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

Subject: Arch: - Geophysical Assistance **Date:** 26 October 2009

To: Serapio Flores Jr.
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Purpose:
At the request of Karri Springer of the North Dakota NRCS State Office and Dr Rinita Dalan of Morehead State University, ground-penetrating radar (GPR) assistance was provided to the St Leo's Cemetery in Casselton, North Dakota. The cemetery has plans to expand and needs to know whether there are burials in an area that is being considered for this expansion.

NRCS Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Keith Anderson, MLRA Soil Survey Leader, USDA-NRCS, Fargo, ND

Activities:
All field activities were completed on 5 October 2009.

Summary:

1. Comparatively recent interments (last 30 to 50 years) consisting of concrete liners were identified on radar records collected in an area of Overly soils in the St. Leo's Cemetery, Casselton, North Dakota. However, older graves provided no indications as to their presence. The inability of GPR to detect older graves was attributed to unfavorable soil and site conditions. The detection of burials with GPR is dependent on the materials used to contain the corpse and the relative dates of interment.

2. If present, based on the results of reconnaissance surveys, it is unlikely that GPR can reveal the locations of older, unmarked graves.

3. A detailed GPR grid survey revealed four persistent, high-amplitude subsurface reflection patterns. One (A in Figure 3) is considered the most likely to be a potential unmarked grave site. This feature needs to be further explored and identified by an archaeologist to confirm this interpretation.

It was my pleasure to assist your staff in this project and to demonstrate the potential of ground-penetrating radar (GPR) in archaeological investigations.

With kind regards,

James A. Doolittle
Research Soil Scientist
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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) and Jol (2008) discuss the use and operation of GPR. The 200 and 400 MHz antennas were used in the investigation at St. Leo's Cemetery.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[1] Basic processing steps that were applied to all radar records include: header editing, setting the initial pulse to time zero, color table and transformation selection, display range gain adjustments. All radar records used to prepare the 3D pseudo-images shown in this report were subjected to signal stacking to improve visualization and interpretation (see Daniels (2004) and Jol (2008) for discussions of this processing technique).

The recent use of digital signals and addition of sophisticated signal-processing software, have enabled signal enhancement and improved pattern-recognition on some radar records. Processing algorithms used to improve the interpretability of subsurface archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers and Goodman (1997). In recent years, an advanced type of GPR data manipulation, known as *amplitude slice-map analysis*, has been used in archaeological investigations (Conyers and Goodman, 1997). In this analysis method, a 3D pseudo-image of a small grid area is constructed from the computer analysis and synthesis of closely-spaced, two-dimensional radar records. Amplitude differences within the 3D pseudo-image are analyzed in "*time-slices*" that examine changes within specific depth intervals in the ground (Conyers and Goodman, 1997). In the *time-slice* process, reflected radar energy is averaged horizontally between adjacent, parallel radar records and in specified time (or depth) windows to create a *time-slice* (or *depth-slice*) image. Each amplitude *time-slice* shows the spatial distribution of reflected wave amplitudes, which may indicate changes in soil properties or the presence of subsurface features. In many instances, 3D-GPR imaging techniques have been used to distinguish and identify potential targets and to reduce interpretation uncertainties.

Survey Procedures:
In order to calibrate the GPR and assess site conditions, random GPR traverses were conducted across a representative area of the cemetery. To collect the data required for the construction of a 3D-GPR pseudo-image, a small survey grid was established across a portion of the cemetery. In order to construct a survey grid, two parallel lines were established across the grid site. Along each of these parallel lines, survey flags were inserted into the ground at a spacing of 50 cm. A reference line was extended between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along the distance-graduated rope. For each grid, the 200 MHz antenna was towed along the graduated rope, and as it passed each 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially moved to the next pair of survey flags to repeat the process. In this manner, a series of closely spaced parallel GPR traverse lines were collected for the construction of a 3D pseudo image.

A 10 by 15 m grid was established. Using the 200 MHz antenna, 21 parallel radar traverses were conducted across the grid area in essentially a south-north direction. Each traverse line was 15-m long. The distance between each traverse line was 50 cm. The traverse lines were used to construct a 3D pseudo-image of the grid site.

Soils:
The area that is being considered for expansion is located in the northwest corner of the cemetery. This grassy area is located in a delineation of Overly silty clay loam on 0 to 2 % slopes (map unit 1383A). The very deep, well drained to moderately well drained Overly soils formed in calcareous sediments on glacial lake plains and terraces. The 10- to 40-inch control section of Overly soil is calcareous and slightly alkaline or moderately

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

alkaline. It averages between 27 and 35 percent clay. Because of these properties (moderate clay content and calcareous conditions), areas of Overly soils are considered to have low potential for most GPR applications (http://soils.usda.gov/survey/geography/maps/GPR/index.html). The Overly series is a member of the fine-silty, mixed, superactive, frigid Pachic Hapludolls family.

Figure 1. The portion of St. Leo's Cemetery that was surveyed with GPR is identified by the rectangle in the upper left-hand corner of this soil map (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) from the Web Soil Survey The grid site is located in an area of Overly silty clay loam on 0 to 2 % slopes (1383A).

Ground-penetrating radar:

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. The system operates by transmitting short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing dielectric permittivity (E_r), a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy, and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a video screen and are be stored on a hard disk for future playback, processing, and/or display.

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., bedrock, soil horizon, buried archaeological feature) and back. To convert the travel time into a depth scale, 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 (Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (Daniels, 2004):

$$E_r = (C/v)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is typically expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and *v*. The v and E_r at this site were estimated from the probed depth to the top of a buried concrete liner.

Results:

Figure 2 is a radar record that was conducted orthogonal to seven headstones. This traverse was designed to crossover seven identified graves whose dates of burial spanned much of the 20th century. The approximate locations of the seven headstones are indicated by white, vertical lines at the top of the radar record. On this radar record, older grave sites are located to the left and the most recent are to the right. Depth and distance scales are expressed in meters. In Figure 2, only the four most recent burials are detectable with GPR. The right-most, three graves are believed to all consist of concrete liners, which provide higher-amplitude (colored white, pink, blue, and green) reflections that are easily identified on the radar record.

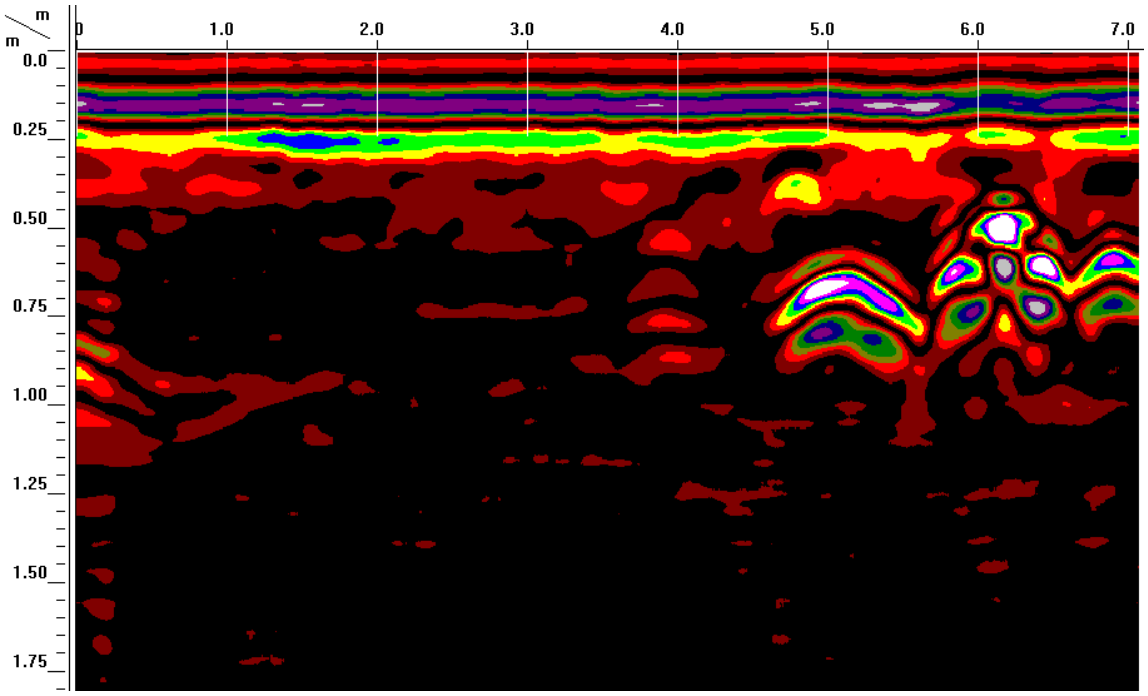

Figure 2. This radar record was collected at the calibration site in St. Leo's Cemetery. The white vertical lines at the top of the radar record represent the locations of gravesites identified by nearby headstones.

Within a cemetery, burials produce different geophysical responses not only because of differences in states of preservation and spatial differences in soil properties, but differences in burial practices over time (Nobes, 1999). Within a given cemetery, materials used to enclose corpses may consist of shrouds, body bags, wooden caskets, concrete vaults, and/or fiberglass, composite or metal coffins. Early settlers probably buried their dead wrapped in shrouds and placed in coffins made of wood. Preservation of these early burials and their identification with GPR depends on soil conditions, but is generally poor (Owsley and Compton, 1997). Metallic or lead coffins and burial vaults provide relatively larger, longer-lasting, and more contrasting features, which generally produce high-amplitude, recognizable radar reflections.

With the passage of time, corpse and burial materials decompose and become less electrically contrasting to GPR. Koppenjan et al. (2003) noted that, because of decomposition and the settling of soil materials, burials become less noticeable on radar records with the passage of time. Untreated, wooden coffins (pine) will decompose more rapidly and, because of soil pressures, will collapse. Bevan (1991) was successful using GPR to detect burials that consisted of intact coffins, but not burials that consisted of collapsed, soil-filled coffins, or bones alone. If a buried coffin is intact, an air-filled void will exist, which may be detectable with GPR. Presently, coffins are usually covered by a burial liner or placed in a burial vault. Burial liners and vaults prevent the coffin from collapsing under the weight of the soil. As liners and vaults are made of concrete, plastic or metal, they are good radar reflectors (see Figure 2).

As noted by Henderson (1987) "burials exist in an environment in which a complex interaction occurs between wide ranges of variable". This partially explains differences that have been observed in the state of burial preservations within the same site or cemetery. Rates of decomposition depend upon the depth and duration of burial, soil type, moisture content, temperature, flora and fauna (Killam, 1990; Henderson, 1987; Rodriquez and Bass, 1985). Floral and faunal activities will disarticulate and disperse decomposing corpses and skeletal remains (Dupras et al., 2006). In general, bodies and skeletal remains are more quickly decomposed in soils that have high clay and moisture contents (Dupras et al., 2006). Preservation of skeletal remains is favored in dry, alkaline, sandy soils (Dupras et al., 2006).

3D-GPR:

In the northwest portion of St Leo's Cemetery (see Figure 1), a relatively open area contains no headstones or grave markings. Records are ambiguous, but some accounts suggest that there may be unmarked graves in this portion of the cemetery. Cemetery officials wish to confirm whether this open area contains unmarked graves. If not, this open area can be used for additional burials.

Figure 3 contains three, horizontal time-sliced images of the grid site (for location, see Figure 1). These horizontal time- or depth-sliced images were extracted from a 3D pseudo-image of the grid site at depths of 0, 60, and 120 cm. In the 0-cm depth-sliced image (surface), variations in signal amplitude are attributed mainly to differences in soil moisture and/or soil compaction. The spatial patterns evident in this depth-slice image appear natural and random. In the 60- and 120-cm depth-sliced images, some high-amplitude (colored black) reflections are apparent across the site. The four largest and most persistent reflections have been identified (A, B, C, D) in these two depth-sliced images. While these reflections attract our attention, their identities are unknown. However, their size, depths and orientations may provide clues to their identities.

The shape and orientation of burials can aid their identification with GPR. On radar records, a subsurface anomaly that is narrow (about twice the width of a body) and linear (about 100 to 200 cm long) may suggest a burial. Burials are often uniformly spaced and aligned in a particular direction (usually east-west). Multiple, similarly aligned, elongated subsurface anomalies that occur at a common depth on radar records suggest probable burials. None of these characteristics are plainly evident on the depth-sliced images shown in Figure 3. In the 60-cm depth-sliced image, several higher amplitude reflections that are aligned in a north-south orientation have been ignored as potential burials. Because of there size, alignment, prominence and persistence with depth, four subsurface anomalies (A, B, C, and D) have been identified. Because of the strengths of these attributes, the subsurface feature ("A") occurring in the extreme northwestern portion of the grid area (near X= 1 to 2 m; Y= 1 to 3 m) is deemed the most worthy of further attention by an archaeologist.

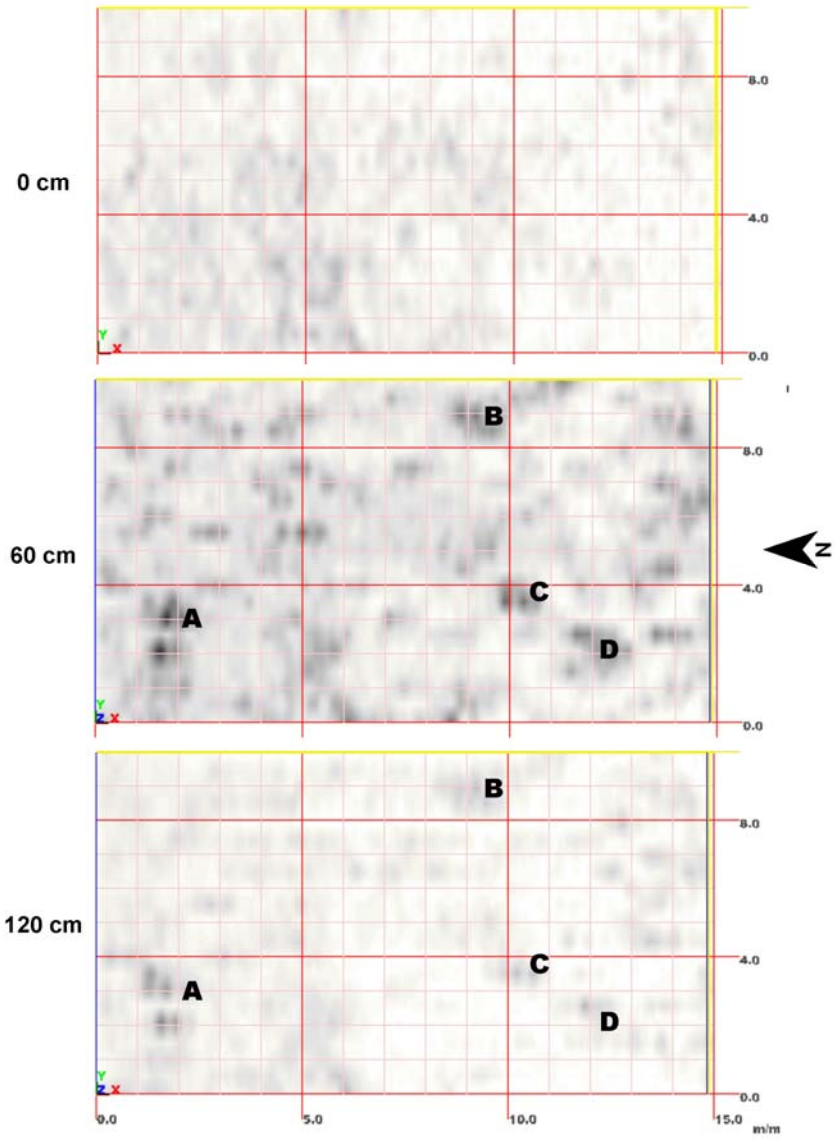

Figure 3. These three time-slice images are from the grid site constructed within the St. Leo's Cemetery.

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