GEOPHYSICS, VOL. 63, NO. 4 (JULY-AUGUST 1998); P. 1408–1413, 9 FIGS., 2 TABLES.

# Land streamer for shallow seismic data acquisition: Evaluation of gimbal-mounted geophones

Michiel van der Veen* and Alan G. Green*

## ABSTRACT

To increase the speed and efficiency of shallow seismic data recording and thereby decrease acquisition costs, the concept of a towed land streamer containing self-orienting, gimbal-mounted geophones is being evaluated. Our initial experiments at two locations within Switzerland demonstrate that good coupling with the ground may be achieved when the gimbal-mounted vertical geophones are contained in heavy (∼1 kg) casings and pulled along a very shallow (2–3 cm deep) furrow. Such a furrow may be created by mounting a heavy wheel on the towing vehicle. Placing the geophones in even heavier casings may provide the necessary good coupling with the ground, negating the need for the furrow. Shot gathers and stacked sections recorded with the gimbal-mounted geophones are practically indistinguishable from those recorded with conventional spike geophones. The principal advantage of this approach is that significantly fewer field personnel (only two or three) are required than for conventional shallow seismic surveying. When fully operational, the new acquisition system should be faster and less expensive for a wide variety of engineering and environmental applications.

## INTRODUCTION

High-resolution seismic reflection techniques are powerful tools for mapping shallow geological structures (Steeples and Miller, 1990; Lanz et al., 1996; Büker et al., 1998a). New technological developments, such as the introduction of inexpensive 24-bit recording systems with large channel capacity, together with an improved understanding of the various waveforms recorded during typical shallow surveys (e.g., Robertsson et al., 1996a,b), have led to substantial improvements in the quality and reliability of high-resolution seismic reflection data. In addition to increasing our ability to record highfold and densely spaced data, the new technologies have also increased markedly the logistical complexity of a typical shallow seismic survey. For the same length of survey line, many more geophones must now be planted and many more source points used (Büker et al., 1998b). Accurate surveying of receiver and source locations and the manual planting of geophones are time consuming and costly aspects of shallow seismic data acquisition.

In light of this, we have initiated a project aimed at increasing the efficiency of high-resolution seismic reflection techniques, with the principal goal of decreasing the number of field personnel, time, and costs involved in conducting shallow surveys. To achieve these goals, we are adapting the concept of a snow streamer (Eiken et al., 1989) for use in engineering-scale land surveys.

## TOWED LAND STREAMER

A new type of multichannel seismic cable has been designed and manufactured specially for efficient shallow data acquisition on land. It consists of 96 takeouts at fixed 1-m intervals. Each takeout is attached to a single self-orienting, gimbal-mounted vertical geophone. The seismic cable, or land streamer (Figure 1), is to be towed behind an all-terrain vehicle. A kevlar outer casing increases significantly the strength of the cable and helps prevent it from being damaged as it is pulled across rugged ground. The experiments reported here were conducted with a provisional set of six self-orienting, gimbal-mounted test geophones. Long recording spreads were simulated by moving the six-geophone spread and multiple firing of shots at the same locations.

The gimbal-mounted vertical geophones are key elements of this new system (Figure 2). Each geophone consists of a self-orienting velocity sensor mounted in a heavy cylindrical outer casing. To damp the motion of the sensor around its rotational axis, the inside of the casing is filled with viscous oil. Technical specifications of the geophones are given in Table 1.

## GEOPHONE-TO-GROUND COUPLING TESTS

A critical issue of the land streamer concept is the geophone-to-ground coupling. In seismic reflection surveys,

---

Manuscript received by the Editor June 17, 1997; revised manuscript received October 27, 1997.

*Institute of Geophysics, Swiss Federal Institute of Technology, ETH-Hönggerberg, CH-8093 Zürich, Switzerland. E-mail: michiel@augias.ig.erdw.ethz.ch; alan@augias.ig.erdw.ethz.ch.

the frequencies of the useful signal depend on the energy spectrum of the source, the attenuation in the ground, and the coupling resonant frequency of the geophones. Krohn (1984) shows that this resonant frequency depends on the firmness of the soil and the actual coupling. In most practical situations, the maximum recorded frequencies rarely exceed ~500 Hz. We define good coupling as the ability to record the seismic signal in the frequency range of interest (up to ~500 Hz) with a minimum of distortion. To help ensure good coupling, each gimbal-mounted vertical geophone is housed in a heavy casing (~1 kg). Various tests aimed at comparing the coupling of traditional spike geophones with equivalent gimbal-mounted geophones have been conducted.

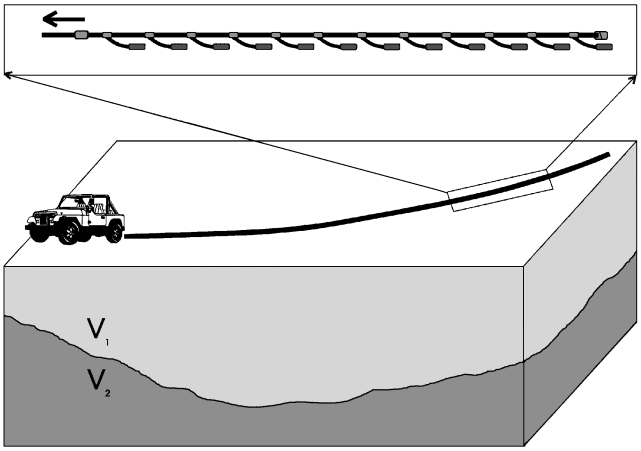

FIG. 1. Schematic of a land streamer to be towed by an all-terrain vehicle. The total land streamer comprises 96 self-orienting gimbal-mounted vertical geophones.

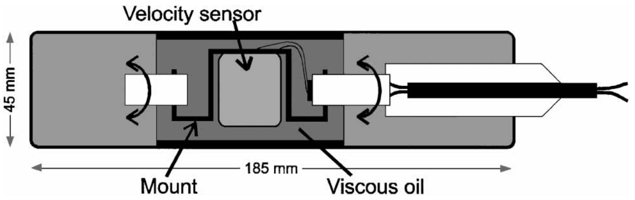

FIG. 2. Self-orienting, gimbal-mounted vertical geophone (reproduced with permission of Sensor NL BV).

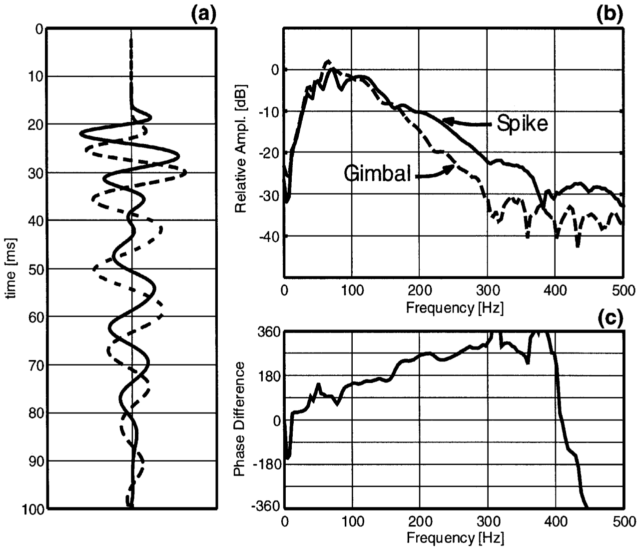

FIG. 3. Results of ground coupling comparisons between 30-Hz spiked (solid line) and poorly planted 30-Hz, gimbal-mounted geophones (dashed line); the gimbal-mounted geophone was simply laid on the ground. (a) Traces recorded from a common source (5-kg sledgehammer); this particular comparison represents the worst-case example of the initial field tests (i.e., the similarity of adjacent spike and gimbal-mounted geophones was usually higher than that shown here). (b) Amplitude spectra of the two traces. (c) Phase differences between the responses of the two geophone types.

At one test site (Zürich, Switzerland), six spike geophones were planted carefully alongside six gimbal-mounted ones, each containing identical 30-Hz vertical sensors. The distance between the two parallel sets of geophones was <10 cm, and the common source was a 5-kg sledgehammer. At this site, moist sandy silt and sandy clay covered by grass provided good surface conditions for planting the spike geophones (spike length = 10 cm). In Figure 3, the response of a standard 30-Hz spike geophone is compared with the worse-case response of a 30-Hz gimbal-mounted geophone that is poorly planted. This experiment was intended to simulate the effect of pulling the land streamer across rugged terrain without preparing the surface. Major phase and amplitude differences between the responses of the two types of geophones are shown in the figure.

When the gimbal-mounted geophones are placed in a shallow furrow and the entire experiment is repeated (on the same day as the previous experiment), the results are strikingly different (Figure 4). This experiment was intended to simulate

**Table 1. Technical specifications of the self-orienting, gimbal-mounted vertical geophone units (SG-1, Sensor).**

| Characteristic | Measurement |
|---|---|
| Diameter | 45 mm |
| Length | 185 mm |
| Weight | 1 kg |
| Velocity sensor | 30 Hz |

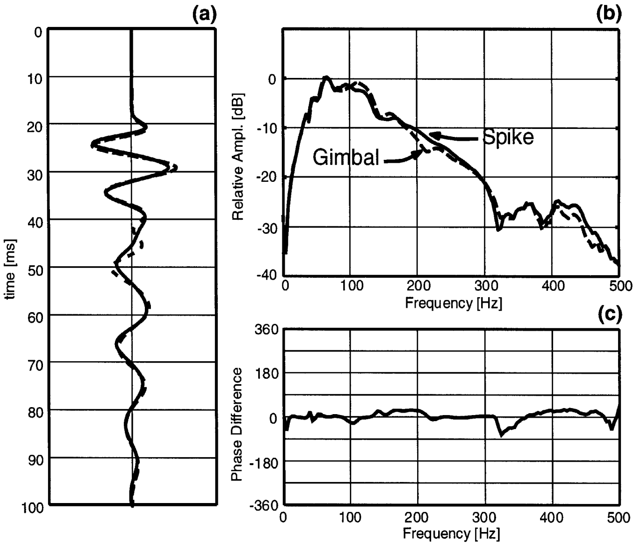

FIG. 4. Results of ground coupling comparisons between the same 30-Hz spiked (solid line) and gimbal-mounted (dashed line) geophones as shown in Figure 3. The gimbal-mounted geophone was laid in a shallow furrow for this test. (a) Traces recorded from a common source (5-kg sledgehammer). (b) Amplitude spectrum of the two traces. (c) Phase differences between the responses of the two geophone types.

the towing of the land streamer along a shallow furrow (2–3 cm deep) generated by a heavy wheel at the back of the towing vehicle. Clearly, the geophone-to-ground coupling of the gimbal-mounted geophone has improved considerably (compare Figures 3 and 4). Phase and amplitude differences between the two types of geophone have significantly reduced. Remaining minor differences in geophone response may be due to local variations in near-surface conditions and differences in electromechanical characteristics of the individual sensors, but these are likely to be small compared to the effects of varying geophone-to-ground coupling (Faber et al., 1994).

The results of our detailed coupling experiments suggest that gimbal-mounted geophones in good contact with the ground

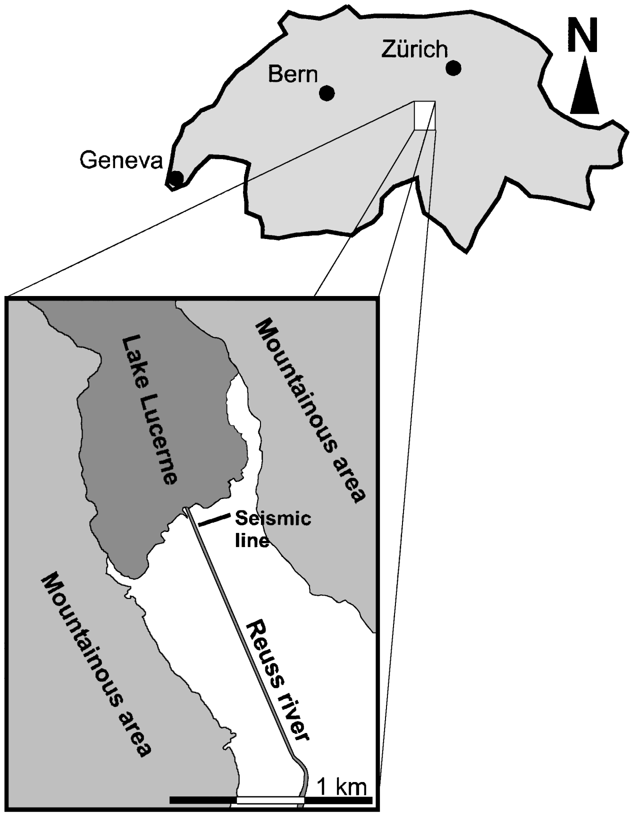

FIG. 5. Location of the survey site in the Reuss delta, central Switzerland.

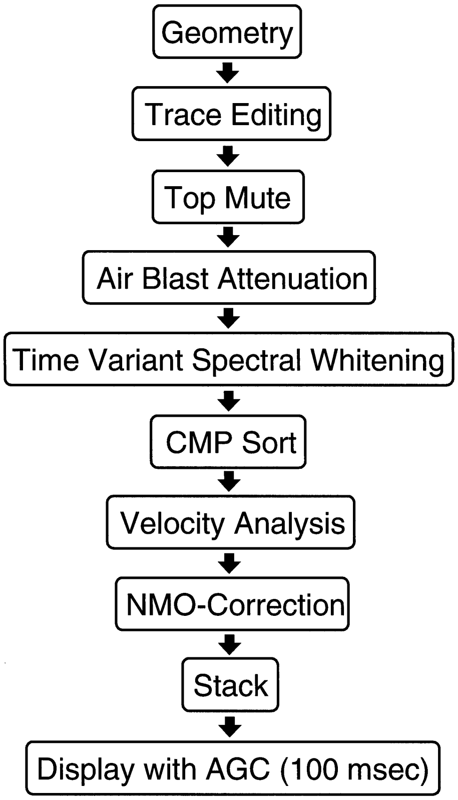

FIG. 7. Data processing flow.

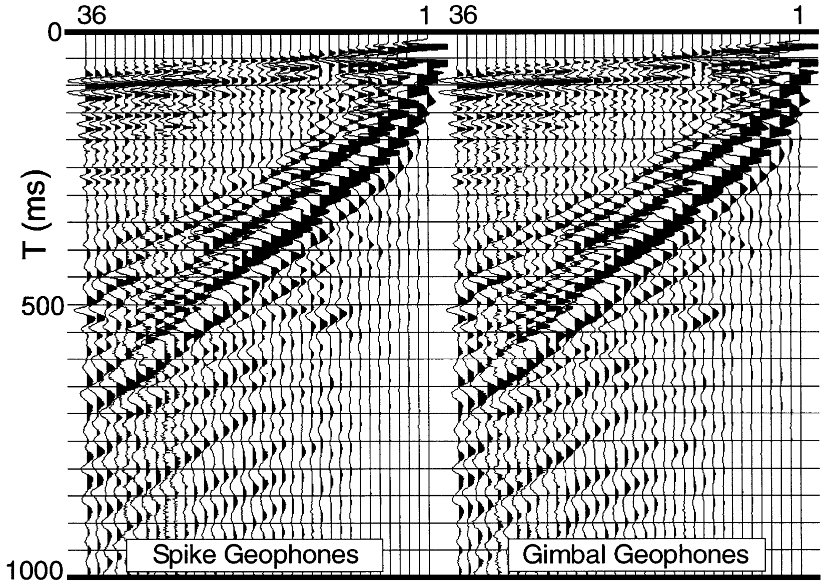

FIG. 6. Two typical shot gathers recorded in the Reuss delta. The left gather was recorded with standard spike geophones, the right one with gimbal-mounted vertical geophones. The raw data have been scaled with a single individual scaling factor (i.e., trace normalized) for each trace.

have the potential to record high-resolution seismic data faithfully. Good geophone-to-ground coupling can be achieved by housing the sensors in heavy casings and by pulling the land streamer along a shallow furrow. We will shortly be testing the practicality of using even heavier casings in anticipation that eventually the furrow may be avoided.

## MULTICHANNEL TEST REFLECTION SURVEY

### Acquisition

Two coincident short seismic reflection profiles were recorded simultaneously within the Reuss delta, central Switzerland (Figure 5). Nominal 18-fold data sets were simulated with six standard spike geophones and six self-orienting, gimbal-mounted test units. Moist, fine sediments (sandy silts and sandy clays) deposited during recent flooding provided excellent coupling conditions for both sets of geophones. To obtain the nominal 18-fold data, each set of six geophones was repositioned six times; for each repositioning, the shots were repeated. A pipe-gun source in 0.5- to 1.0-m-deep boreholes provided a repeatable signal. The most significant differences between signals generated by sequential shots at the same location were time delays caused by progressive deepening of

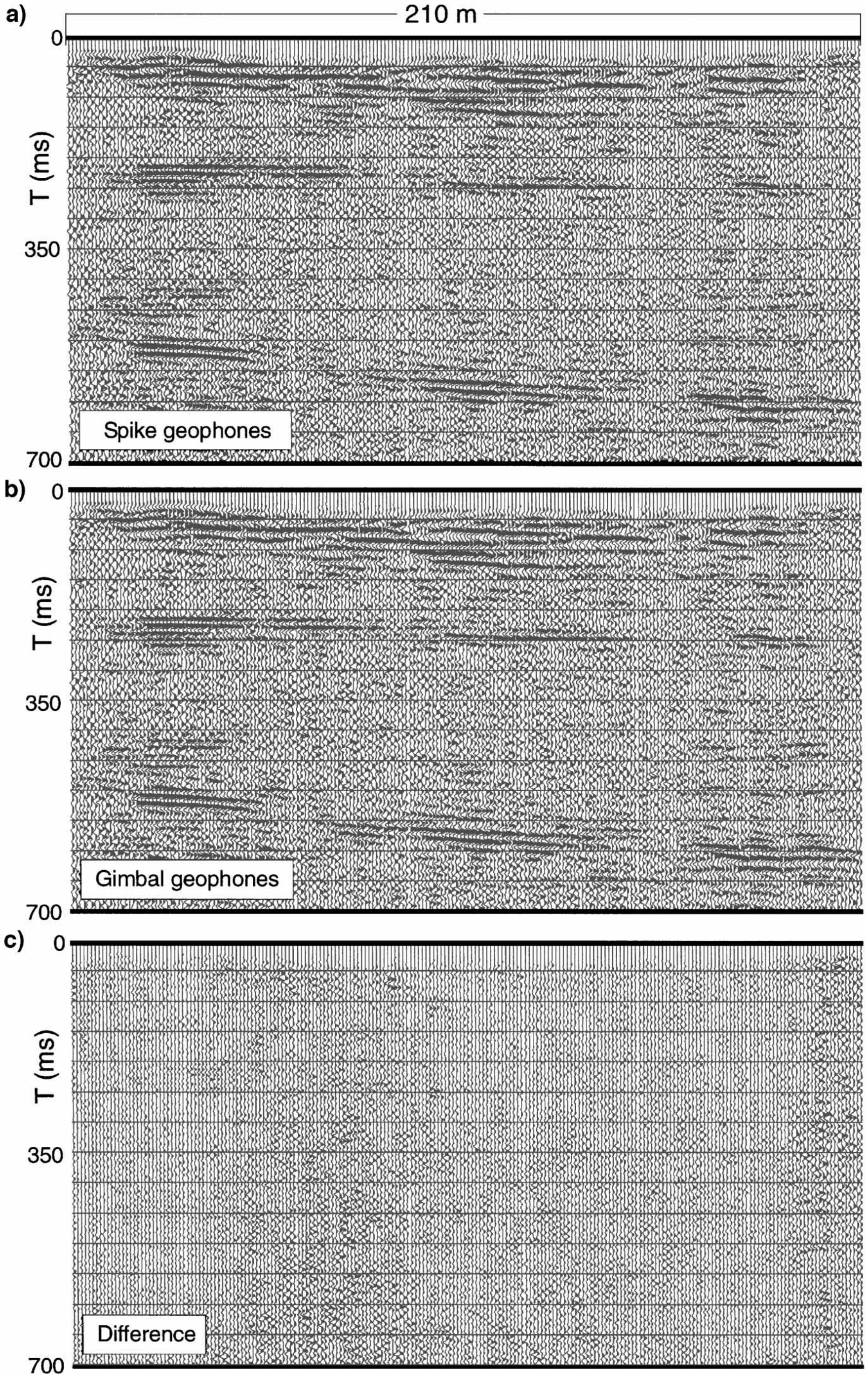

FIG. 8. Seismic reflection data sets recorded simultaneously at the same location. (a) Stacked section recorded with standard spike geophones. (b) Stacked section recorded with self-orienting, gimbal-mounted geophones. (c) Difference between the two stacked sections.

the hole. To account for these delays, we applied simple static corrections based on airwave arrival times.

Detailed recording parameters are given in Table 2. Typical shot gathers recorded with the spike and gimbal-mounted geophones are displayed on the left and right sides of Figure 6, respectively (note the relatively uniform signal character in these shot gathers). Very minor differences between the two shot gathers are attributed mostly to small differences in the noise characteristics of the two sets of geophones.

## Processing

The two data sets were passed through the same simple processing sequence (Figure 7) using identical processing parameters. Stacking velocities ranged from 1000 to 3000 m/s. As for the shot gathers (Figure 6), the resultant stacked sections. (Figures 8a,b) are very similar. All important reflection zones are imaged on both sections. Figure 8c is a plot of the differences between Figures 8a and 8b. It demonstrates that the amplitudes of some reflections vary slightly between the two stacked sections (e.g., between 200 and 250 ms on the left side of the section) but that the principal differences are at the noise level.

**Table 2. Parameters for the high-resolution seismic reflection profiles collected in the Reuss delta.**

| Characteristic | Measurement |
|---|---|
| Survey length | 210 m |
| Receiver spacing | 2 m |
| Source type | Pipegun in 0.5- to 1.0-m-deep holes |
| Inline source offset | 2 m |
| Source spacing | 2 m |
| Number of geophones | 2 × 36 |
| Geophone type | 30-Hz spike/gimbal |
| Surface soil type | Fine-grained sediments |
| Sample rate | 0.25 ms |
| Recording time | 1000 ms |
| Nominal fold | 18 |

## Geological interpretation

The Reuss Delta has experienced a complex history of tectonism and multiple glaciations. Following the last ice age (Würm glaciation) approximately 18 000 years ago, the region was covered by a lake in which clays and then fine sands were deposited. Subsequently, a thick sequence of gravels (known as the Reuss gravels) were laid down by a large braided river system. Deposition of the Reuss gravels was interrupted periodically by flooding events, the most recent of which occurred in 1987.

On the basis of information from a 300-m-deep borehole approximately 2 km south of the survey area, the strong reflection at 200 to 250 ms is interpreted as the boundary between the Reuss gravels and the underlying fine sands (Figure 9). The top of the basement is interpreted as the strong reflection that dips from ~500 ms at the eastern end of the profiles to ~600 ms at the western end.

## CONCLUSIONS

Results of our acquisition and processing experiments have demonstrated the potential of towed land streamers with self-orienting, gimbal-mounted geophones as a means of efficient shallow seismic data acquisition. Housing the sensors in heavy casings and pulling the land streamer along a shallow furrow offers a solution to the geophone-to-ground coupling problem. Applying these techniques has shown that high-quality data, comparable to carefully planted spike geophone data, can be acquired with gimbal geophones.

Major advantages of this innovative approach to shallow data acquisition are

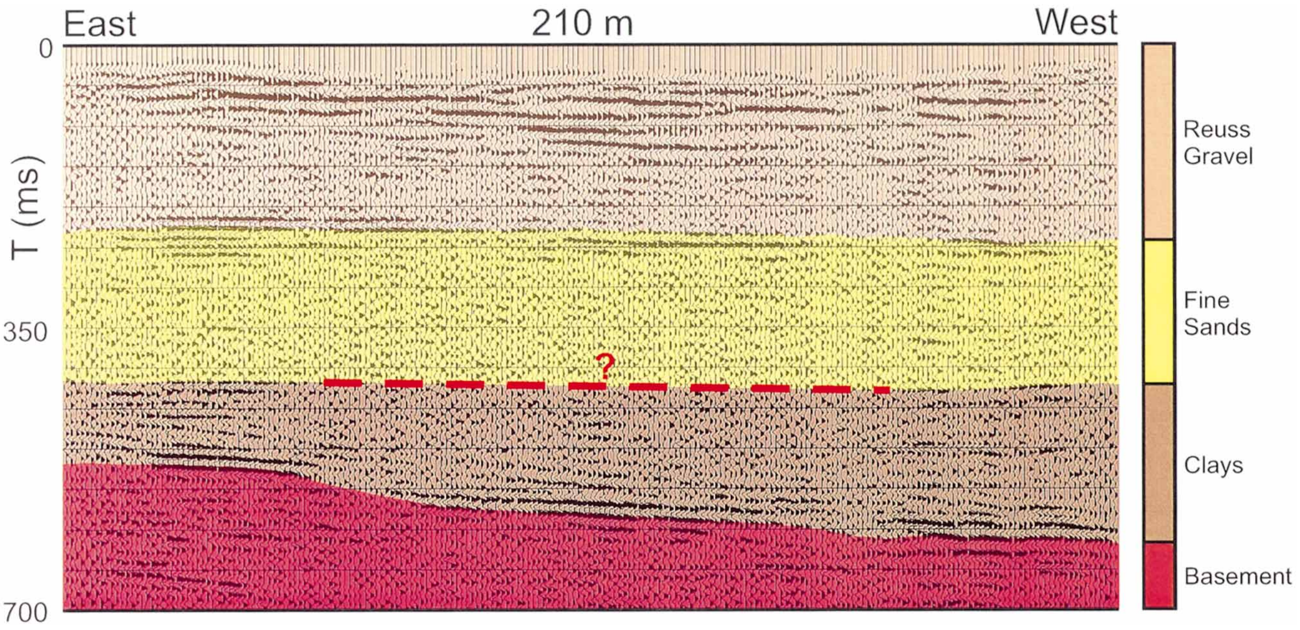

FIG. 9. Simplified interpretation based on the surface geology and information obtained from numerous nearby shallow boreholes and one deep (300-m) borehole approximately 2 km south of the survey line.

1) no need for geophone planting;
2) fewer field personnel (only two or three) compared to traditional surveys (typically six to ten);
3) significant increase in acquisition speed; and
4) marked decrease in survey costs.

Clearly, operation of this system will depend on local surface conditions (e.g., the presence of trees, steep slopes, large boulders, etc.). Despite these limitations, it is expected that in many areas the acquisition time and costs of shallow seismic data recording can be decreased significantly. Over the next two years, the acquisition system will be expanded to include an automated positioning unit (GPS and/or laser-ranging theodolite) and a fast, high-frequency energy source.

## ACKNOWLEDGMENTS

We gratefully acknowledge valuable discussions with colleagues Heinrich Horstmeyer, Frank Lehmann, and Peter Wild of ETH Zürich (Switzerland) and Pete Maxwell of Sensor (Netherlands). We thank Christoph Barlöcher of ETH for technical support. The seismic data were recorded with a Bison 120-channel Jupiter acquisition system. Timely and constructive reviews by R. Jefferson, B. K. Macy, and an anonymous journal reviewer are much appreciated. ETH Institute of Geophysics Publication no. 1026.

## REFERENCES

Büker, F., Green, A., and Horstmeyer, H., 1998a, Shallow seismic reflection study of a glaciated valley: Geophysics, **63**, 1395–1407.

——— 1998b, Shallow 3-D seismic reflection surveying: Data acquisition and processing strategy: Geophysics, **63**, 1434–1450.

Eiken, O., Degutsch, M., Riste, P., and Rod, K., 1989, Snowstreamer: An efficient tool in seismic acquisition: First Break, **7**, 374–378.

Faber, K., Maxwell, P. W., and Edelmann, A. K., 1994, Recording reliability in seismic exploration as influenced by geophone-ground coupling: 56th Ann. Internat. Mtg., Euro. Assoc. Geophys. Eng., Expanded Abstracts, B014.

Krohn, C. E., 1984, Geophone ground coupling: Geophysics, **49**, 722–731.

Lanz, E., Pugin, A., Green, A. G., and Horstmeyer, H., 1996, Results of 2- and 3-D high-resolution seismic reflection surveying of surficial sediments: Geophys. Res. Lett., **23**, 491–494.

Robertsson, J. O. A., Holliger, K., and Green, A. G., 1996a, Source-generated noise in shallow seismic data: Europ. J. Environ. Engin. Geophys., **1**, 107–124.

Robertsson, J. O. A., Holliger, K., Green, A. G., Pugin, A., and De Iaco, R., 1996b, Effects of near-surface waveguides on shallow high-resolution seismic refraction and reflection data: Geophys. Res. Lett., **23**, 495–498.

Steeples, D. W., and Miller, R. D., 1990, Seismic reflection methods applied to engineering, environmental and groundwater problems, *in* Ward, S., Ed., Geotechnical and Environmental Geophysics, Vol. **I**: Review and Tutorial: Soc. Expl. Geophys., 1–30.