Seismic Reflection and Ground Penetrating Radar for Environmental Site Characterization

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SUMMARY

There are well-established needs for geophysical techniques to assist in hydrologic site characterization and in non-invasive testing at DOE facilities. The primary objective of the work-in-progress reported here is to compare near-surface geologic imaging results using both seismic reflection techniques and ground-penetrating radar (GPR). Although various seismic and GPR surveys have been used for near-surface imaging, little is known about how the two techniques might work in concert for very-high-resolution surveys when both techniques work well.

INTRODUCTION

The primary objective of the work-in-progress reported here is to compare near-surface imaging results using seismic reflection techniques, and ground-penetrating radar (GPR), at a site where both techniques work well. As part of an effort to evaluate what each geophysical method reveals, we will repeat the seismic and GPR surveys several times on a seasonal basis to establish how the complementary information gleaned may vary over time. For example, we know that the 2-3 meter-deep water table at our primary test site fluctuates on a seasonal basis and that this fluctuation can be expected to result in temporal variations in the two types of data.

The authors are aware of only one example in the refereed scientific literature (Cardimona et al, 1998) that reports successful work involving both shallow seismic-reflection data and GPR data obtained from the same volume of shallow earth at depths of less than 20 m. Although various seismic and GPR surveys have been used for near-surface imaging, little is

known about how the two techniques might work in concert for very-high-resolution surveys when both techniques work well. In fact, most environmental geophysicists regard seismic-reflection as a "deep" imaging technique and GPR as a "shallow" technique.

Although GPR and seismic signals respond to different physical parameters in the earth, as well as to various changes in them, in some cases the two techniques can be expected to yield similar results. In cases in which the two techniques work well and respond to the same geologic and hydrologic phenomena, the advantage in resolution would usually go to GPR. In other instances, however, the techniques may yield substantially different geologic information as each may respond to changes in different parts of the volume of material under investigation. For example, seismic reflections arise from changes in acoustic impedance, which means that the product of seismic-wave velocity and density must change for a seismic reflection to occur.

In contrast, ground-penetrating radar responds to changes in the constitutive electrical parameters of the soil. These parameters are permittivity, permeability, and conductivity. When any of these electromagnetic parameters changes at an interface, a radar reflection may be seen, but a seismic reflection might not occur. An opposite example might be envisioned in which the constitutive electrical parameters would be constant across an interface at which either bulk density or seismic-wave velocity vary.

In sum, seismic data and radar data can give us distinct but complementary information about different physical parameters in the earth volume surveyed. In practice, important geologic and hydrologic interfaces often are characterized by changes in density, seismic velocity, and dielectric permittivity.

Seismic Data

We have selected a test site in central Kansas at which both high-quality, shallow *P*-wave seismic-reflection and GPR data have been collected. We have demonstrated that both techniques work well in the depth range of 0.5 m to approximately 8 m at our test site. Although not environmentally sensitive, the test site offers the advantage of acting as an outdoor mesoscale laboratory, i. e., it is larger than a core sample or a manufactured sandbox, but smaller than a typical environmental remediation site. The combined seismic-reflection and GPR data collected in the upper 8 m at the site will contribute to a better understanding of the relationships between seismic and radar signatures in the shallow subsurface.

The site is adjacent to the Arkansas river, near the geographic center of Kansas. The upper portion of the test area is composed mostly of sand and gravel several meters thick. This combination allows good penetration of radar energy.

An unprocessed example of field seismograms (Figure 1) shows three high-quality seismic *P*-wave reflections from layers at 0.6 meters, 1.5 meters, and 2.1 meters deep, respectively. The reflection from 2.1 meters deep is from the top of the saturated zone. Birkelo et al. (1987) were able to follow the deepest of these seismic reflections downward in space during a seven-day pumping test in 1986. They found that the reflector was the top of the saturated zone at 2.6 m. On the date of our 1997 data collection, the water table was at a depth of 2.1 m.

Figure 2 shows both a layered model and a synthetic seismogram resulting from interpretation of the data in Figure 1. Figure 3 shows the left halves of three real seismograms matched with the right halves of three synthetic seismograms.

GPR Test Data

Ground-penetrating radar data were acquired using a Sensors and Software PulseEKKO 1000 GPR unit with a 225 MHz antenna. Initial GPR data are shown in Figure 4 (a CMP spread to establish the time/depth relationship from the hyperbolic-moveout curve) plotted against relative permittivity measured in a hole with a network analyzer. The CMP spread shows that the water-table reflection at 2.1 m arrives at about 38 ns. Figure 5 is a GPR profile line showing data collected in March and in June of 1998 along the same line. The GPR section shows the water table fairly clearly at the 38-ns reflection time.

CONCLUDING SUMMARY

Because the water table fluctuates at this site on a seasonal basis, variations in the two types of data over time can be observed. Consequently, when we have established optimal field parameters with seismic and GPR techniques, we will repeat the surveys seasonally, when the water table is at different depths.

LITERATURE CITED

Birkelo, B. A., Steeples, D.W., Miller, R.D., and Sophocleous, M. A., 1987, "Seismic-reflection study of a shallow aquifer during a pumping test," *Ground Water*, vol. 25, pp. 703-709.

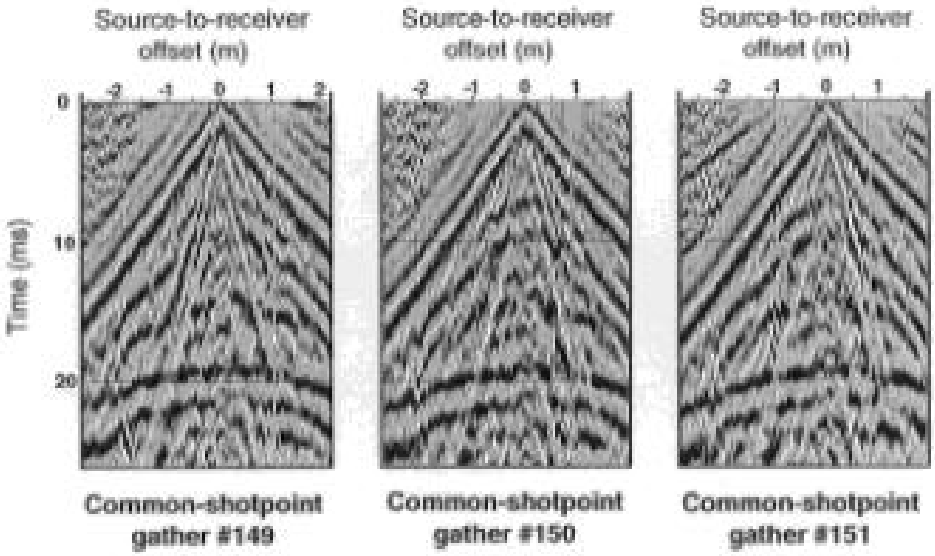


Fig. 1. Three representative common-shotpoint gathers collected in the Arkansas River Valley near Great Bend, Kansas. The three sequential gathers have a shotpoint separation of 10 cm. The geophone interval is 5 cm. Digital automatic gain control scaling (4-ms window) and band-pass filtering (500-900 Hz, with 12 dB/octave slopes) have been applied.

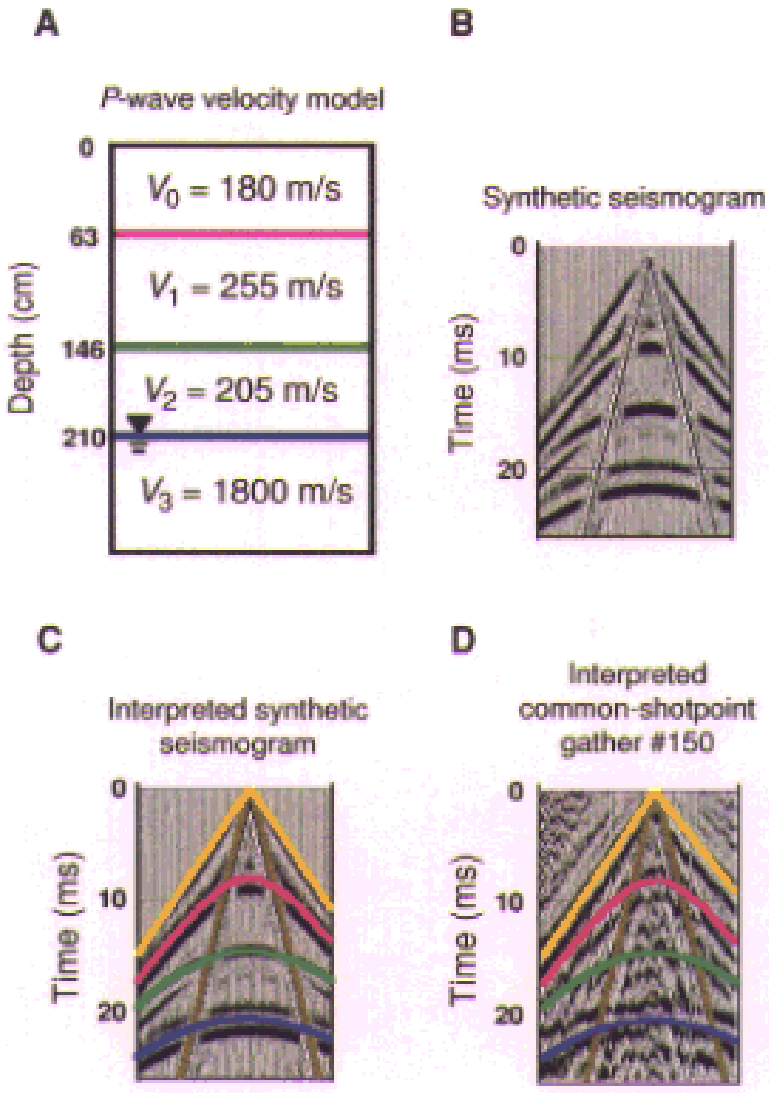


Fig. 2. (**A**) The *P*-wave velocity model used to generate the wave-equation finite-difference synthetic seismogram in (**B**). The interpreted synthetic seismogram (**C**) shows the reflections from the three layer boundaries in the velocity model (red, green, blue), the direct *P*-wave (orange), and the Rayleigh wave (brown). The interpretation of common-shotpoint gather #150 (**D**) was used as input to the forward model to create (**A**), (**B**), and (**C**).

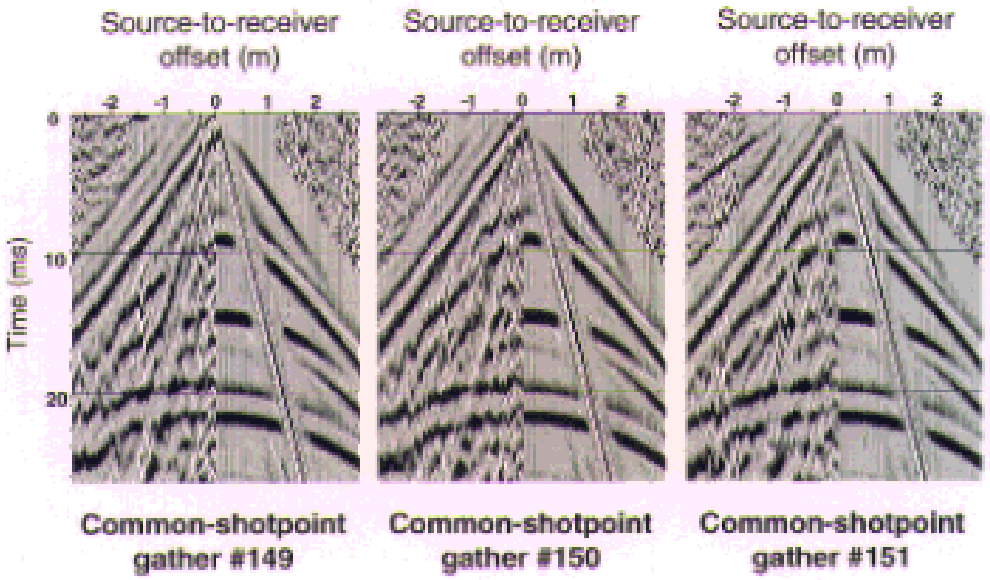


Fig. 3. Spliced side-by-side comparisons of the three common-shotpoint gathers in Fig. 1 with the modeled data in Fig. 2B. The left portion of each section is real data; the right portion is model data.

Publications and Preprints from this project:

Baker, Gregory S., Chris Schmeissner, Don W. Steeples, and Richard G. Plumb(1998) Seismic reflections from depths of less than two meters: submitted to Geophysical Research Letters, June, 1998, in review.

Steeples, D. W., G. S. Baker, C. Schmeissner, and B. K. Macy (1998), Geophones on a board: submitted to Geophysics, May 1998, in review.

Steeples, D. W., and Gregory S. Baker (1998), Near-surface contributions to seismic static corrections: AAPG Explorer, v 19, #6, p 20-21, 29.

Baker, G. S., R. G. Plumb, D. W. Steeples, M. Pavlovic, and C. Schmeissner (1998), Coincident GPR and ultrashallow seismic imaging in the Arkansas River Valley, Great Bend, Kansas: SEG Expanded Abstracts, SEG 1998 International Meeting, New Orleans, in press.

Baker, G. S., D. W. Steeples, C. Schmeissner, and B. K. Macy, (1998), In-situ, high-resolution P-wave velocity measurements within 1 m of the Earth's surface: SEG Exp. Abstr., SEG 1998 International Meeting, New Orleans, in press.

Steeples, D. W., G. S. Baker, C. Schmeissner, and B. K. Macy (1998), Geophones on a board: SEG Exp. Abstr., SEG 1998 International Meeting, New Orleans, in press.

measurement

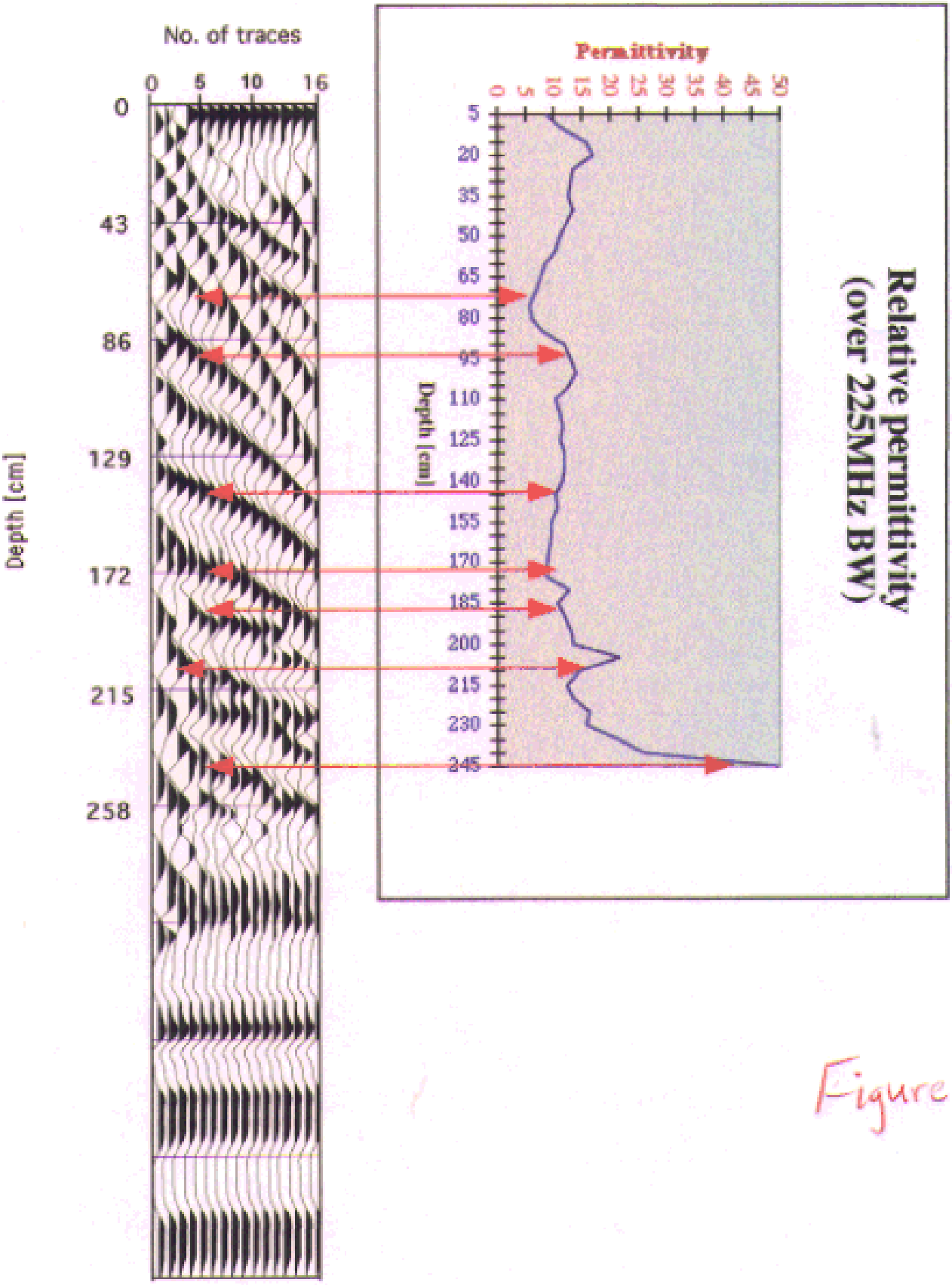
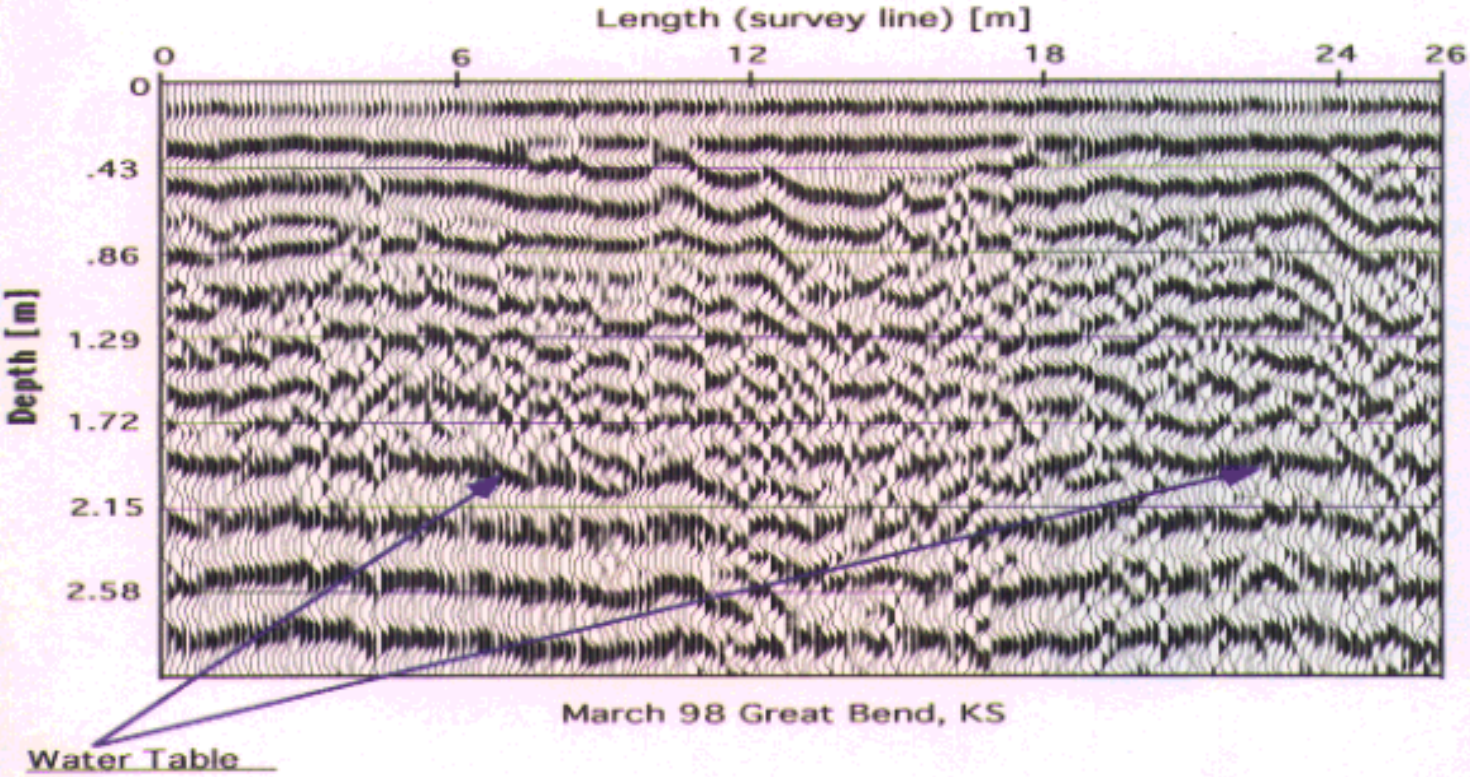


Figure 4

March vs. June data
(same line, 225 MHz antennae, Great Bend, KS)



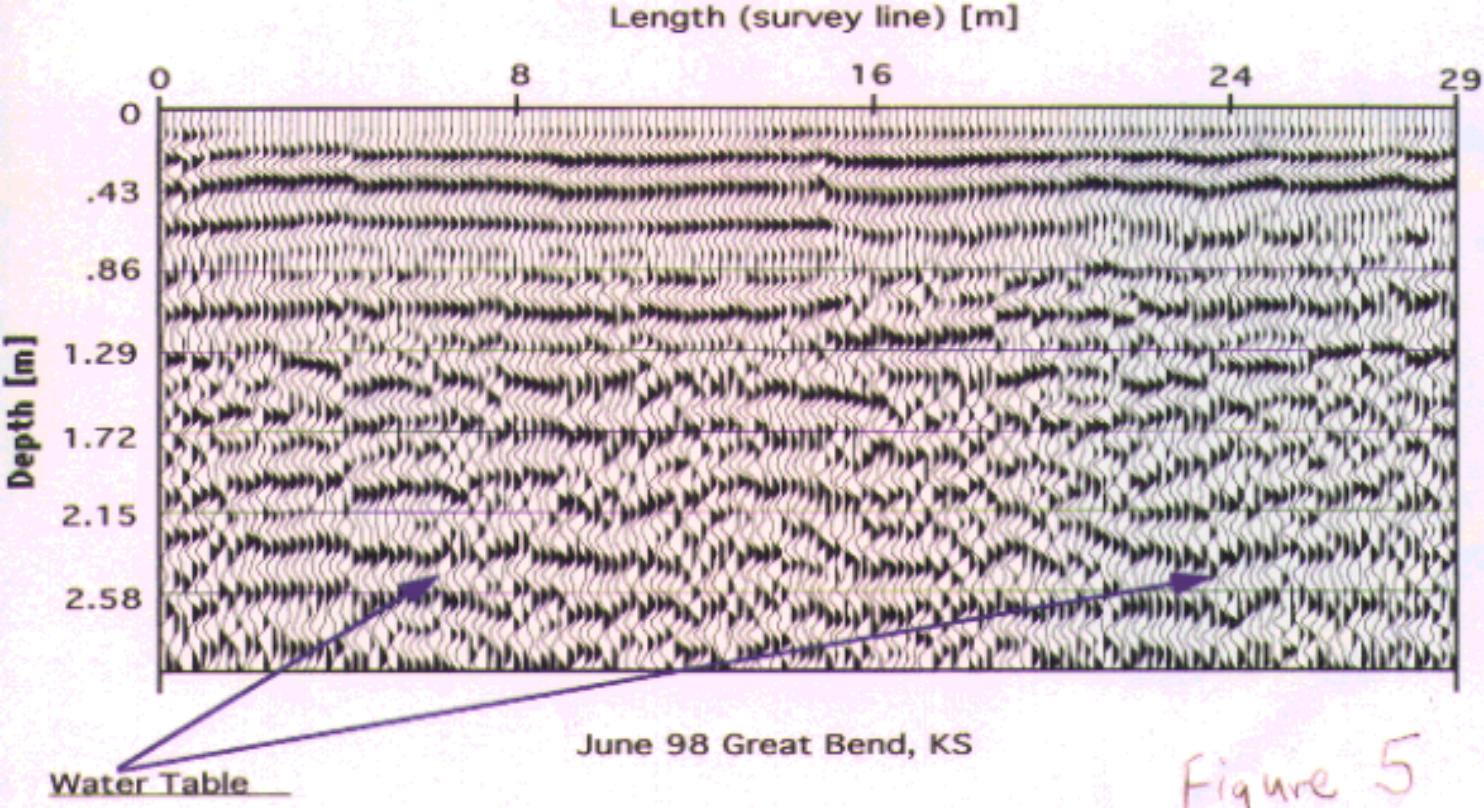
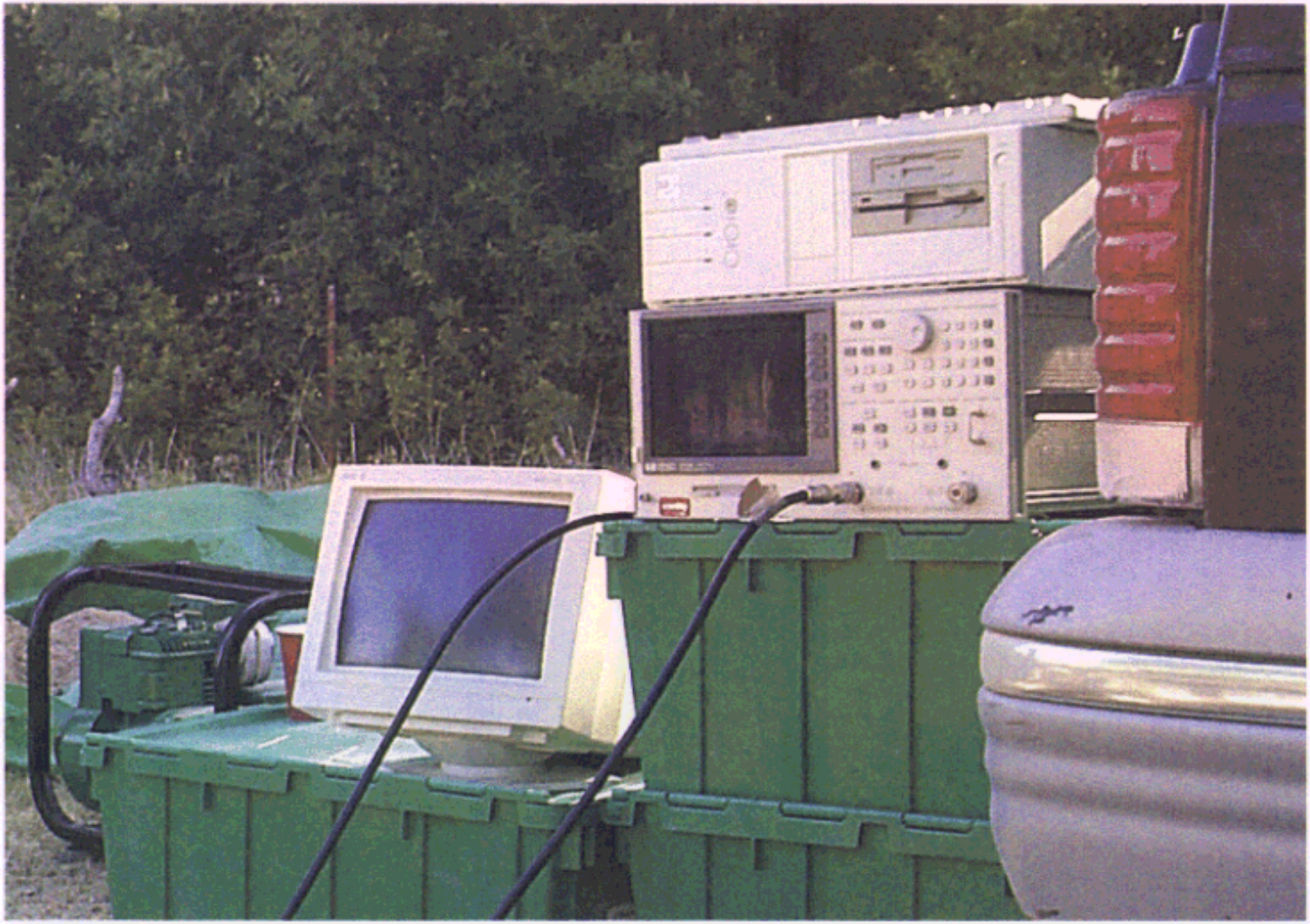


Figure 5

Network analyzer field set-up for permittivity measurement



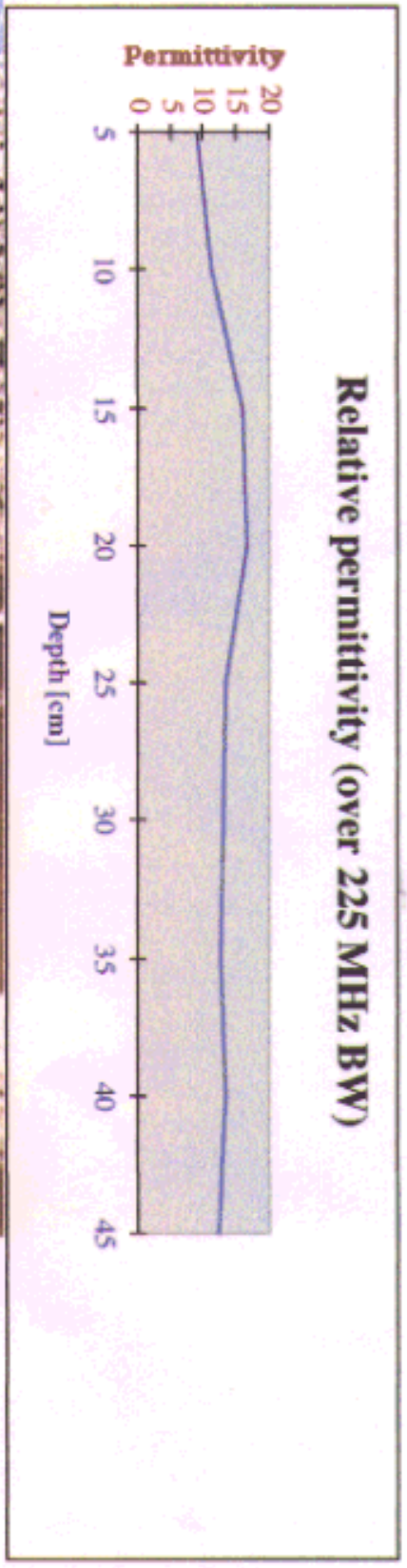
RESEARCH OBJECTIVES:

1. To examine the complementary site-characterization capabilities of modern, three-component shallow-seismic techniques and ground-penetrating radar (GPR) methods at depths ranging from 0.5 to 8 m;

2. To demonstrate the usefulness of the two methods when used in concert to characterize the cone of depression of a pumping well, which will serve as a proxy for fluid-flow at a polluted site;

3. To use the site as an outdoor meso-scale laboratory to validate existing three-dimensional ground-penetrating radar and seismic-reflection computer models developed at the University of Kansas.

Photo of the site matched to permittivity measurement (Depth section 1)



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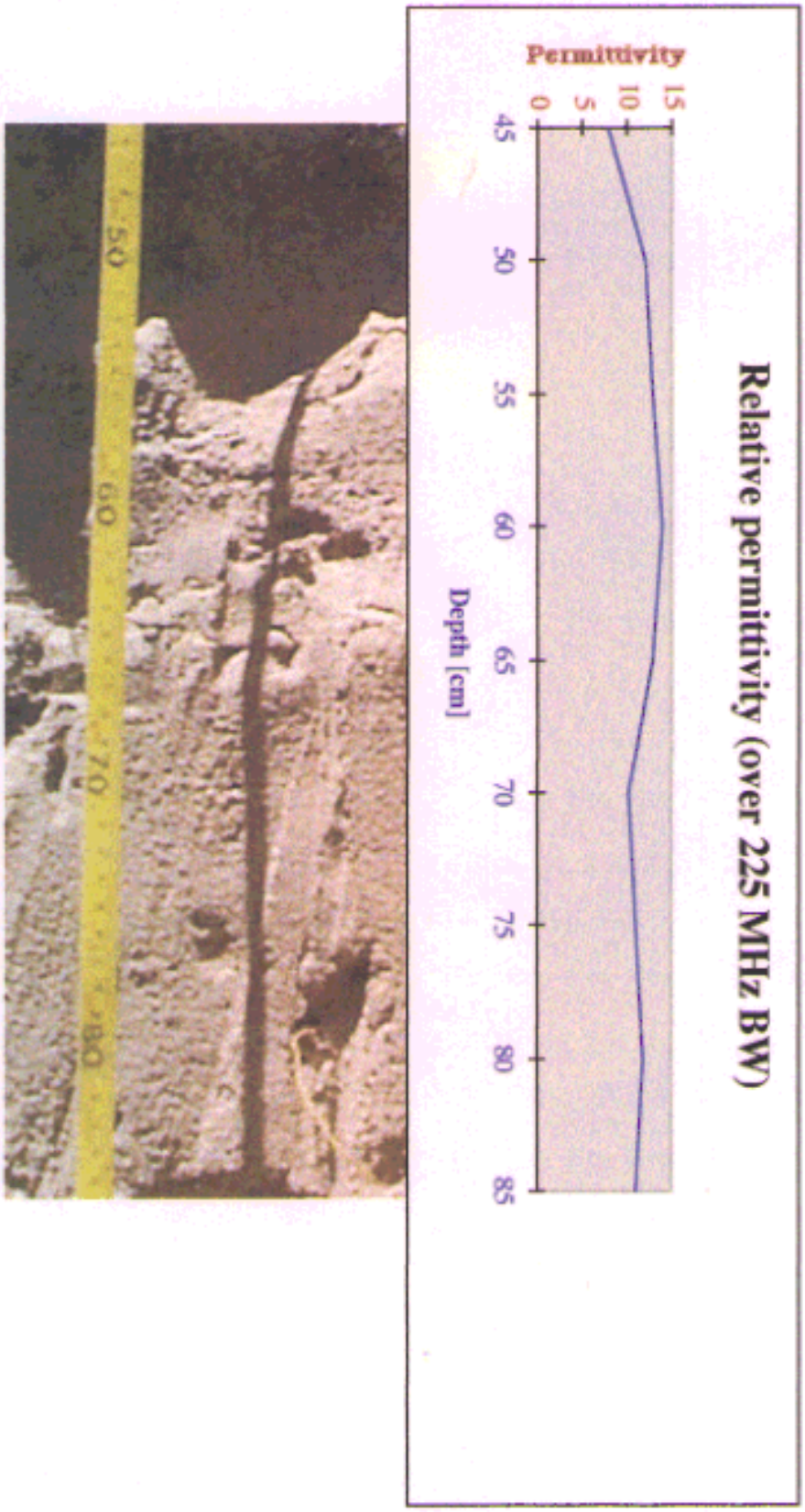

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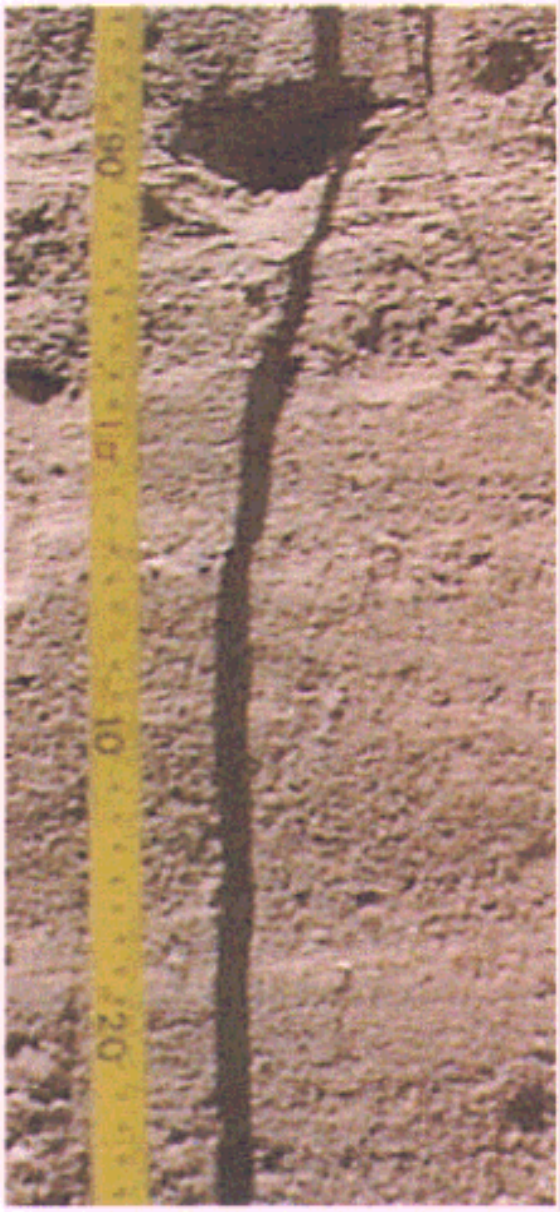

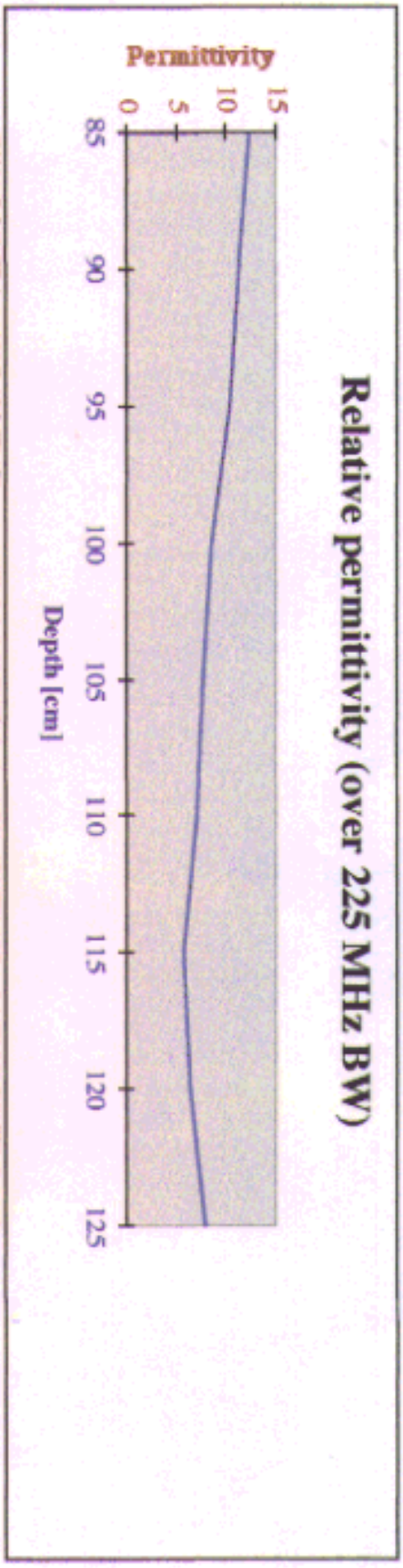

Photo of the site matched to permittivity measurement (Depth section 4)

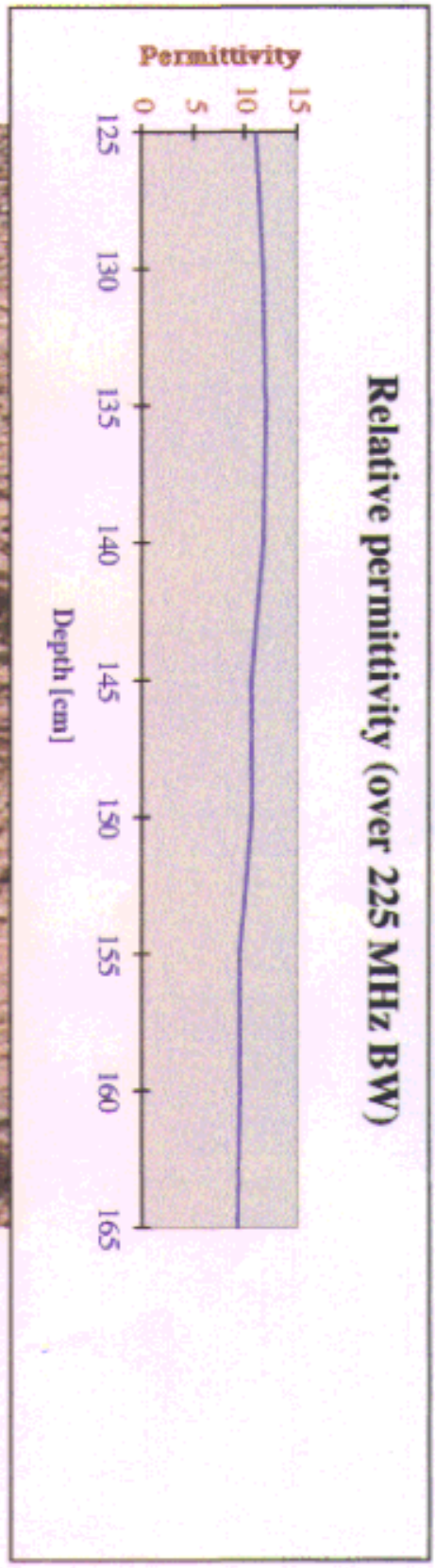
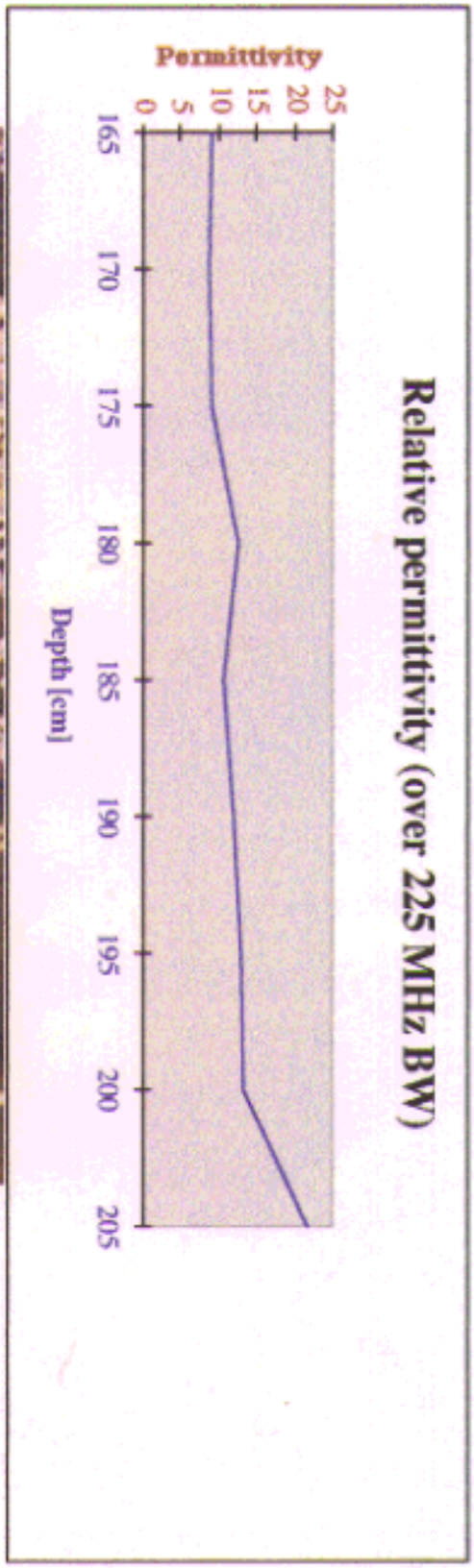
Photo of the site matched to permittivity measurement (Depth section 5)