Project ID: **60199**

Project Title: **Seismic-Reflection and Ground Penetrating Radar for Environmental Site Characterization**

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Annual Research Report
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Project Title: Seismic Reflection and Ground-Penetrating Radar for Environmental Characterization

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RESEARCH OBJECTIVE:

The goals of the project are:

1. To examine the complementary site-characterization capabilities of modern, three-component shallow seismic reflection (SSR) techniques and ground-penetrating radar (GPR) methods at depths ranging from 2 to 8 m at an existing test site;

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

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

To do this, seismic and GPR data are being collected along the same line(s) and within the same depth range. The principal investigators selected a site in central Kansas as a primary location, and although the site itself is not environmentally sensitive, the area offers attributes that are particularly useful for this research and allow the site to serve as a proxy for areas that are contaminated.

As part of an effort to evaluate the strengths of each method, the seismic and GPR surveys are repeated on a seasonal basis to establish how the complementary information obtained varies over time. Because the water table fluctuates seasonally at this site, variations in the two types of data over time also can be observed.
Such noninvasive, in-situ methods of identifying and characterizing the hydrologic flow regimes at contaminated sites support the prospect of developing effective, cost-conscious cleanup strategies in the near future.

RESEARCH PROGRESS AND IMPLICATIONS:

As of this writing (May 1999), the project remains on schedule. We report here primarily on the second year of a three-year project. The first field survey employing both methods was conducted in October of 1997, the second in March 1998, and additional experiments were performed in June, September, and November of 1998 and March of 1999. One of our stated tasks is to reoccupy the same survey line on a quarterly basis for two years to examine changes in both the SSR data and the GPR data over time. Two factors drive such changes: First, soil-moisture conditions vary on a seasonal basis at the site. Secondly, the water table rises and falls about 1 m in response to changes in the level of the Arkansas river and in response to the presence of the many irrigation wells found nearby.

At the test site, which is in the alluvial valley of the Arkansas River near Great Bend, Kansas, surface material consists of unconsolidated medium- to coarse-grained sand interspersed with clay stringers and clay lenses deposited by the Arkansas River. A hand-dug test pit about 10 meters from the seismic line revealed the presence of a paleosol at a depth of about 0.6 meters and cross-bedded sand descending to about 1.5 meters. A sand and gravel layer was found between 1.5 m and the water table. At the time of our seismic and GPR surveys, the water table was at a depth of 2.1 meters, based on a measurement taken in a test well located 25 meters from the seismic line. A well drilled about 40 meters away from the seismic line encountered bedrock--a fine- to medium-grained Cretaceous-age sandstone--at a depth of 29 meters.

Our experiments with GPR have included antennas with 110-, 225-, and 450-MHz center frequencies. Both common-offset and common-midpoint (CMP) surveys have been conducted. The CMP surveys greatly improved signal-to-noise ratio but did not increase significantly the depth from which we were able to acquire interpretable data. Using GPR, we were able to image the water table at a depth of about 2 m; we found indications of stratigraphic variation along the line as well.

In the past, shallow seismic-reflection methods have been capable of imaging the subsurface from about 2 to 30 meters, but because of near-source nonelastic deformation and insufficient receiver density, these technologies have not been adequate for imaging ultrashallow subsurface geology. Modifying the field layout of the geophones and using an alternative seismic source have allowed us to image the subsurface from 0.6 to 2.1 m using seismic reflections. In our experiments, three distinct reflections were observed within this range while using surface sources and receivers at the test site in the Arkansas River valley. These were confirmed by 4th-order, finite-difference wave-equation modeling.

Our progress to date toward achieving workable ultrashallow seismic reflection imaging is largely attributable to an improved ability to measure the near-source wavefield. To accomplish this, we have collected data using a single 100-Hz geophone group interval of 5 cm. In contrast, typical "shallow" seismic surveys have receiver-group intervals of 1 m or more. Because we increased receiver coverage by a factor of 20 or more, our ability to delineate and improve the coherence of ultrashallow reflections over other interfering phases was enhanced. Seismic-source energy was provided by a single shot from a .22-caliber rifle using subsonic, solid-point, short ammunition. We found that larger, more powerful shallow seismic exploration sources tested at the site (commercial seisguns and sledgehammers) generated enough near-field nonlinear deformation to make near-source (i. e., ultrashallow) reflection information undetectable.

Reports based on this work so far have been published in *Geophysics, Geophysical Research Letters* (GRL), the American Association of Petroleum Geologists' *Explorer* and other journals, as listed below. As of this writing, manuscripts have been submitted to *Science,* the *Journal of Geophysical Research* (JGR), the

Bulletin of the Seismological Society of America (BSSA), *Geophysics*, and the *Environmental and Engineering Geoscience* (EEG) Journal. Abstracts have appeared in the expanded abstracts volume of the 1998 Society of Exploration Geophysicists (SEG) meeting in New Orleans, and an additional abstract has been submitted for the 1999 meeting. A poster session was presented at the American Geophysical Union's (AGU) annual meeting in San Francisco in 1998, and another will be presented at the International Geoscience and Remote Sensing Society (IGARSS) 1999 meeting in Hamburg, Germany in June 1999.

PLANNED ACTIVITIES

In the third year of the project, we plan to use the combined seismic and GPR techniques to characterize the cone of depression of three nearby irrigation wells, which will be pumping during this time. Data sets will be collected at each well prior to pumping (when equilibrium has been reached) and several weeks after pumping stops. The latter half of the third year will be used to finish processing the data and to prepare manuscripts for publication.

OTHER ACCESS TO RESULTS (Publications, Preprints, etc.):

Published Papers and Abstracts

1999

Baker, G. S., C. Schmeissner, D. W. Steeples, and R. G. Plumb, 1999, Seismic reflections from depths of less than two meters: *Geophys. Res. Lett.*, **26**, No. 2, 279-282.

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*, **64**, 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*: **26**, 8, 1085-1088.

Steeples, D. W., G. S. Baker, C. Schmeissner, and B. K. Macy, 1999, Geophones on a board: *Geophysics*, **64**, 3, 809-814.

1998

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, 859-861.

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, 856-858.

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

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, 852-855.

Steeples, D. W., Baker, G. S., and C. Schmeissner, 1998, Toward the autojuggie: Planting 72 geophones in 2 seconds, 1998, American Geophysical Union, 1998 Fall Meeting, Dec. 6-10, San Francisco, CA.

Dissertation

1999

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

Papers, Abstracts, and Other Publications Submitted, in Review, or in Revision

Baker, G. S., D. W. Steeples, C. Schmeissner, M. Pavlovic, and R. Plumb, Improved vadose-zone imaging: submitted to *Science*, June 1999.

Baker, G. S., D. W. Steeples, and C. Schmeissner, The effect of seasonal soil-moisture conditions on near-surface seismic reflection data quality: submitted to the *Journal of Geophysical Research – Solid Earth*, May 20, 1999.

Baker, G. S., D. W. Steeples, C. Schmeissner, and K. T. Spikes, Source-dependent frequency content of ultrashallow seismic reflection data: submitted to *BSSA*, May 20, 1999.

Baker, G. S., D. W. Steeples, and C. Schmeissner, Shallow underground reflection feasibility (SURF) diagrams: submitted to *Geophysical Research Letters*, May 18, 1999.

Baker, G. S., D. W. Steeples, C. Schmeissner, and K. T. Spikes, Ultrashallow seismic reflection monitoring of seasonal fluctuations in the groundwater table: submitted to *Environmental and Engineering Geoscience Journal*, May 18, 1999.

Baker, G. S., D. W. Steeples, C. Schmeissner, and M. Pavlovic, On coincident seismic and radar imaging: submitted to *Geophysics*, May 11, 1999.

Baker, G. S., D. W. Steeples, and C. Schmeissner, On coincident seismic and radar imaging: SEG Exp. Abstr., submitted electronically April 1999; in review.

Plumb, R. G., D. W. Steeples, G. W. Baker, C. Schmeissner, and M. Pavlovic, A combined ground-penetrating radar and shallow seismic reflection approach to characterizing hydrological flow, International Geoscience and Remote Sensing Society (IGARSS) meeting, Hamburg, Germany, June 1999 (poster session).

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