rough terrain	2003	Continuing	
Year 2-4	Overall ease of use	2003	Continuing	
Year 3-1	Multiple modes	2003	2002	
Year 3-2	Comparison of results	2003	Continuing	

BUDGET DATA (as of June xx, 2003)

			Approved Spending Plan			Actual Spent to Date		
Phase/Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	09/14/00	09/13/01	$255,180	0	$255,180	$186,321	0	$186,321
Year 2	09/14/01	09/13/02	$273,595	0	$273,595	$248,158	0	$248,158
Year 3	09/14/02	06/03/03	$263,463	0	$263,463	$114,638	0	$114,638

SPENDING PLAN

We anticipate requesting a one-year, no-cost extension to complete our data analysis and prepare additional manuscripts for submission to refereed journals.

Dissertations and Theses (1998-2003)

Blair, Jason, Analysis of the seismic response of rigidly interconnected geophones attached to variously shaped steel media, Master's thesis, The University of Kansas, Lawrence, KS (May), 71 p., 2003.

Johnson, Elizabeth, Imaging the cone of depression around a pumping well using shallow seismic reflection, Master's thesis, The University of Kansas, Lawrence, KS (May), 100 p., 2003.

Ralston, M. R., New approaches to seismic data acquisition, Ph.D. dissertation, The University of Kansas, Lawrence, KS, 225 p., 2003.

Spikes, K. T., Recording near-surface common-midpoint seismic data with automatically planted geophones, Master's thesis, The University of Kansas, Lawrence, KS (May), 128 p., 2002.

Pavlovic, Mario, Ground-penetrating radar in shallow aquifer detection and monitoring, Master's thesis, The University of Kansas, Lawrence, KS (May), 151 p., 2000.

Baker, G. S., Seismic imaging shallower than three meters: Ph.D. dissertation, The University of Kansas, Lawrence, KS (May), 328p., 1999.

Schmeissner, C. M., Seismic detectability of vertical transverse isotropy in the near-surface, Ph.D. dissertation, The University of Kansas, Lawrence, KS (December), 142 p., 1998.

Refereed Papers in Review, In Press, and Published (1997-2003)

In Review

Blair, J. D., D. W. Steeples, P. D. Vincent, N. Butel, and J. Powers, 2003, Analysis of the seismic response of rigidly interconnected geophones attached to steel media of various shapes: Exp. Abstr., SEG Intl. Exposition and 73rd Annual Meeting, October 26-31, Dallas, TX, in review.

Blair, J. D., D. W. Steeples, P. D. Vincent, N. Butel, and J. Powers, 2003, Field testing hydraulically planted receivers fitted with custom-made spikes: Exp. Abstr., SEG Intl. Exposition and 73rd Annual Meeting, October 26-31, Dallas, TX, in review.

Ralston, M. D. and D. W. Steeples, 2003, Automated orientation of three-component shallow seismic land data to source-centered cylindrical coordinates, Geophysics, in review.

Ralston, M. D., D. W. Steeples, and R. Black, Field measurements of the *P*- and *S*-wave velocity of soils, Geophysics, in review.

In Press

Baker, G. S., D. W. Steeples, and C. Schmeissner, 2003, Shallow underground reflection feasibility (SURF) diagrams: Environmental and Engineering Geoscience, in press.

Tian, Gang, D. W. Steeples, Jianghai Xia, and Kyle T. Spikes, 2003, A useful resorting in surface wave method with the Autojuggie: Geophysics, in press.

Papers and Maps Published

2003

Gang Tian, Don W. Steeples, Jianghai Xia, Richard D. Miller, Kyle T. Spikes, and Matthew D. Ralston, 2003, Multichannel analysis of surface-wave method with the Autojuggie: Soil Dynamics and Earthquake Engineering, v. 23, n. 3, 61-65.

2002

Baker, G .S., D. W. Steeples, and C. Schmeissner, C., 2002, The effect of seasonal soil-moisture conditions on near-surface seismic reflection data quality: First Break, v. 20, n. 1, 35-41.
Ralston, M. D. and D. W. Steeples, 2002, Automated orientation of three-component shallow seismic land data to source-centered cylindrical coordinates: Exp. Abstr., SEG Intl. Exposition and 72nd Annual Meeting, October, Salt Lake, UT.
Ralston, M. D., D. W. Steeples, Kyle Spikes, Jason Blair, and Tian Gang, 2002, Analysis of an automated three-component shallow seismic acquisition system: Exp. Abstr., SEG Intl. Exposition and 72nd Annual Meeting, October, Salt Lake, UT.

2001

Baker, G. S., D. W. Steeples, C. Schmeissner, M. Pavlovic, and R. Plumb, 2001, Near-surface imaging using coincident seismic and GPR data: Geophysical Research Letters, v. 28, n. 4, 627-630.
Ralston, M. D., D. W. Steeples, Kyle Spikes, and Jason Blair, 2001, Near-surface three-component seismic data acquisition using rigidly interconnected geophones: Exp. Abstr., SEG Intl. Exposition and 71st Annual Meeting, Sept. 9-14, San Antonio, TX.
Schmeissner, C. M., K. T. Spikes, and D. W. Steeples, 2001, Recording seismic reflections using rigidly interconnected geophones: Geophysics, v. 66, n. 6, 1838-1842.
Spikes, K. T., D. W. Steeples., C. Schmeissner, R. Prado, and M. Pavlovic, 2001, Varying the effective mass of geophones: Geophysics, v. 66, n. 6, 1850-1855.
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Steeples, D. W., 2001, Engineering and environmental geophysics at the millennium: Geophysics, v. 66, n. 1, 31-35.

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Baker, G. S., D. W. Steeples, C. Schmeissner, and K. T. Spikes, 2000, Ultrashallow seismic reflection monitoring of seasonal fluctuations in the water table: Environmental and Engineering Geoscience, v. 6, n. 3, 271-277.
Baker, G. S., D. W. Steeples, C. Schmeissner, and K. T. Spikes, 2000, Source-dependent frequency content of ultrashallow seismic reflection data, Bull. Seis. Soc. Amer., v. 90, n. 2, 494-499.
Baker, G. S., D. W. Steeples, C. Schmeissner, and K. T. Spikes, 2000, Collecting seismic-reflection data from depths shallower than three meters: in Proc. of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), Washington, D. C., 1207-1214.
Baker, Gregory, Calista McIntyre, Laura Walczak, and D. W. Steeples, 2000, Improving ultrashallow seismic reflection data by reducing source energy: Exp. Abstr., SEG Intl. Exposition and 70th Annual Meeting, August 6-11, Calgary, Canada, vol. II, 1267-1270.
Schmeissner, C., D. W. Steeples, Mario Pavlovic, Renato Prado, and Kyle Spikes, 2000, Recording seismic reflections using rigidly interconnected geophones: Exp. Abstr., SEG Intl. Exposition and 70th Annual Meeting, August 6-11, Calgary, Canada, Vol. II, 1279-1282.
Spikes, K. T., D. W. Steeples, C. Schmeissner, and R. Prado, 2000, Varying the effective mass of geophones: Exp. Abstr. SEG Intl. Exposition and 70th Annual Meeting, August 6-11, Calgary, Canada, vol. II, 1385-1388.

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Baker, G. S., C. Schmeissner, and D. W. Steeples, 1999, Seismic reflections from depths of less than two meters: Geophysical Research Letters: v. 26, n. 2, 279-282.
Baker, G. S., D. W. Steeples, and C. Schmeissner, 1999, On coincident seismic and radar imaging: Exp. Abst., SEG 1999 International Exposition and 69th Annual Meeting, Houston, TX, 484-487.
Baker, G. S., D. W. Steeples, and C. Schmeissner, 1999, In-situ, high-frequency *P*-Wave velocity measurements within 1 m of the Earth's surface: Geophysics, v. 64, n. 2, 323-325.
Steeples, D. W., G. S. Baker, and C. Schmeissner, 1999, Toward the autojuggie: Planting 72 geophones in 2 seconds, Geophysical Research Letters: v. 26, n. 8, 1085-1088.
Steeples, D. W., G. S. Baker, C. Schmeissner, and B. K. Macy, 1999, Geophones on a board: Geophysics, v. 64, n. 3, 809-814.

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The "Autojuggie"

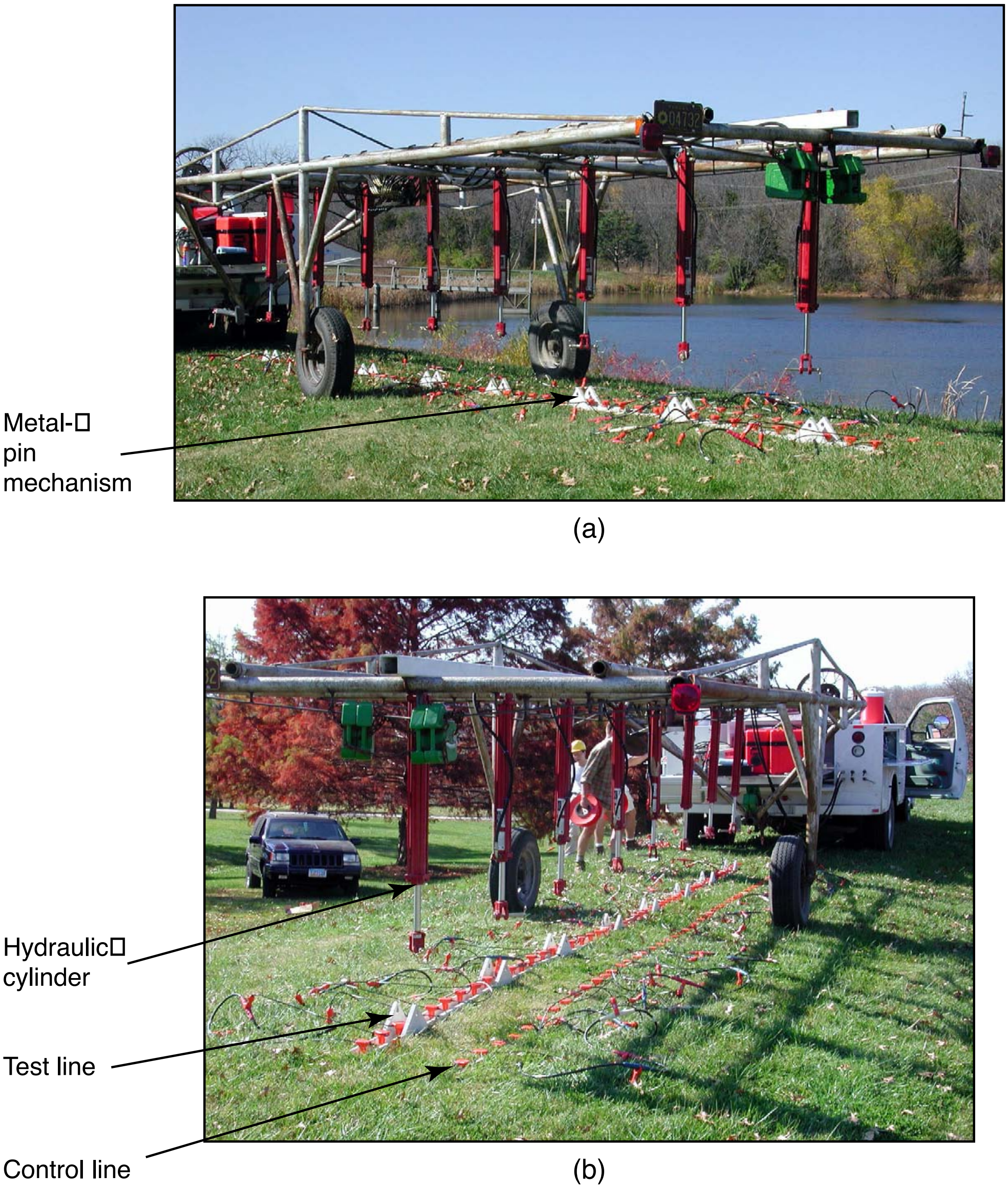


Figure 1. Two views of the Autojuggie during field trials. The bar-mounted geophones in these photos were planted quickly and automatically by the device. Metal pins inserted through holes in the white metal triangles (a,b) were used to connect the rigid bar medium to or detach it from the hydraulic system. The experimental control line (b) can be seen to the right of the test line.

Geophone Attachment Procedure

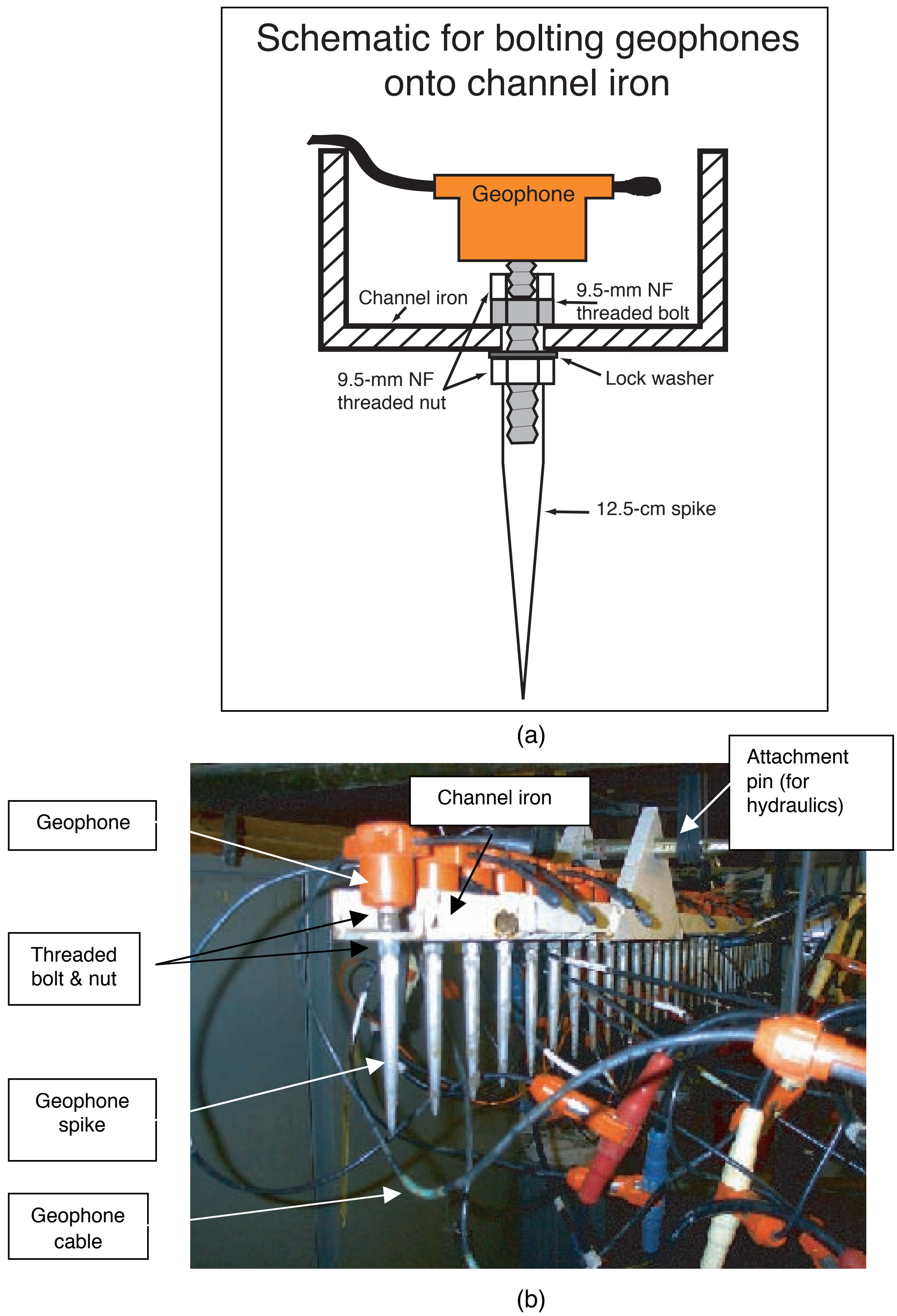


Figure 2. (a) Cross-section of bolting method used to attach geophones to channel iron. (b) Photo of dozens of geophones bolted to channel iron prior to attachment to the Autojuggie.

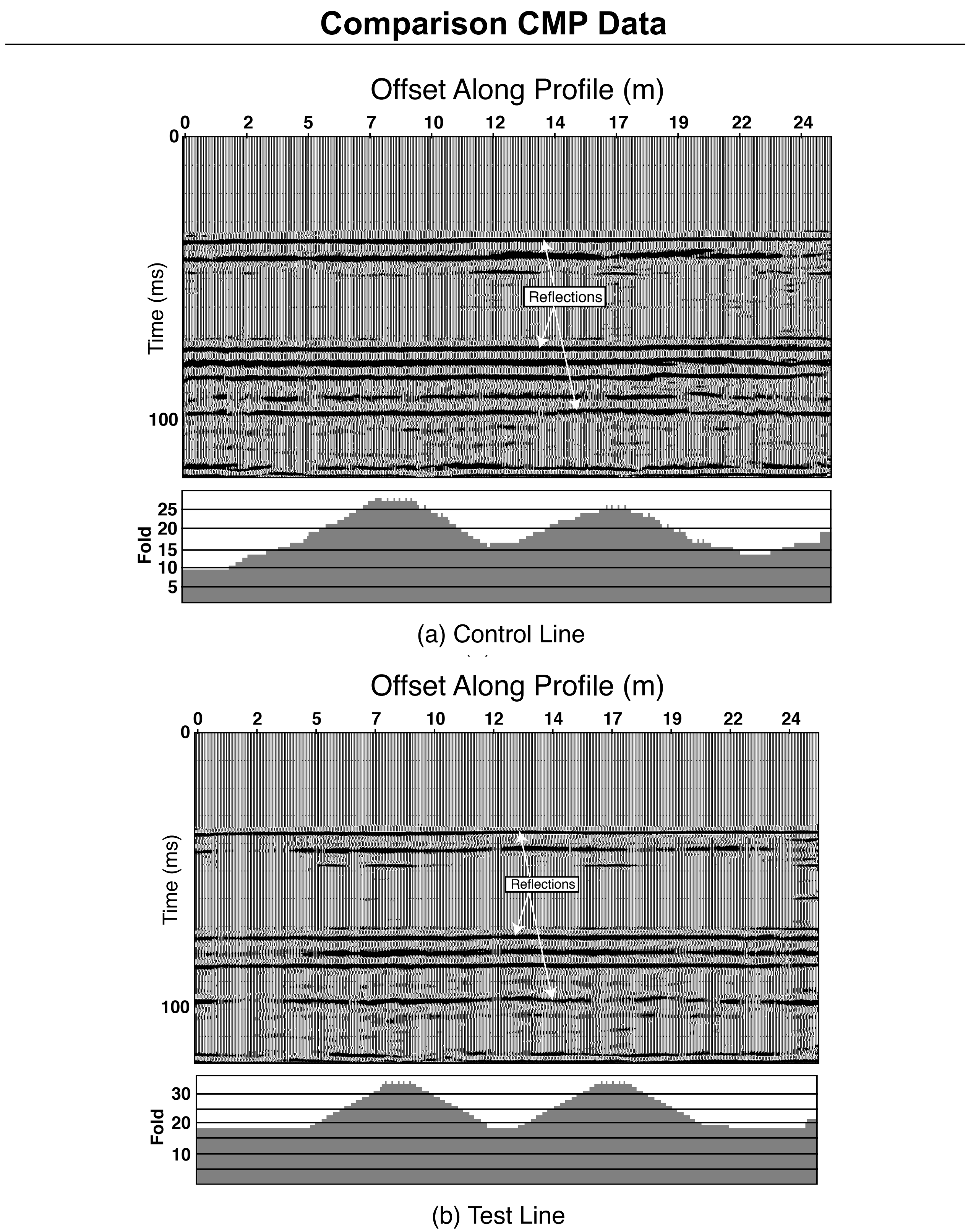
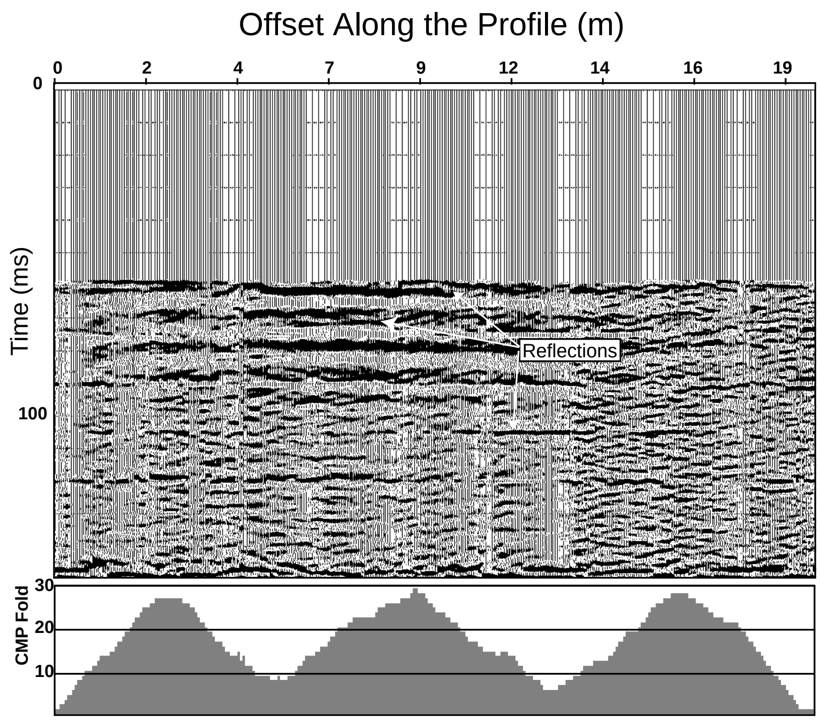
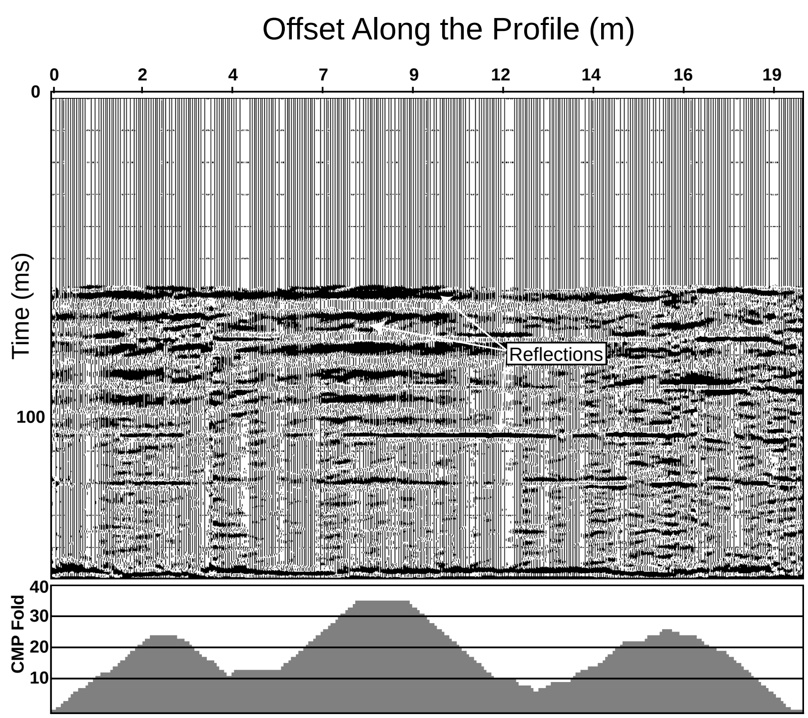


Figure 3. Common-midpoint (CMP) stacked seismic data from KU West Campus test site. (a) Conventional geophone plants (control line) and (b) Autojuggie plants (test line) (from Spikes, 2002).



(a) Control Line



(b) Test Line

Figure 4. Common-midpoint stacked seismic data from the KU geohydrological test site, collected during sustained winds of ~ 30 mph. (a) Conventional geophone plants (control line) and (b) Autojuggie plants (test line). Note that the reflections from the Autojuggie data are more coherent than those from the conventionally planted geophones (Spikes, 2002).

Testing Various Rigid Bar-Media Shapes

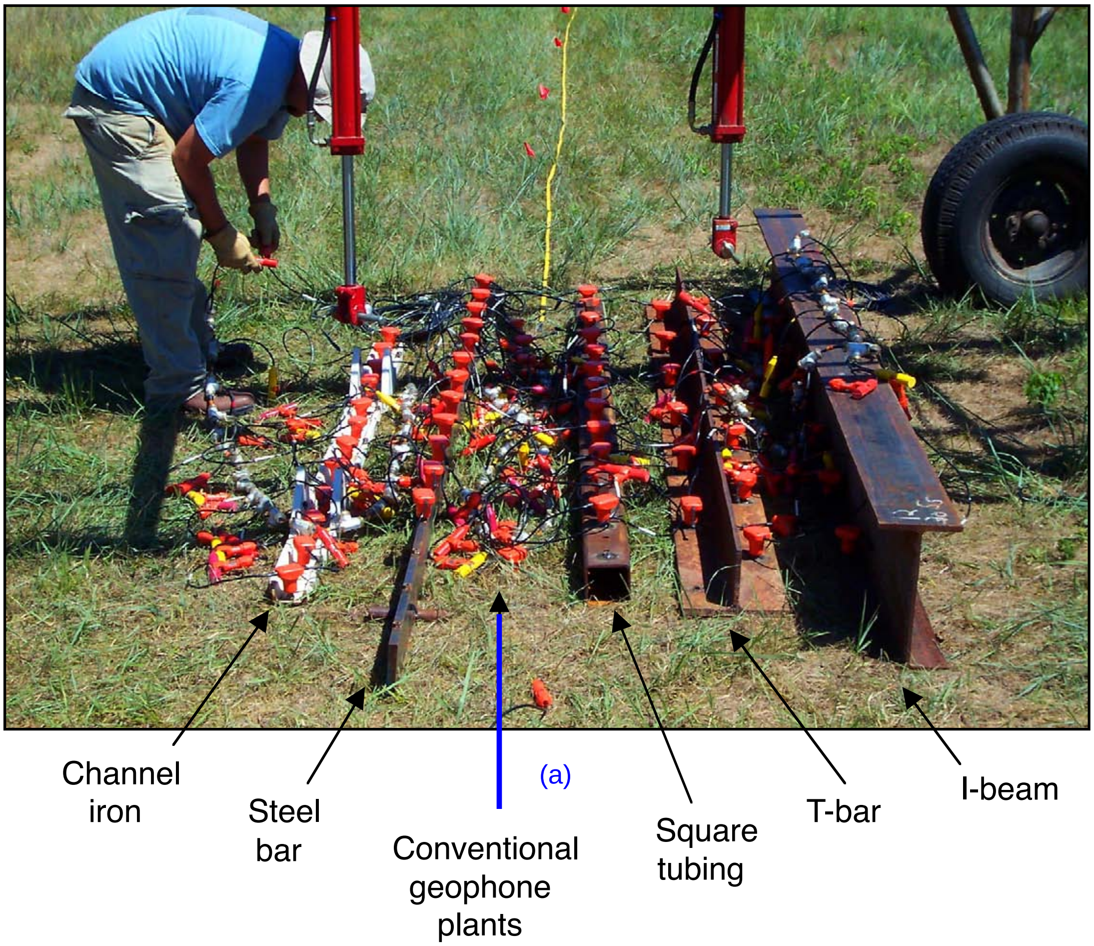
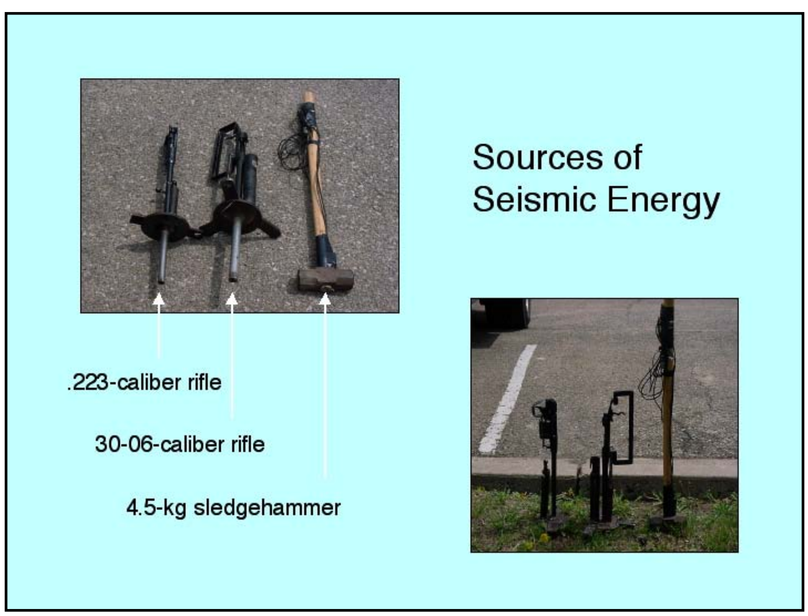
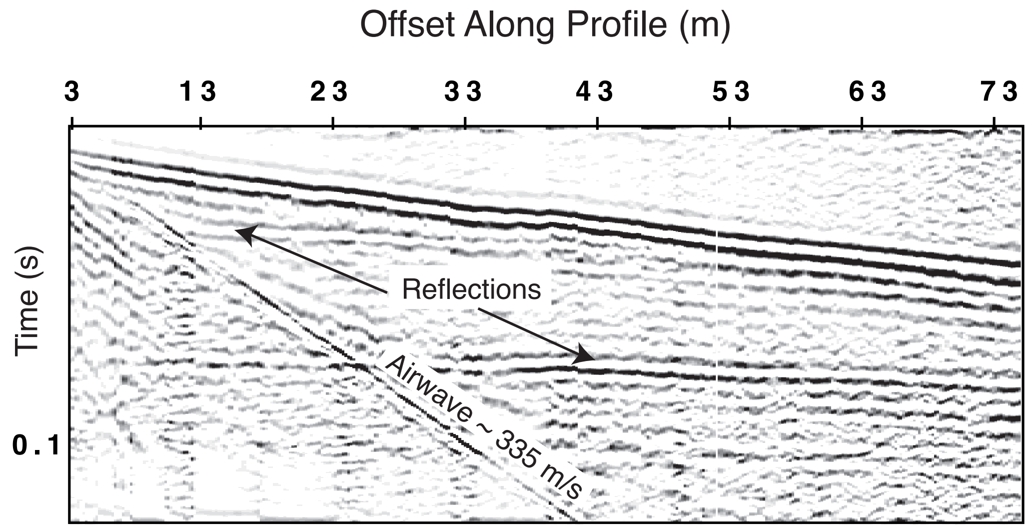


Figure 5. (a) Photo of field layout used to test geophones bolted to various cross-sectional, rigid media (L-R): channel iron (white); 2.5-cm x 12.5-cm steel bar set on edge; conventional geophone plants (control); 12.5-cm square tubing; 30-cm x 15-cm T-bar 2-cm thick; I-beam. (b) Sources of seismic energy.

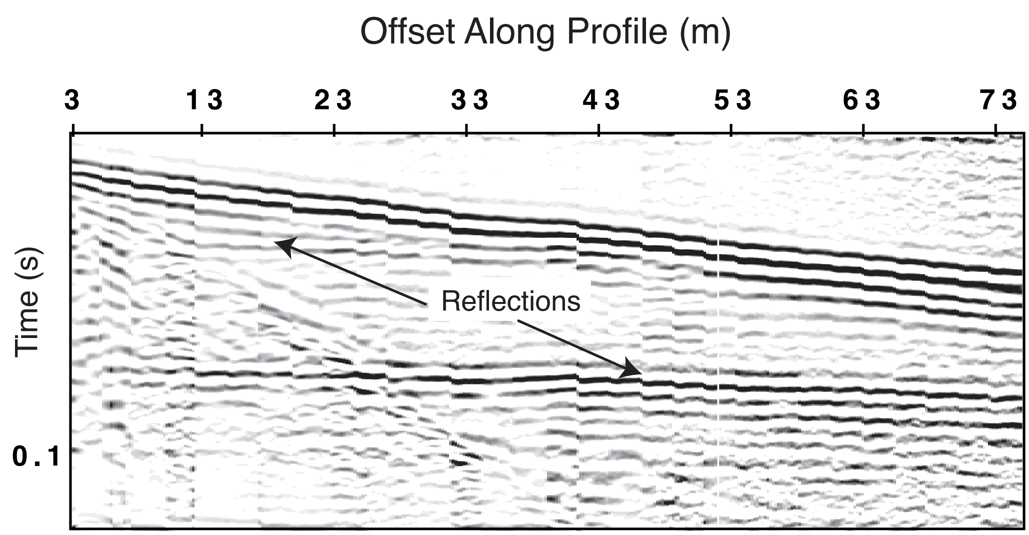


(b)

Walkaway Test Results



(a) Control Line



(b) Test Line (Square Tubing)

Figure 6. Walkaway wave-test results from (a) conventionally planted geophones (control) and (b) geophones mounted on square metal tubing (test). The source was a .223 rifle, and data are displayed with a 200- to 500-Hz filter and a 45-ms AGC window applied. Note the improved coherency of the 80-ms reflection on the square-tubing data, especially at offsets of 3 to 30 m. Note also that the airwave is highly attenuated on the square-tubing data in comparison to the data from the conventionally planted geophones.

Acquisition Geometry for Bar-Motion Test

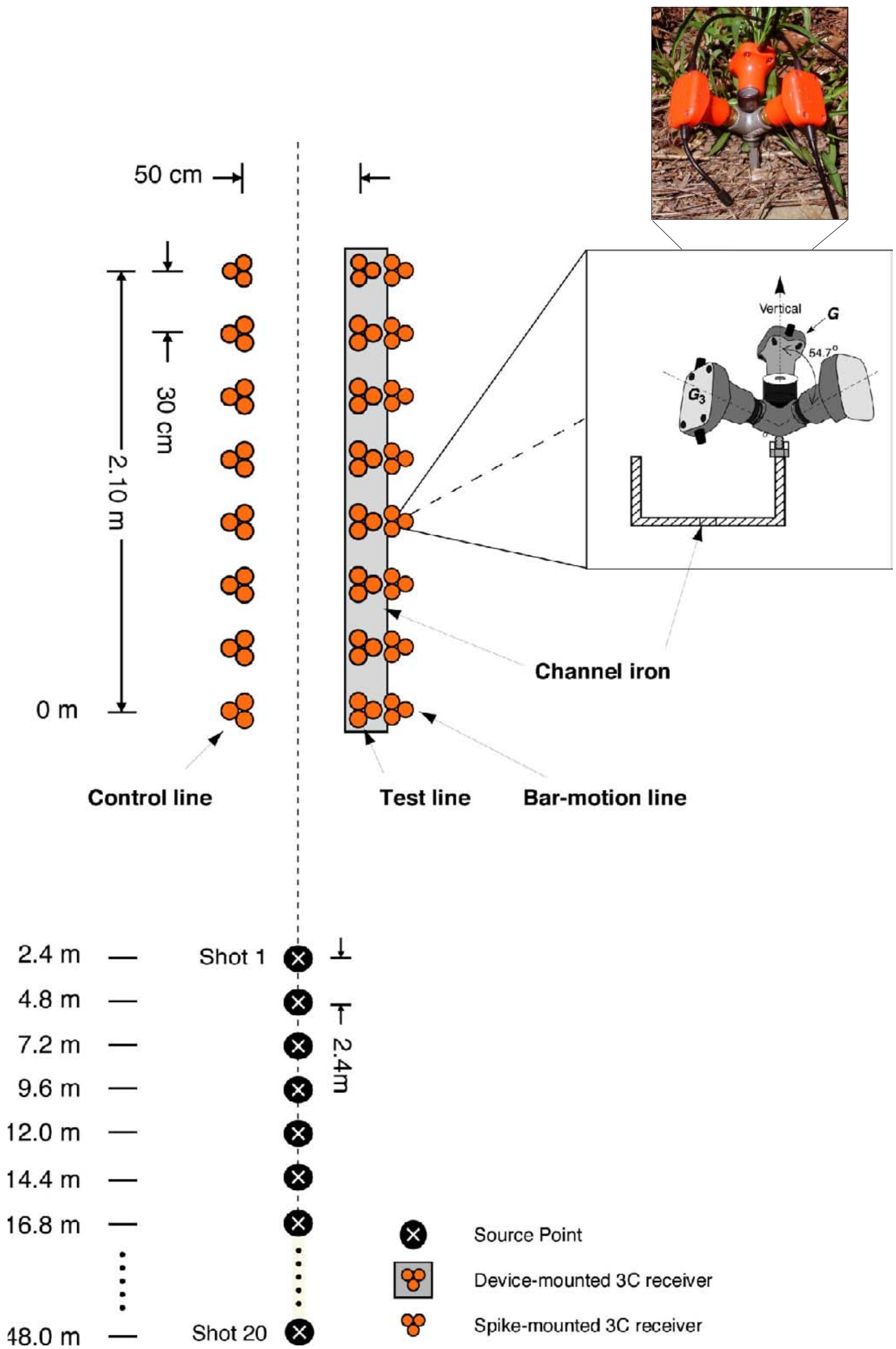


Figure 7. Control-, test-, and bar-motion-line acquisition geometry used to measure excitation of the channel-iron medium to which three-component geophones were attached. A 3C Galperin geophone (mounted on a spike planted in the ground) is shown in the photo at upper right.

Three-Component Records

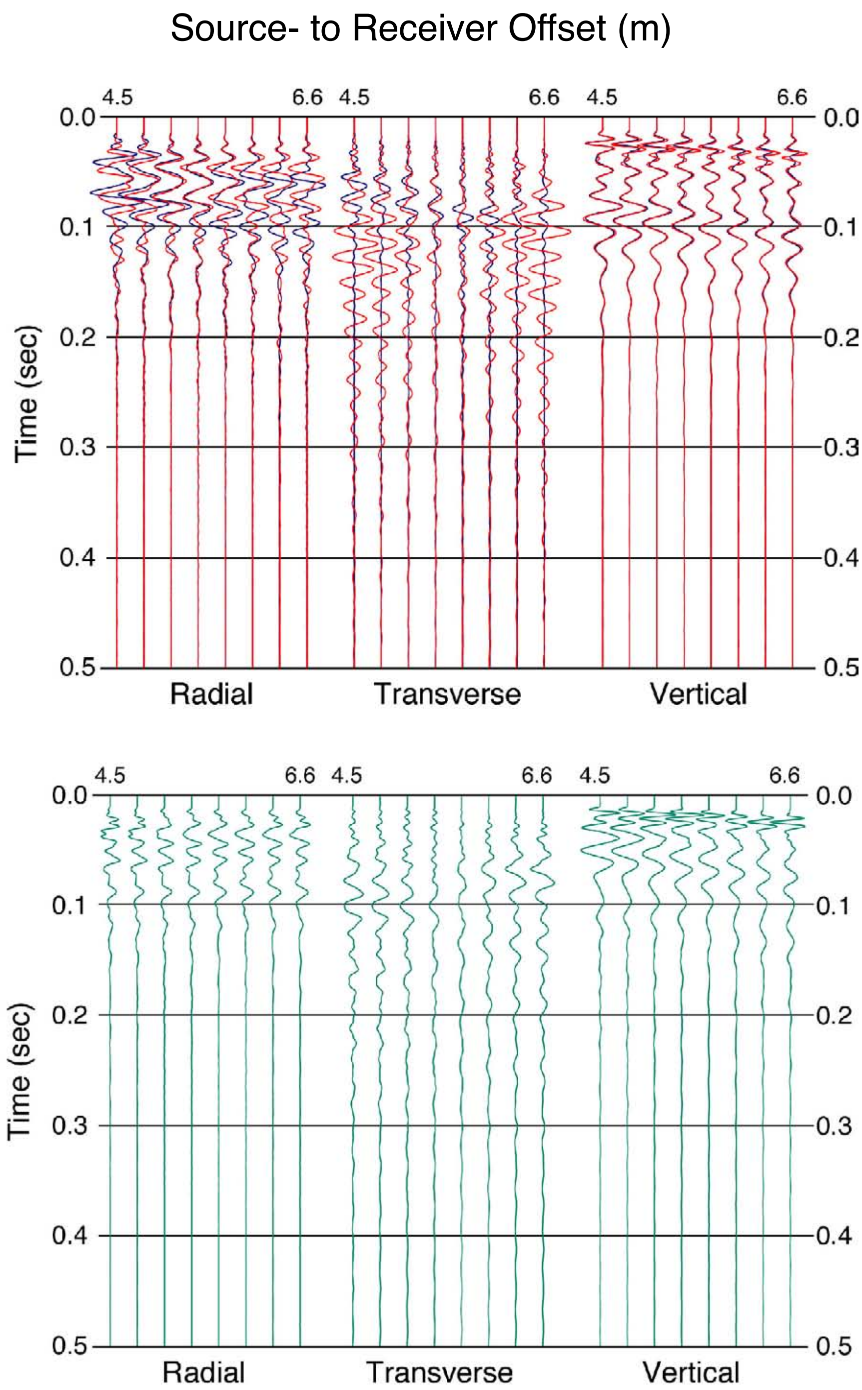


Figure 8. Three-component records acquired using the field geometry shown in Fig. 7. The source-to-near-receiver offset was 4.8 m. Control-line data are displayed in blue, and test-line data are overlain in red (top). Bar-motion seismograms are displayed in green (bottom) (Ralston, 2003).

Motion Snapshots

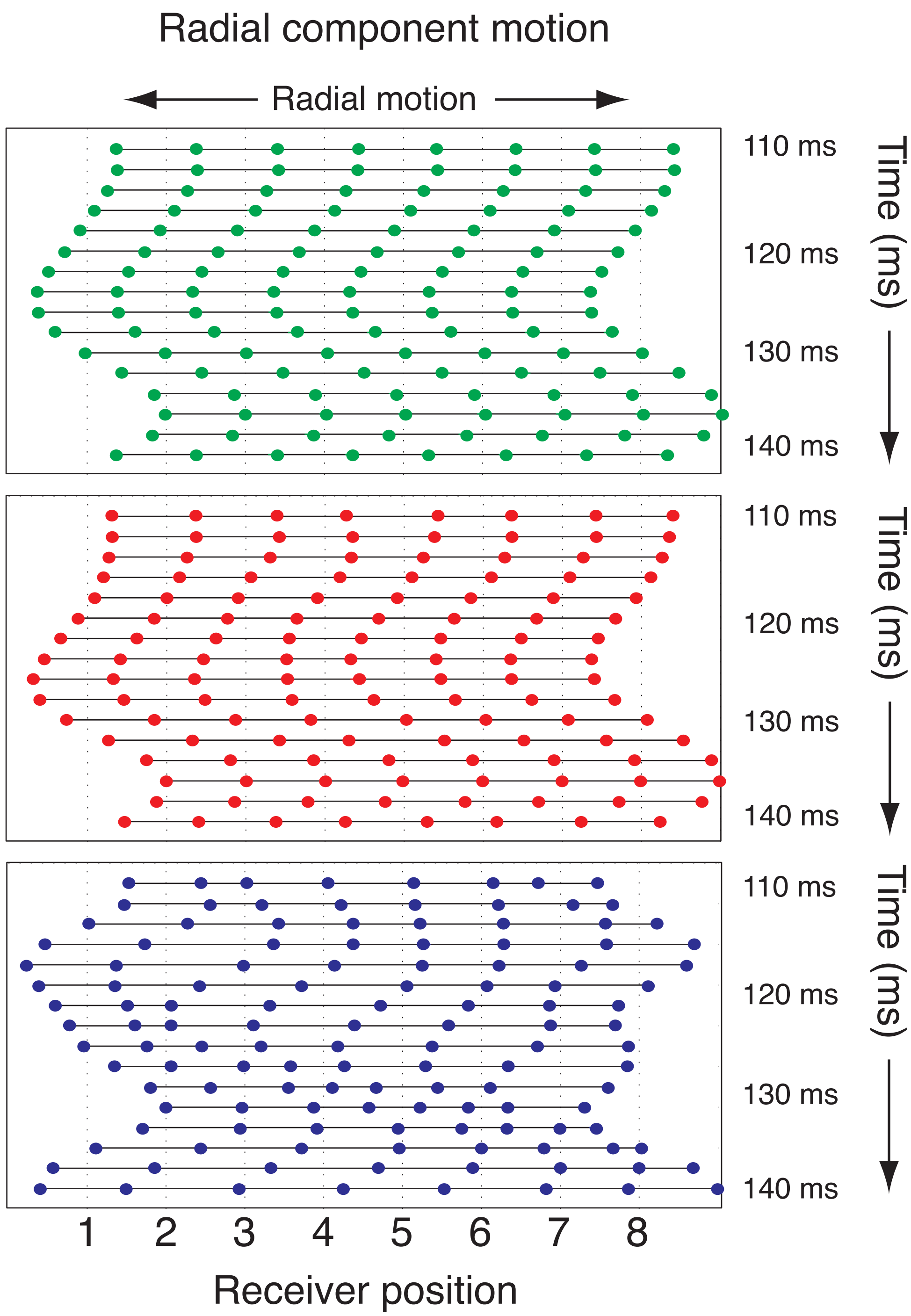


Figure 9. Snapshots of radial-component motion during the passage of a Rayleigh wave acquired with bar-motion (green), test-line (red), and control-line (blue) 3C receivers. The snapshot interval was 2 ms (Ralston, 2003).

Motion Snapshots

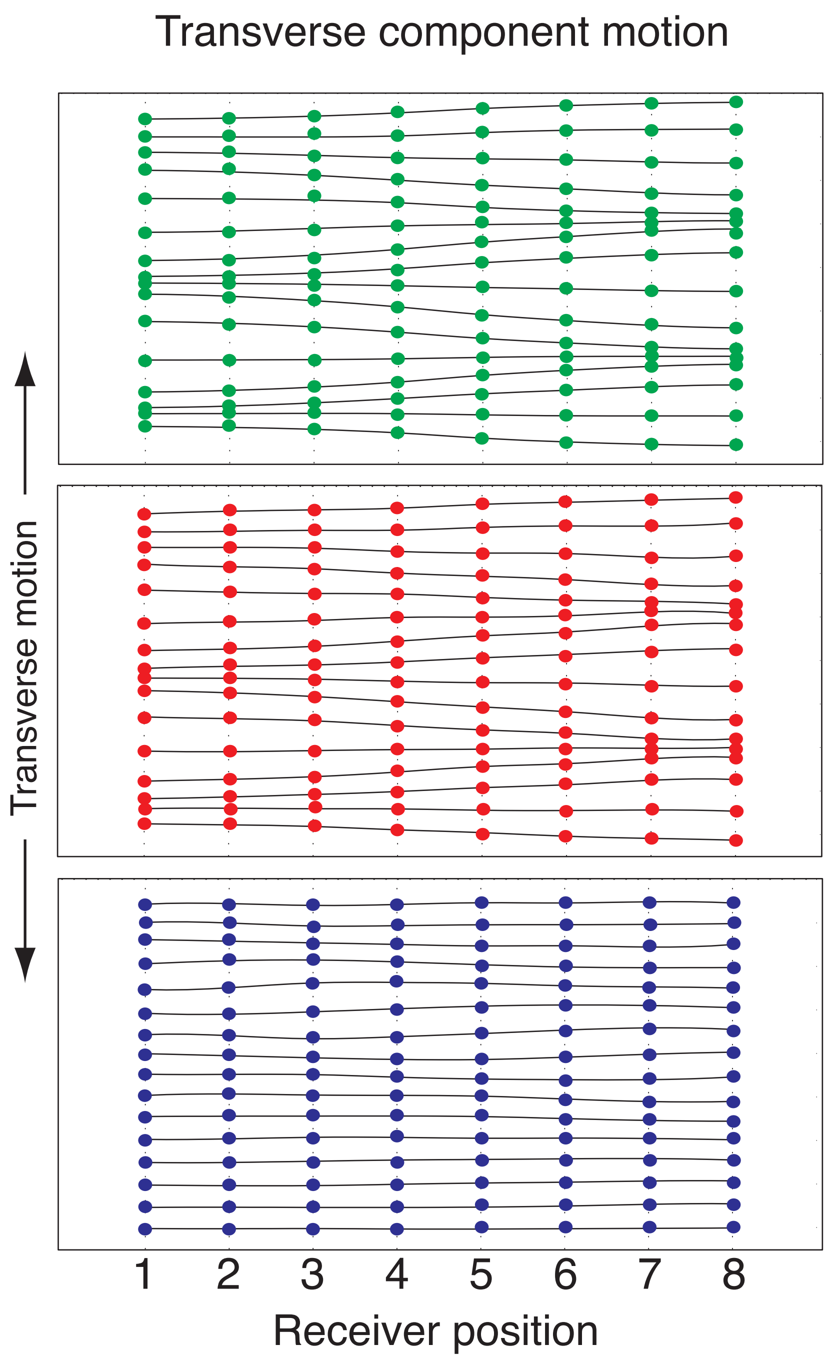


Figure 10. Snapshots of transverse-component motion during the passage of a Rayleigh wave acquired with bar-motion (green), test-line (red), and control-line (blue) 3C receivers. ☐
The snapshot interval was 2 ms (Ralston, 2003).

Motion Snapshots

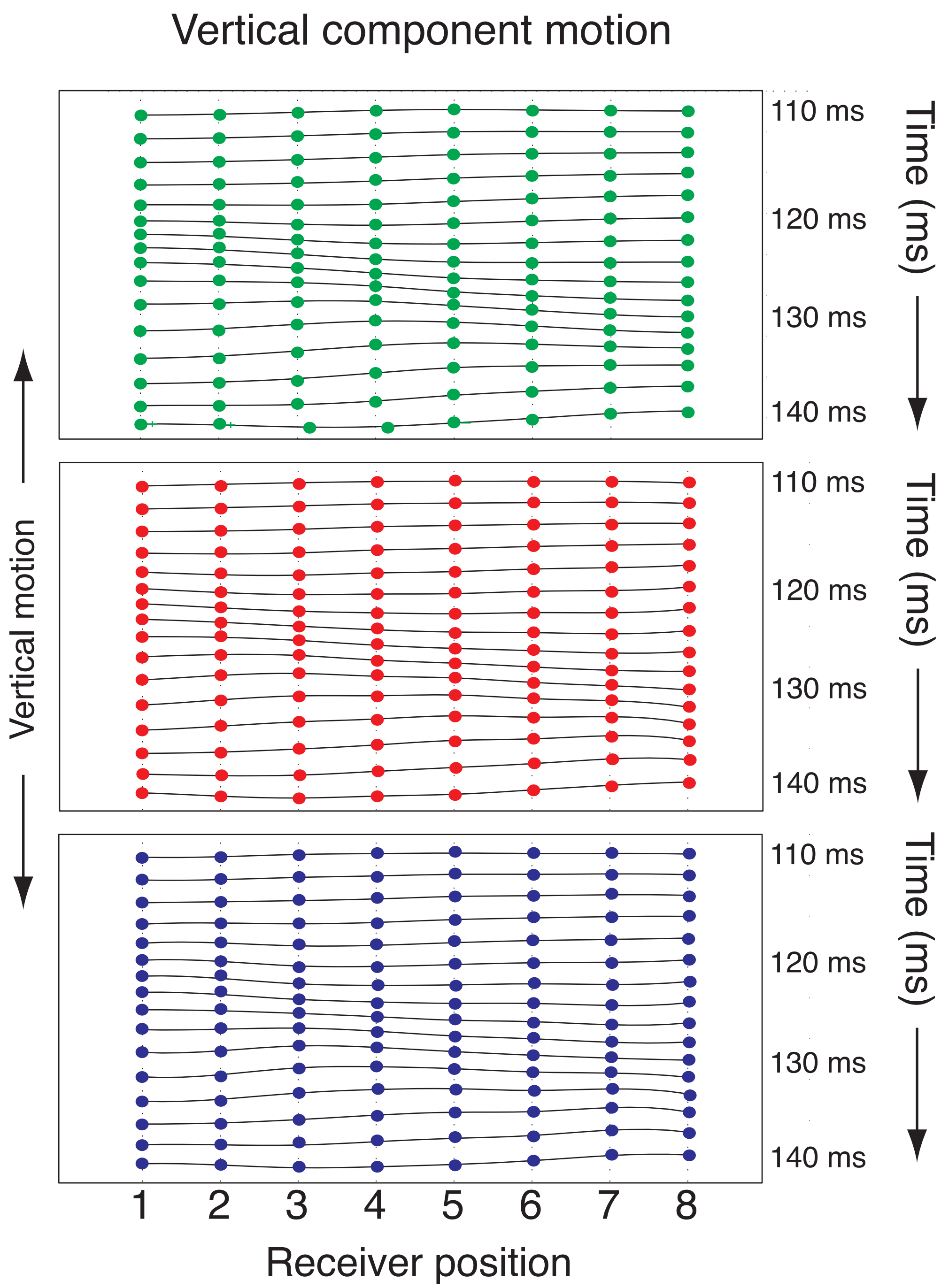
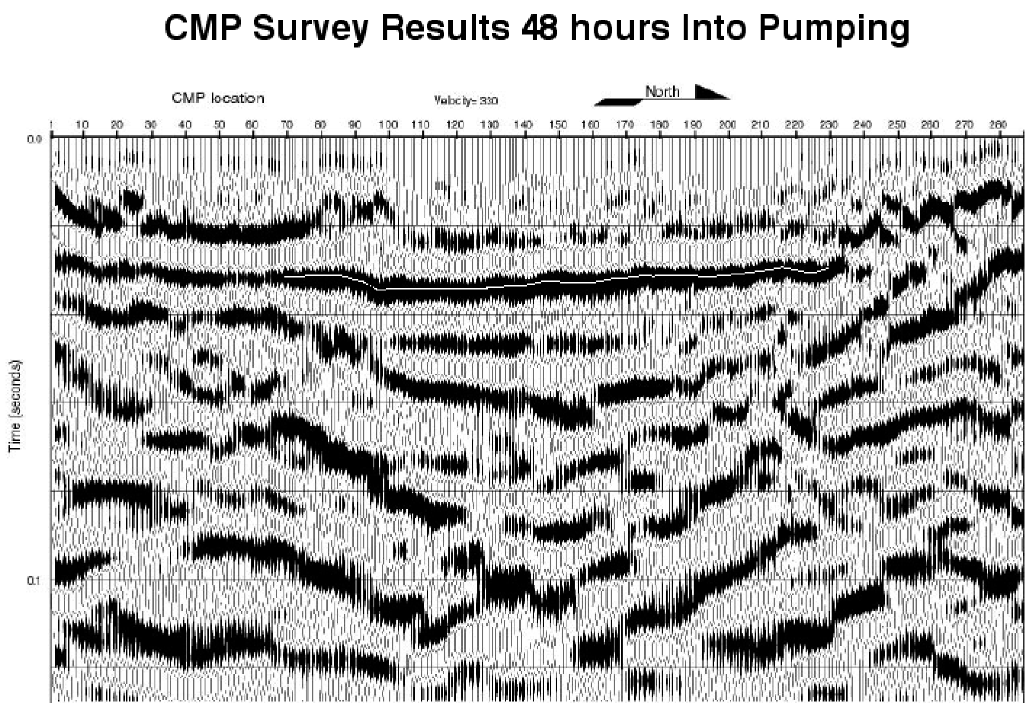
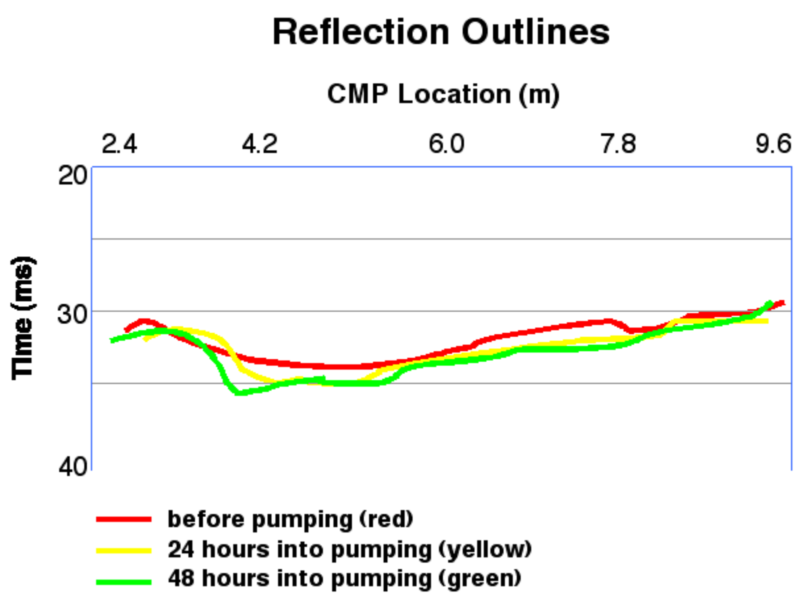


Figure 11. Snapshots of vertical-component motion during the passage of a Rayleigh wave acquired with bar-motion (green), test-line (red), and control-line (blue) 3C receivers. The snapshot interval was 2 ms. Note that only the vertical-component motion is coherent (cf. Figs. 9, 10) on all three lines, explaining why automatic ☐ *P*-wave recording is simpler than automatic *SH*-wave recording (Ralston, 2003).



(a)



(b)

Figure 12. (a) The coherent arrival visible at about 30 ms is the top of the saturated zone. (b) The three lines represent the location of the peak of the coherent arrival, seen in the previous figure, before pumping (red), 24 hours into pumping (yellow), and 48 hours into pumping (green) (Johnson, 2003).