Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

Subject: Soils – Geophysical **Date:** 19 September 2012

To: Juan Hernandez
State Conservationist
USDA-Natural Resources Conservation Service
967 Illinois Avenue, Suite 3
Bangor, ME 04401

Purpose:
The Houlton Band of Maliseet Indians wishes to establish a tribal cemetery near Houlton, Maine. Ground-penetrating radar (GPR) was used to assess the depth to bedrock within the proposed site.

Principal Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Mathew Edberg, Natural Resource Specialist, Houlton Band of Maliseet Indians, Houlton, ME
Robert Evon, Soil Survey Office Leader, USDA-NRCS, Dover-Foxcroft, ME
Dave Hopkins, Project Manager, CES Inc., Presque Isle, ME
Helen Swiatek, District Conservationist, USDA-NRCS, Houlton, ME
Sue Young, Natural Resource Director, Houlton Band of Maliseet Indians, Littleton, ME

Activities:
All activities were completed on 11 July 2012.

Summary:
1. The synergy of several rapidly advancing technologies (such as Geoprobe, ground-penetrating radar and LIDAR) provided complementary and detailed information on site conditions, which can greatly facilitate site assessments.

2. Although the soil/bedrock interface was not always clear and well expressed on radar records, it was interpreted and charted on all radar traverses that were conducted across the proposed site. Within the proposed cemetery site, based on 993 *picked* radar measurements, the average depth to bedrock is estimated to be 2.06 meters (6.76 feet) with a range of 0.64 to 4.18 meters (2.1 to 13.7 feet). Spatially, the depth to bedrock is relatively shallower in the eastern and northeastern portion of the site. In general, soils are projected to be deeper in the western and southern portions of the site.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance to you and your fine staff.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
James Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, USDA-NRCS, Newtown Square, PA
Robert Evon, Soil Survey Office Leader, USDA-NRCS, 42 Engdahl Drive, Dover-Foxcroft, ME 04426
Dave Hopkins, Project Manager, CES Inc., 549 Main Street, PO Box 827, Presque Isle, ME 04769
Tony Jenkins, State Soil Scientist, USDA-NRCS 967 Illinois Avenue, Suite 3, Bangor, ME 04401
Helena Swiatek, District Conservationist, USDA-NRCS, 304 North Road, Houlton, ME 04730
Wes Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, USDA-NRCS, Wilkesboro, NC
Larry West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Lincoln, NE
Michael Wilson, Research Soil Scientist/Liaison MO12, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Lincoln, NE

Ground-penetrating radar (GPR) investigation of a proposed cemetery site for the Houlton Band of Maliseet Indians on Lowery Road, Houlton, Maine

Jim Doolittle

Purpose:
The purpose of this survey was to use ground-penetrating radar (GPR) to assess the depth to bedrock across a proposed cemetery site for the Houlton Band of the Maliseet Tribe in northeast Maine. The proposed site is mapped principally as Mapleton shaly silt loam on 0 to 8 % slopes (MhB). Mapleton soils are moderately deep (20 to 40 inches) to bedrock. Ground-penetrating radar was used to acquire high-resolution information to support the interpretations and the extrapolation of information obtained with a Geoprobe.

Background:
Previously, CES Inc. had established a survey grid across the proposed cemetery site (Figure 1). David Hopkins, Project Manager for CES Inc., completed a detailed subsurface investigation of the proposed site using a Geoprobe 5410 Direct Push Unit mounted on a Ford F-350 chassis (Geoprobe Systems, Salinas, KS) [1]. The Geoprobe was used to provide highly detailed soil information to a maximum depth of 2.44 m (8 feet) or refusal at 54 of the grid intersections. As sampling was confined to a limited number of sampling points, soil properties and the depth to bedrock in the greater area among the sampling points must be inferred. Because of its economy, speed, ease of use, noninvasiveness, and capacity for collecting spatially dense data of relevant to soil properties, GPR can offer considerable advantages in site assessments.

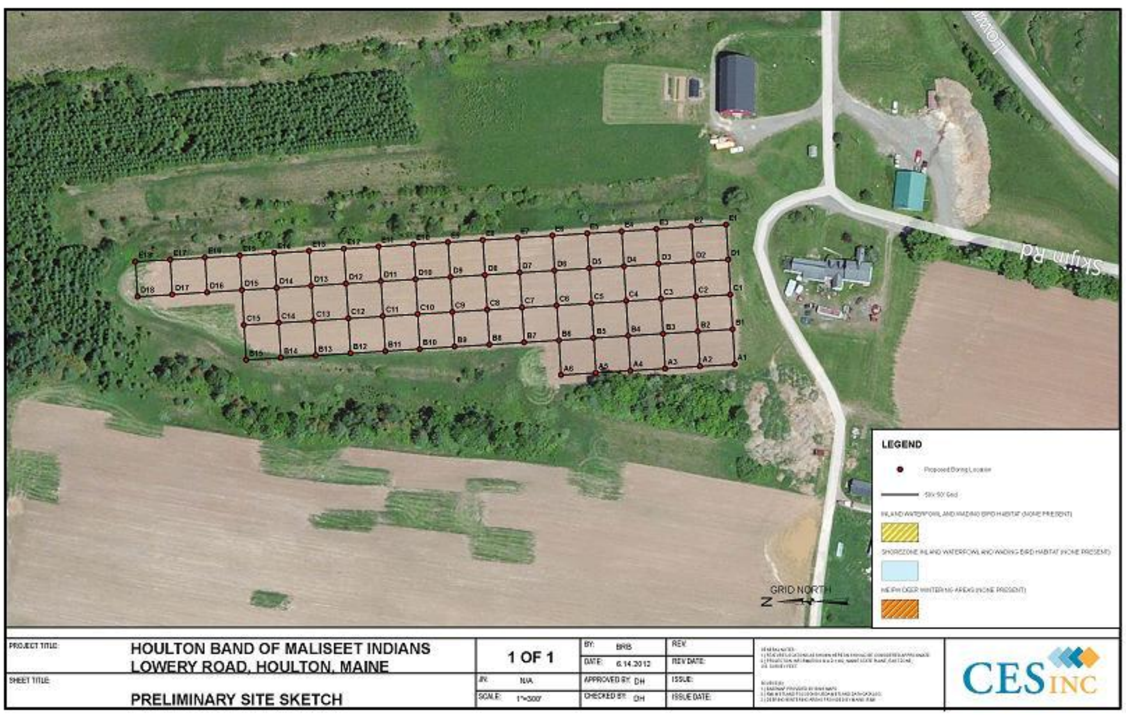

Figure 1. This image shows the survey grid that was established across the proposed cemetery site by CES Inc. Lines are labeled A thru E. The grid interval is 50 feet (15.24 m).

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

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[2] 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 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 200 MHz antenna was used in the investigations.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records. [2] Processing used included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high pass filtration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). The *Interactive 3D Module* of RADAN was used to semi-automatically "*pick*" the depths to the interpreted bedrock surface on radar records. The picked data were exported to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to bedrock).

The SIR-3000 system contains a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows was used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver.[1] A Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to collect position data. [2] Position data were recorded at a time interval of one reading per second. The scanning rate of the GPR was 64 scan/sec.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock surface) 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 equation [1] (after 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 equation [2] (after Daniels, 2004):

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

Where C is the velocity of light in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest affect on the E_r and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in substantial increases in the relative permittivity of soils (Daniels, 2004). Using a 100 MHz antenna, Daniels (2004) observed that the relative dielectric permittivity of most dry mineral soil materials is between 2 and 10, while for most wet mineral soil materials, it is between 10 and 30. At the time of this investigation, soils were dry, but undoubtedly varied spatially and vertically in soil moisture content.

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

A shallow depth of refusal (1.37 m) for the Geoprobe at one of the grid intersection (D5) was used to depth scale the radar imagery. The depth of refusal is considered the depth to bedrock. A radar traverse was conducted adjacent to this point and the bedrock surface was interpreted on the radar record (see D5 in Figure 4). Based on the measured depth to this interface and the two-way pulse travel times to the interpreted bedrock surface on the radar record, the velocity of propagation and the relative dielectric permittivity through the upper part of a soil profile were estimated using equations [1] and [2]. With the 200 MHz antenna, the estimated E_r was 5.26. The estimated v was 0.1308 m/ns. Both v and E_r will vary spatially across the survey area and with depth. This variability affects the accuracy of soil depth measurements.

Study Sites:
Figure 2 contains the soil map of the study site from the Web Soil Survey.[3] Black segmented lines have been used in this image to approximate the boundary of the proposed cemetery site. The soils at this site are mapped mostly as Mapleton shaly silt loam on 0 to 8 % slopes (MhB). The site also contains small areas of Mapleton shaly silt loam on 8 to 15 % slopes (MhC). The moderately deep, well drained Mapleton soils formed in glacial till on uplands. The depth to bedrock ranges from about 50 to 100 cm (20 to 40 inches). For Mapleton soils, the bedrock is described as being principally metamorphosed limestone, calcareous sandstone or calcareous shale. The bedrock may be fractured or have weathered into saprolite in the upper part. The soil texture is dominantly loam or silt loam throughout. Rock fragments ranges from 5 to 40 percent in individual horizons. Mapleton is a member of the fine-loamy, mixed, superactive, frigid Dystric Eutrudepts taxonomic family.

Figure 2. This soil map of the proposed Maliseet Tribal cemetery site is from the Web Soil Survey. The approximate boundary of the survey area is shown.

[3] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [9/04/2012].

Figure 3 is LIDAR imagery of the proposed site. Although the topology of the site suggests possible bedrock control, the LIDAR signature reveals a relatively smooth surface with no evidence of rock outcroppings or bedrock on the site.

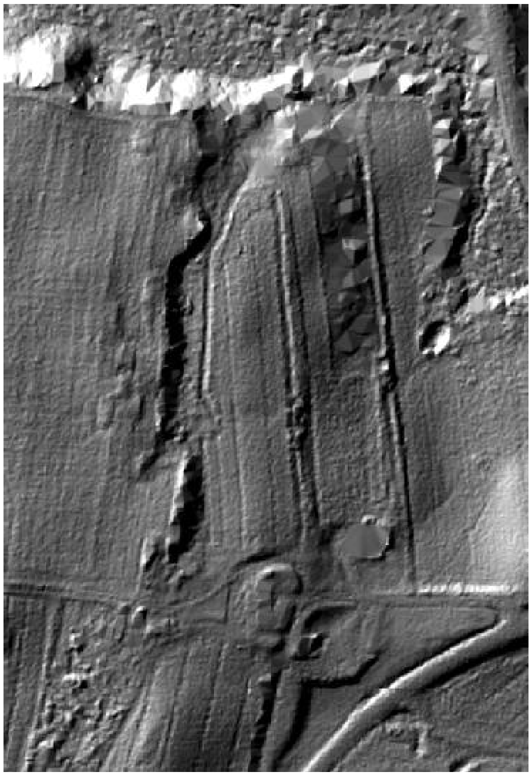

Figure 3. This LIDAR image shows a relatively smooth surface across the proposed cemetery site (courtesy of Nicholas Butler (Soil Scientist, USDA-NRCS, Dover, ME)).

Survey Procedures:
A survey grid had been established across the site by CES Inc (see Figure 1). The grid interval was 15.24 (50 feet). A pedestrian GPR survey was completed by pulling the 200 MHz antenna on the ground surface along grid lines A thru E in a back and forth pattern across the site. Additional traverses were completed across the site between grid lines E and D, D and C, and C and B (see Figure 1 for general locations of these lines). A GPS receiver was used to georeference the track of the radar system. As the antenna passed near each flagged, grid intersect, a mark was inserted on the radar record by the operator. Each radar traverse was stored as a separate file.

Results:
Figure 4 is a representative portion of a radar record from the study area. This segment is 45 m long and was collected between grid intersections D4 and D7 (see Figure 1) on line D. On the radar record all scales are expressed in meters. A segmented, green-colored line has been used to approximate the interpreted bedrock surface. In Figure 4, the till is characterized by low amplitude (colored red and black on the radar record), chaotically arranged, point reflectors. These reflectors are assumed to represent larger rock fragments and soil inhomogeneities. The bedrock is characterized by higher amplitude (colored white, grey, and blue on the radar record), segmented, planar reflectors. Often these linear reflectors are grouped, aligned and steeply inclined, suggesting bedding and/or fracture planes.

The till/bedrock interface was frequently poorly defined and unclear on the radar records from the proposed cemetery site. This may be due to the large amount of dielectrically similar rock fragments in the till that overlies the bedrock or differences in soil moisture, which can reduce the dielectric gradient and mask the soil/bedrock interface. Also suspected areas of more weathered (and probably rippable) bedrock appear on the radar records from this site. These areas (see “A” in Figure 4) consist of low amplitude, segmented and inclined reflectors.

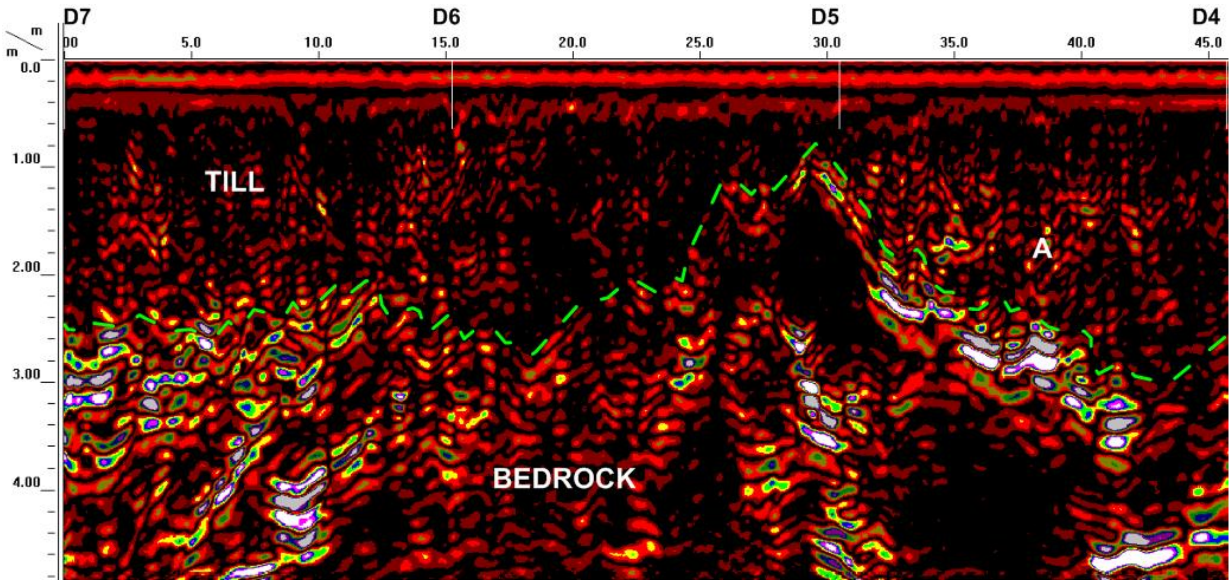

Figure 4. This representative segment of a radar record from the proposed cemetery site suggests a deep and highly irregular bedrock surface.

Within the proposed cemetery area, based on 993 *picked* radar measurements, the average depth to bedrock is estimated to be 2.06 meters (6.76 feet) with a range of 0.64 to 4.18 meters (2.1 to 13.7 feet). One half of all *picked* measurements are between 1.64 and 2.47 meters (5.38 and 8.10 feet).

Figure 5 is a plot showing the depth to bedrock within the proposed cemetery site as estimated from radar interpretations. As evident in this image, the depth to bedrock is relatively shallower in the eastern and northeastern portion of the site. Spatial patterns suggest a shallower ledge of bedrock within this area. In general, soils are projected to be deeper in the western and southern portions of the site.

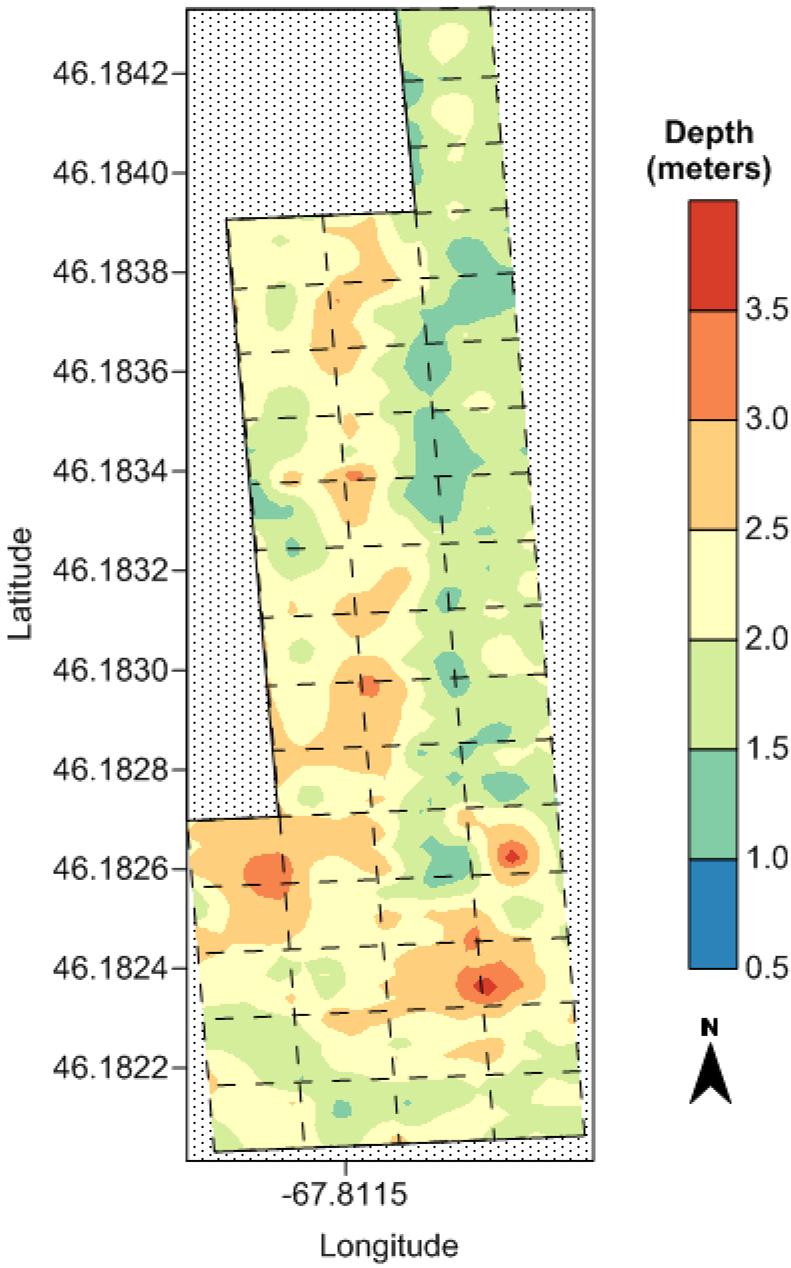

Figure 5. This simulation shows the interpreted depths to bedrock within the proposed cemetery site. All depths are expressed in meters.

References:

Cassidy, N.J. 2009. Electrical and magnetic properties of rocks, soils, and fluids. In *Ground Penetrating Radar: Theory and Applications*, ed. H. M. Jol, 41-72 pp. Elsevier Science, Amsterdam, The Netherlands.

Daniels, D.J., 2004. *Ground Penetrating Radar; 2nd Edition*. The Institute of Electrical Engineers, London, United Kingdom.

Jol, H., 2009. *Ground Penetrating Radar: Theory and Applications*. Elsevier Science, Amsterdam, The Netherlands.