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

Subject: Soils – Ground-Penetrating Radar Field Assistance **Date:** 3 May 2007

To: Dr Frederick Nelson
Professor
Geography Department
University of Delaware
207 Pearson Hall
Newark, DE 19716

Mark Demitroff
822 Main Avenue
Vineland, NJ
08360-9346

Ronnie Lee Taylor
State Soil Scientist
USDA-Natural Resources Conservation Service
220 Davidson Ave., 4th Floor
Somerset, NJ 08873-4115

Purpose:
To explore the potential of using ground-penetrating radar (GPR) to identify sand wedges and pattern ground in the Pine Barrens of southern New Jersey. The study was held in conjunction with a field exercise offered by the Geography Department, University of Delaware (Geography/Geology 482 – "Physical Geography of Cold Environments.")

Participants:
Mark Demitroff, PhD Candidate, Geography Department, University of Delaware, Newark, DE
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Stefan Katz, Student, Geography Department, University of Delaware, Newark, DE
Fritz Nelson, Professor, Geography Department, University of Delaware, Newark, DE
Peter Roth, Student, Geography Department, University of Delaware, Newark, DE
Steph Scholl, Student, Geography Department, University of Delaware, Newark, DE
Aaron Siegel, Student, Geography Department, University of Delaware, Newark, DE
Rachael Young, Student, Geography Department, University of Delaware, Newark, DE

Activities:
All activities were completed on 24 April 2007.

Summary:
Relationships between ground-penetrating radar (GPR) reflection patterns and soil and stratigraphic features were found to be ambiguous. Results indicate that some sand-wedge reflects are identifiable on two-dimensional radar records. The three-dimensional ground-penetrating radar (3D GPR) analysis of the grid site was successful in imaging what appear to be the geometry of sand-wedge relicts and perhaps even a rudimentary polygon network. With two- and three-dimensional imaging of radar data and limited exposures, interpretations will rely on the investigators' knowledge of these relict permafrost features. Final interpretations must await ground-truth observations and confirmation.

In order to improve interpretation and verify results, further GPR studies of these features are recommended.

It was my pleasure to participate in this investigation of sand wedge relicts in southern New Jersey.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
S. Carpenter, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 75 High Street, Room 301, Morgantown, WV 26505
D. Hammer, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

Background:
As indicators of climate change, the recognition of periglacial and permafrost features is important. The Pine Barrens of southern New Jersey lies beyond the maximum southern extent of the late-Pleistocene ice sheets. As a consequence, this region is not typically associated with periglacial and permafrost processes. Recently, however, periglacial and permafrost features (sand wedge relicts, soil wedges, deformed sand wedges, thermokarst involutions) have been identified in the Pine Barrens (French et al., 2003 & 2005).

Sand-wedge relicts, up to 2.5 m deep and 0.4 m wide have been identified in the Pine Barrens of Southern, New Jersey (French et al., 2003). These features occur within 0.5 to 1.0 m of the soil surface and develop mostly in late Miocene sand and gravel deposits. Typically, these wedges contain loosely packed fine to medium sands (with small amounts of gravel), which contrast with the often more indurated enclosing matrix of coarser sands and gravel (French et al., 2003). French et al. (2003) noted that, in the Pine Barrens, exposed sand wedge relicts are neither regularly spaced nor uniformly distributed. Consequently, these features provide little evidence that they form random polygonal patterns, which are indicative of thermal-contraction-crack polygons (French et al., 2003).

Figure 1. Mark Demitroff describes the evolution of a large thermokarst involution at the *Unexpected Road Sand & Gravel Pit*.

Soil wedges, deformed sand wedges, thermokarst involutions and thermokarst kettles have also been identified in the Sand Barrens (French et al., 2003 and 2005). Compared with sand wedges, soil wedges are shallower (< 1.0 m deep), broader (0.3 to 0.6 m wide), more irregular in geometry, and more closely spaced (1.0 to 2.0 m apart) (French et al., 2003). Soil wedges are believed to result from seasonal frost cracks (French et al., 2003). Deformed sand wedges are indicative of gelifluction (French et al., 2005). These fluvial and thermokarst-induced features are often concentrated along troughs associated with thermal-contraction-crack polygons. Deformed sand wedges consist of pockets of deformed sand interspersed in a silty, gravelly diamict. Deformed sand wedges are relatively large and can be 3 to 5 m wide and as much as 3 m deep (French et al., 2005).

Thermokarst involutions represent the deformation of sediments that result from the settling or caving of the ground due to the melting of permafrost (French et al., 2003). These deformed features can extend horizontally for several 10 of meters, and vertically to depths as great as 3 to 4 m (French et al., 2005). Thermokarst kettles appear as large, irregular, kettle-like structures, typically 2 to 4 m in both horizontal and vertical dimensions (French et al., 2005). These features represent thaw-remnants of sand wedges and often form at the intersection of two or more sand wedges (French et al., 2005).

In the Pine Barrens of New Jersey, high regional water tables, forest cover, and urban sprawl have hampered the investigation of periglacial and permafrost features, and generally restricted their identification to exposures in commercial sand and gravel pits (French et al., 2003). This study examines the use of ground-penetrating radar (GPR) to identify periglacial and permafrost features in the Pine Barrens of New Jersey.

Equipment:
The radar unit used is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] The SIR System-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 System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. A 400 MHz antenna was used in this investigation. Daniels (2004) discusses the use and operation of GPR.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program developed by Geophysical Survey Systems, Inc. [1] Processing included setting the initial pulse to time zero, header and marker editing, distance normalization, color transformation, range gain adjustments, and migration. The Super 3D QuickDraw program developed by Geophysical Survey Systems, Inc. was used to construct three-dimensional (3D) pseudo-images of radar records.[1]

Field Methods:
Radar data were collected on a 20 by 15 m grid site. This grid was established across a cleared, accessible, and level area that was adjacent to a side wall of a sand and gravel pit. Two parallel axis lines were laid out and spaced 20 m apart. Along these two parallel axes, survey flags were inserted into the ground at a spacing of 50 cm, and 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 this reference line. The 400 MHz antenna was dragged along the graduated rope on the soil surface and, as it passed each 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially displaced 50-cm to the next pair of survey flags to repeat the process. A total of 31 traverses were required for this relatively smaller (300-m^2) grid site.

Calibration:
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, 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 (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 expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on E_r and v. At the grid site, based on the measured depth and the two-way pulse travel time to a known, subsurface reflector, and equation [1], the velocity of propagation (v = 0.119 m/ns) and the relative dielectric permittivity (E_r = 6.3) through the upper part of the soil profiles were estimated.

Study Sites:
The site is located in a sand and gravel pit (39.56707 N. Latitude, 74.91448 W. Longitude) off of Unexpected Road, Brimfield Crossing, Atlantic County, New Jersey. The grid site is located in the Northern Atlantic Coastal Plain major land resource area (USDA-NRCS, 2006). This area is underlain by unconsolidated sands and gravels that were deposited in the near-shore environment of late Cretaceous seas (USDA-NRCS, 2006). High winds during periods of maximum glacial advance later redeposited some sands across the surface (USDA-NRCS, 2006).

Soils delineated in the immediate area of the grid site include: Downer loamy sands, 0 to 5 percent slopes (DocB); Sassafras sandy loam, 0 to 2 percent slopes (SacA); Pits, sand and gravel (PHG); and Lakehurst sand, 0 to 5 percent slopes (LakB). The soils formed in fluviomarine deposits. The very deep, well drained Downer and Sassafras soils have coarse-loamy and fine-loamy particle-size control sections, respectively. The very deep, moderately well drained Lakehurst soils have a seasonal high water table at a depth of 46 to 107 cm; a thick E horizon; and a sandy particle-size control section. The names and symbols for the soil map units identified in the study areas are listed in Table 1. The taxonomic classifications of the soils identified in the study areas are listed in Table 2.

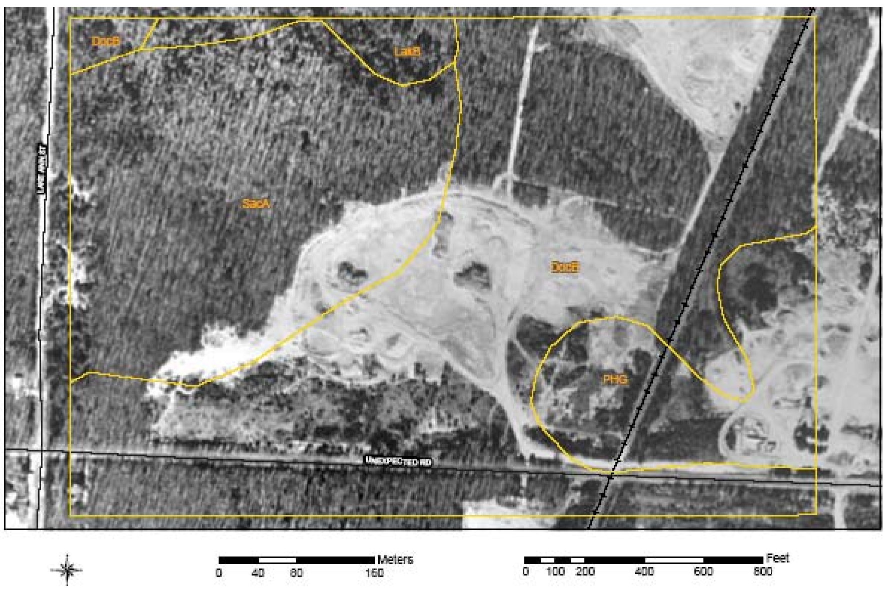

Figure 2. A soil map of the Unexpected Road Pit site. The grid site was located in the western portion of the pit area in an area of Sassafras soil.

Table 1. The names and symbols for the soil map units identified in the study area.

Map Unit Symbol	Map Unit Name
DocB	Downer loamy sand, 0 to 5 percent slopes
LakB	Lakehurst sand, 0 to 5 percent slopes
PHG	Pits, sand and gravel
SacA	Sassafras sandy loam, 0 to 2 percent slopes

Table 2. Taxonomic classifications of the soils identified in the study area.

Soil Name	Taxonomic Classification
Downer	Coarse-loamy, siliceous, semiactive, mesic Typic Hapludults
Lakehurst	Mesic, coated Aquodic Quartzipsamments
Sassafras	Fine-loamy, siliceous, semiactive, mesic Typic Hapludults

Results:
Two-dimensional (2D) radar records from the grid site are shown in Figures 3 thru 5. In each radar record, the same color scale and gain adjustments have been used. The depth and distance scales are in meters. The depth scale is based on an estimated velocity of propagation of 0.119 m/ns through the surface layers. The white, vertical lines at the top of the radar record represent the equally spaced (1 m) graduations on the distance-graduated rope. For each radar record, the depth scale is exaggerated about 2.3 times relative to the distance scale.

The surface pulse and its reverberation mask features within the upper 25 cm of the soil profile. The radar records shown in Figures 3 thru 5 are relatively nondescript. While multiple subsurface interfaces are identifiable on each radar record, no single, high amplitude, continuous reflector is evident on these records. Such a reflector would identify a major soil or stratigraphic interface occurring within the upper 2 m of the soil profile. It is assumed that the materials scanned consist of multiple layers that varied in grain-size distribution, moisture content, and/or density. Though composed of different layers, materials are believed to represent a single stratigraphic unit with only a thin mantle of aeolian materials. Downer and Sassafras soils form in fluviomarine sediments and have thin, sand, loamy sand, sandy loam, loam, and/or sandy clay loam strata in the substratum below depths of 100 cm.

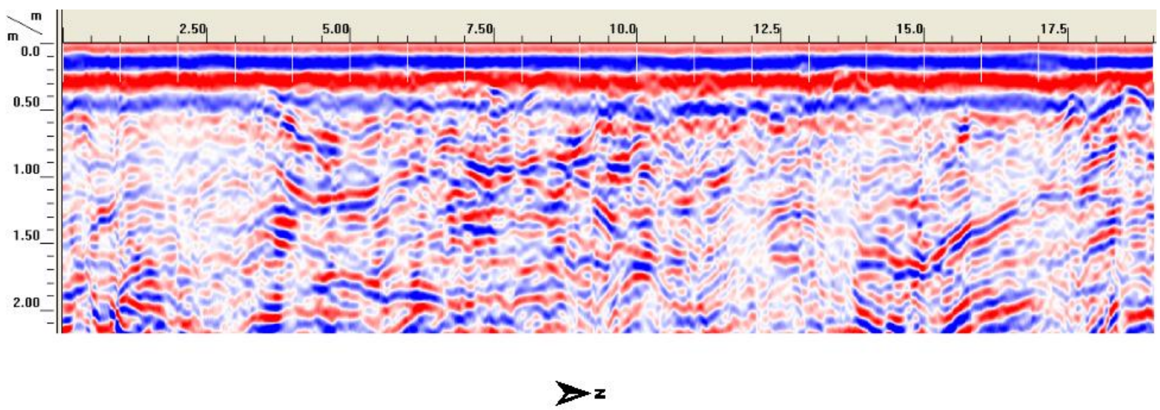

Figure 3. The radar record from the Line Y =0 m.

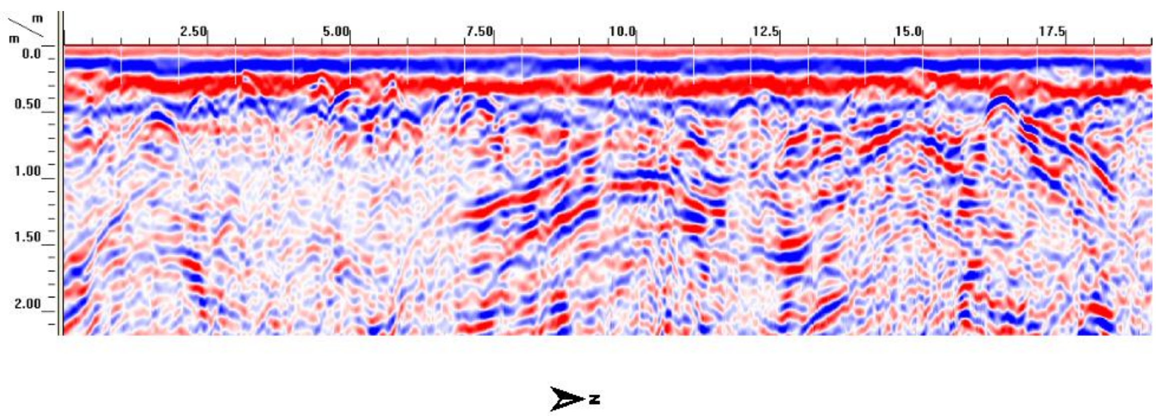

Figure 4. The radar record from the Line Y =10 m.

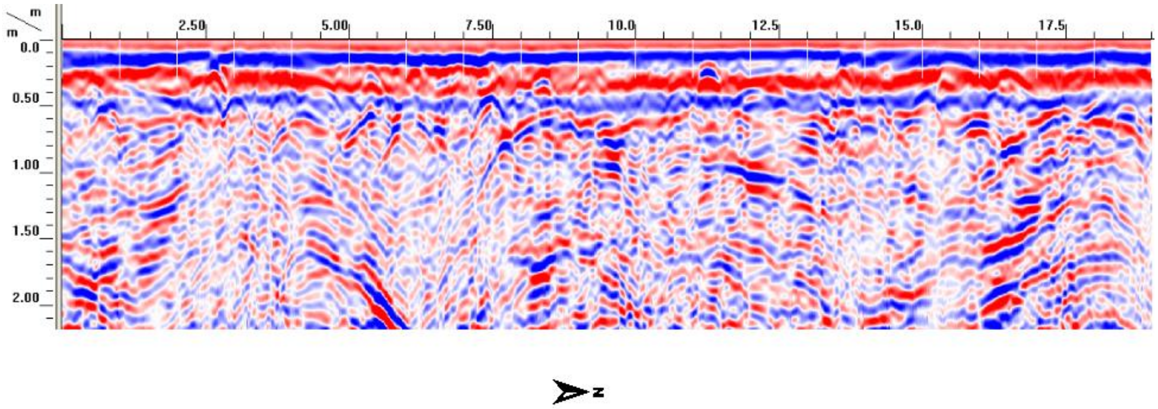

Figure 5. The radar record from the Line Y =15 m.

The radar records shown in Figures 3 thru 5 contain multiple, indistinguishable reflectors, which are difficult to interpret and identify. In each record, several, narrow, vertical breaks that cut across stratigraphic layers or bound subsurface features are apparent. These breaks or fractures separate more continuous subsurface reflectors, which are often offset by these features. In an area suspected to contain sand wedges, these vertical fractures may serve to identify these features. Spatial aliasing restricts the dip-angles that are detectable with GPR (Lane et al., 2000). Vertical interfaces reflect very little energy back towards the radar antenna. As a consequence, these reflectors often appear on radar records as very low-amplitude diffractions whose alignment reflects the orientation of the steeply inclined interface (Grasmueck et al., 2004).

In Figures 6 thru 7, some of the more prominent vertical interfaces have been identified. In Figures 6 and 7 (also Figures 3 and 4), areas of higher amplitude reflection that contain a larger proportion of the vertical fractures are evident. These areas occur between the 4 and 10 m and the 8 to 15 m distance marks on Figures 6 and 7, respectively. The higher amplitude reflections are caused by more abrupt and contrasting soil materials. In an area known to contain permafrost features, these higher amplitude reflections may represent larger sand wedge relicts or deformed sand wedges. In Figures 5 and 6, a segmented black-colored line has been used to highlight a weakly expressed soil interface that overlies areas which contain high amplitude subsurface reflections and vertical fracture traces.

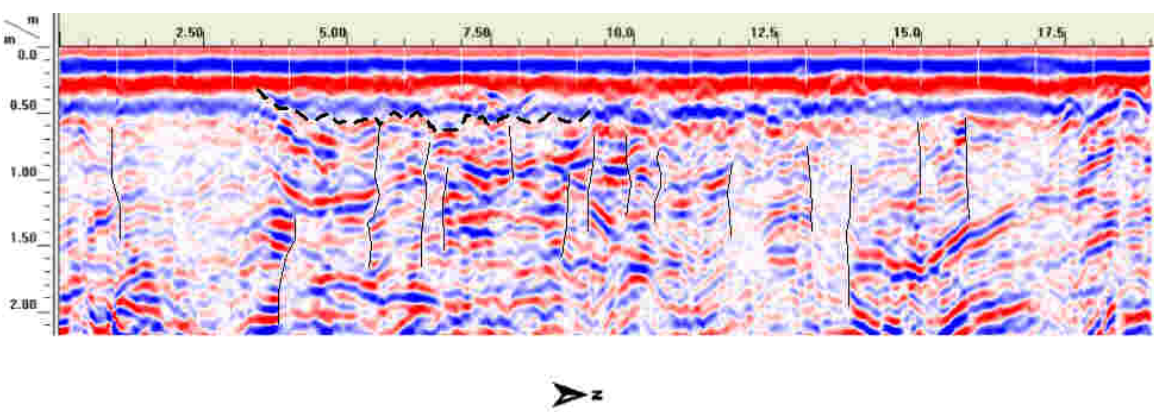

Figure 6. The radar record from the Line Y =0 m.

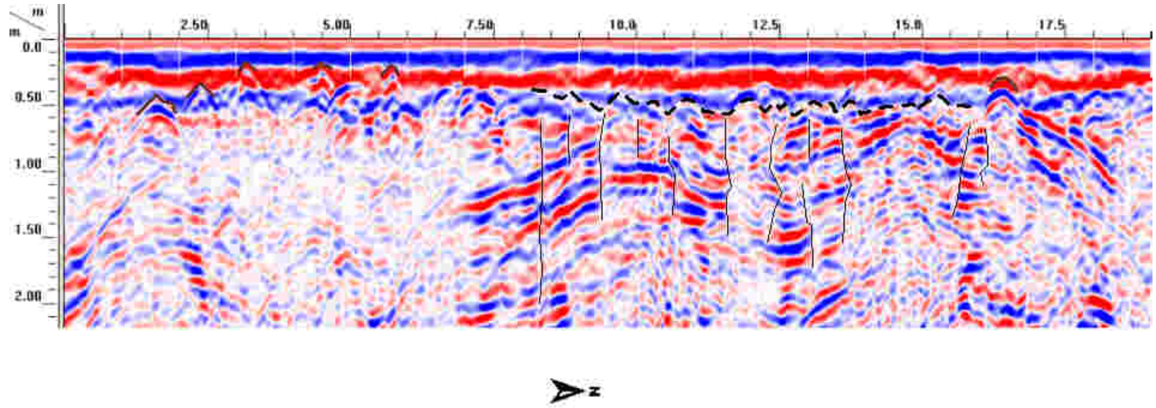

Figure 7. The radar record from the Line Y =10 m.

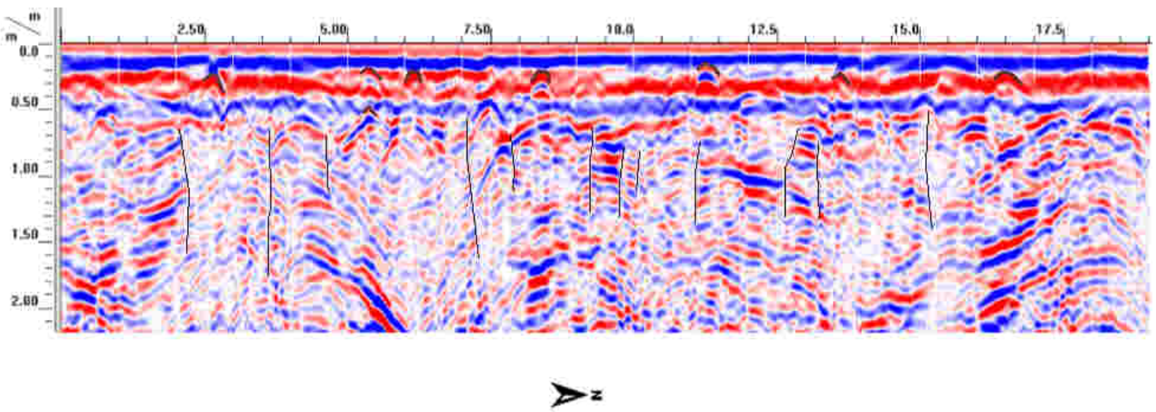

Figure 8. The radar record from the Line Y =15 m.

Also evident on these 2D radar records are areas with lower amplitude subsurface reflectors. These zones are believed to represent materials with slightly greater clay and moisture contents and/or layers with less abrupt and contrasting materials. Higher clay and moisture contents cause higher rates of signal attenuation, which reduces the energy available for reflection. These areas may represent thermokarst features or troughs in which some finer-textured materials were deposited and mixed with relatively coarser-textured soil materials producing more attenuating but not necessarily more contrasting subsurface layers.

The question remained as to the spatial pattern and arrangement of the larger, inferred sand wedges relicts observed on the 2D radar records. Do they form polygons?

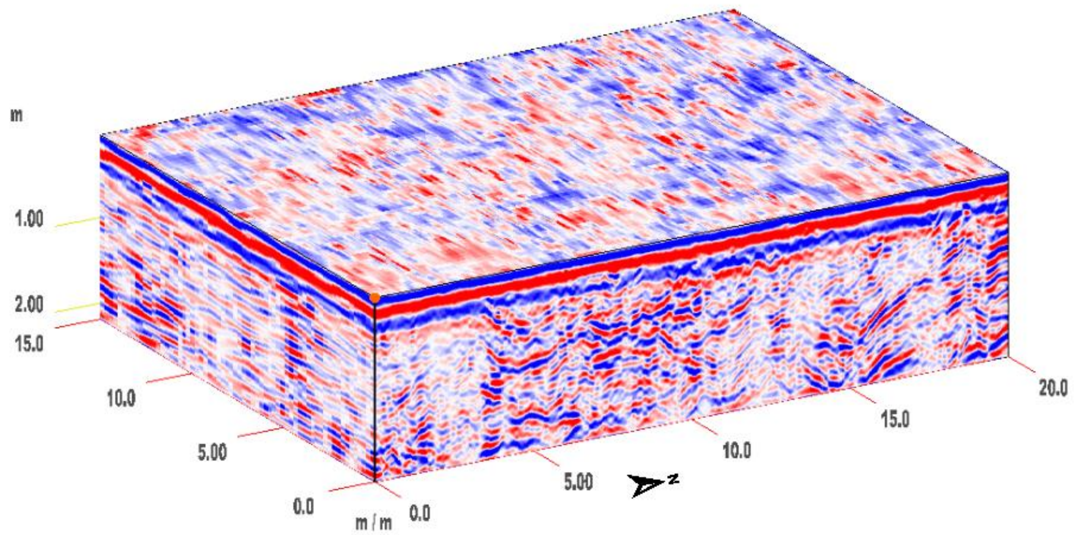

Figure 9. A 3D GPR pseudo-image from the 20 by 15 m survey area

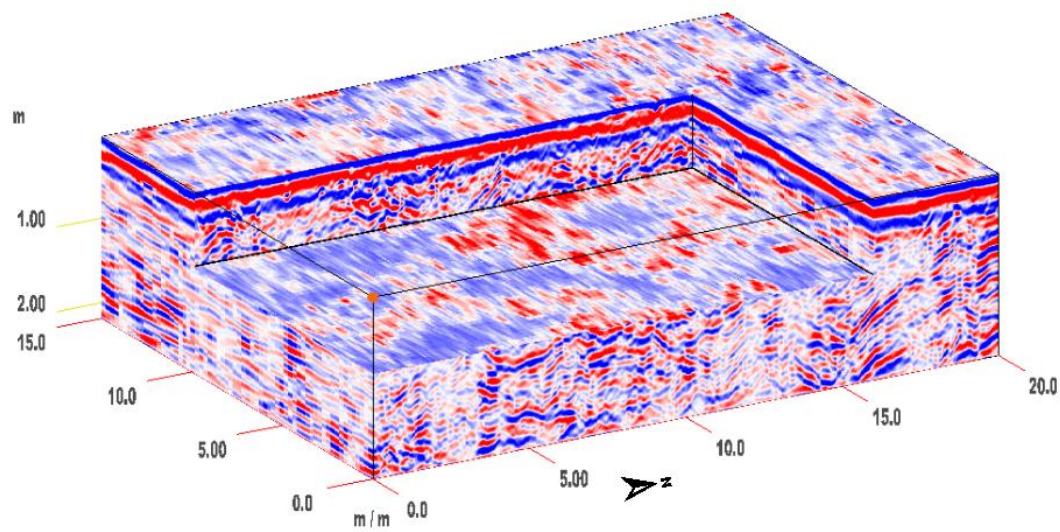

Figure 10. A 3D GPR pseudo-image from the grid site. In this image of the 20 by 15 m survey area, a 15 by 10 by 0.95-m volume has been removed.

The 3D GPR results from the 20 by 15 m grid are presented in Figure 9 thru 11. Figure 9 contains a solid 3D cube of the grid area. In Figure 10, a 15 by 10 by 0.95 m inset has been graphically removed from the 3D cube. In Figure 11, a 20 by 15 by 0.95 m inset has been graphically removed from the 3D cube. All radar traverses were conducted parallel to the X axis (right foreground), which was orientated in a north-south direction. As a result, traces were more continuously sampled in this direction and reflectors are strongly represented with little distortion to the data in this direction. Along the Y axis, however, data were not continuously recorded but interpolated over a 50-cm interval (the distance between radar traverses). As a result, some subsurface information was lost during interpolation and data along the Y-axis appear noticeably smudged, less resolved, and more generalized.

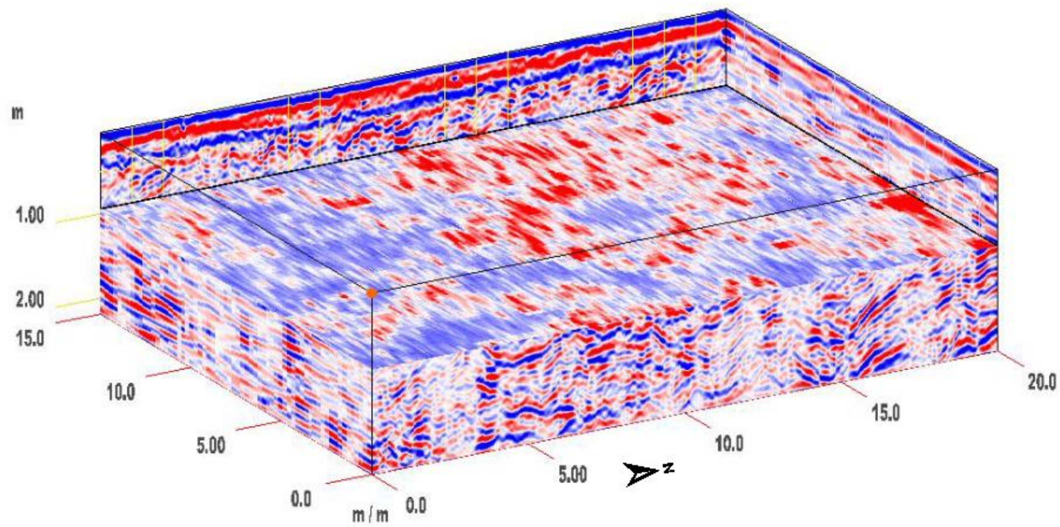

Figure 11. A 3D GPR pseudo-image from the grid site. In this image of the 20 by 15 m survey area, a 20 by 15 by 0.95-m volume has been removed.

In Figures 10 and 11, the portion of the contact that is *sliced* by the base of the cutout cube contains what appears to be linear, intersecting features of high to moderate (colored red) amplitudes. These features vary in width and are not evenly distributed beneath the grid area. These features may represent the sand wedges, which were inferred on the 2D radar records. The linear and seemingly interconnected geometry of these features suggests the possibility of pattern ground.

At this study site, the relationships between reflection patterns and soil and stratigraphic features are ambiguous. Results indicate that some sand-wedge reflects are identifiable on two-dimensional radar records. The three-dimensional ground-penetrating radar (3D GPR) analysis of the grid site was successful in imaging what appear to be the geometry of sand-wedge relicts and perhaps even a rudimentary polygon network. With two- and three-dimensional imaging of radar data and limited exposures, interpretations will rely on the investigators' knowledge of these relict permafrost features. Final interpretations must await ground-truth observations and confirmation.

References:

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

French, H. M., M. Demitroff, and S. L. Forman, 2003. Evidence for Late-Pleistocene permafrost in the New Jersey Pine Barrens (Latitude 39°N) Eastern USA. Permafrost and Periglacial processes 14: 259-274.

French, H. M., M. Demitroff, and S. L. Forman, 2005. Evidence for Late-Pleistocene thermokarst in the New Jersey Pine Barrens (Latitude 39°N) Eastern USA. Permafrost and Periglacial processes 16: 173-186.

Grasmueck, M., R. Weger, and H. Horstmeyer, 2004. Three-dimensional ground-penetrating radar imaging of sedimentary structures, fractures, and archaeological features at submeter resolution. Geology 32(11): 933-936.

Lane Jr., J. W., M. L. Buursink, F. P. Haeni, and R. J. Versteeg, 2000. Evaluation of ground-penetrating radar to detect free-phase hydrocarbons in fractured rocks – results of numerical modeling and physical experiments. Ground Water, 38(6): 929-938.

USDA-NRCS, 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. USDA Handbook 296, US Government Printing Office, Washington, District of Columbia.