United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Soil – Ground-Penetrating Radar (GPR) Field Assistance **Date:** 23 February 2000

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Purpose:
A ground-penetrating radar survey was conduct near a gravel pit face in New Castle County, Delaware. The purpose of this study was to determine the appropriateness of GPR for detecting frost wedge casts in coastal plain sediments.

Activities:
All activities were completed on 17 February 2000.

Background:
Frost wedge casts have been observed in the exposed walls of the Middletown gravel pit. These features and their spatial patterns are not be readily detectable by conventional drilling or mapping techniques. Researchers are interested in knowing the suitability of GPR to detect these narrow, vertical features.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. A 400 mHz antenna were used in this study. For this survey, the scanning time was 40 nanoseconds (ns); the scanning rate was 32 scan/second. Hard copies of the radar data were printed and reviewed in the field on a model T-104 printer.

Study Site:
The study area was located south of Middletown, Delaware, at a Delaware Department of Transportation facility. Frost wedge casts are exposed in the walls of a gravel pit. The study site is located in an area of Matapeake silt loam, 2 to 5 percent slopes, moderately eroded (Mathews and Lavoie, 1970). The very deep, well drained Matapeake soil formed in silty eolian sediments overlying coarser fluvial or marine sediments. The Matapeake soil is a member of the fine-silty, mixed, semiactive, mesic Typic Hapludults family.

Field Procedures:
A 5 by 10 meter grid was established across a portion of the study site. The grid interval was 1 meter. Survey flags were inserted in the ground at each grid intersection. This process provided a total of 66 observations points. The radar antenna was pulled along the six, 10-m, east-west grid lines. The GPR provides a continuous profile of the subsurface. As the radar antenna was pulled passed each flagged observation point, the operator impressed a vertical mark on the radar record. The vertical marks identified the observation points. The observation points provide a horizontal scale and identify relative locations along each traverse line.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., soil horizon, fracture, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (d), two-way pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t \qquad [1]$$

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2 \qquad [2]$$

Where c is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of a material.

The depth to the interface separating the silty eolian and coarse-loamy fluvial was measured at one observation point. Based on this depth (50 cm) and equation [1], the velocity of propagation was estimated to be about 0.1016 m/ns through the upper part of the soil profile. Using equation [2], the dielectric permittivity was 8.72. A scanning time of 40 ns was used in this study. Using equation [1], a scanning time of 40 ns, and a propagation velocity of 0.1016 m/ns, the maximum depth of observation was estimated to be about 2 m.

Results:

With a scanning time of 40 ns, high-resolution profiles were obtained with the 400 mHz antenna along each transect to a depth of about 2.0 meters. Figure 1 is a representative radar profiles from the site. In Figure 1, the vertical scale is a depth scale and is expressed in cm. The horizontal scale is expressed in m. In Figure 1, the interface separating the silty eolian mantle from the underlying coarser-textured, stratified fluvial deposits has been highlighted with a dark line. Because of the absence of reflectors within the upper part of the soil profile, the silty eolian mantle is inferred to lack highly contrasting soil horizons and rock fragments. The silty mantle appears on the radar profile as a zone of little or no signal returns.

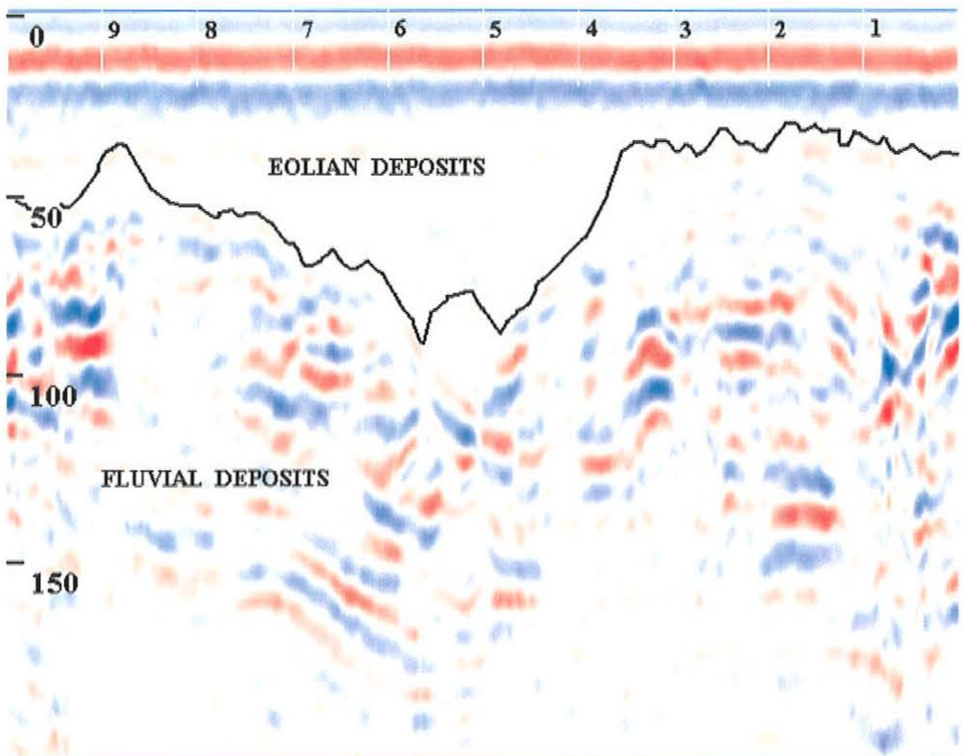

Figure 1. A representative radar profile from the Middletown, Delaware, Site.

The underlying, coarser-textured, fluvial deposits appear stratified and consist of discontinuous, often coalescing reflectors. These reflectors represent interfaces separating contrasting strata (grain size, density, porosity, clay and moisture contents). While breaks in stratification are evident on radar profiles, the detection of vertical discontinuities that may be attributed to frost wedge casts is obscured. Frost wedge casts are narrow, nearly vertical features that occur within the stratified, coarser-textured fluvial deposits. Frost wedge casts though readily apparent on the face walls of the gravel pit, do not appear to contain materials that contrast strongly with the enveloping soil matrix. Their narrow widths, elongated vertical dimensions, and lack of contrasting materials, makes the detection of these features with GPR difficult. As no clear and unmistakable graphic signature is apparent for these features, the identification of a vertical discontinuity as a frost wedge cast would be capricious.

The 400 mHz antenna did not provide sufficient resolution to discriminate frost wedge cast. Resolution can be improved by using a higher frequency antenna (900 mHz or 1.5 gHz). However, higher frequency antennas will suffer greater signal loss in the silty mantle. These antennas may not provide sufficient observation depths to discern frost wedge casts in the underlying coarser-textured fluvial deposits. In addition, the frost wedge casts, though readily apparent in exposures, do not appear to contain highly contrasting soil materials. As a consequence, the reflection coefficients for the wedges and the adjoining soil matrix will be low. Low reflective coefficients will produce low signal amplitudes that may be difficult to distinguish on radar profiles. In addition, as these features are nearly vertical, reflected signals are less likely to be redirected directly back to the antenna.

It was my pleasure to work with you and Dr Nelson.

With kind regards,

James A. Doolittle
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