United States Department of Agriculture	**Natural Resources Conservation Service**	**c/o USDA Forest Service 11 Campus Boulevard Suite 200 Newtown Square, PA 19073** (610) 557-4233; FAX: (610) 557-4200

Subject: Soils-Geophysical Field Assistance **Date:** 22 July 2008

To: Ron Alvarado
State Conservationist
USDA-NRCS
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Purpose:
Approximately 12 acres of land at the southern end of Lake George is being purchased by Warren County, the town of Lake George, and three environmental groups (Lake George Association, Lake George Land Conservancy, and the Land Conservancy Fund). The goals of the *West Brook Project* are to restore much of the purchased area to a wetland with walking paths and gardens (*north parcel*), and to construct a storm water treatment facility (*south parcel*). During Colonial times, much of the site was a marsh. Historically, the project area was repeatedly used by military forces during the French and Indian (1754-1763), American Revolution (1775-1783), and the War of 1812 (1812-1815). After this period of military use, the area was subjected to multiple episodes of filling, grading, and different land use. The Lake George Association and the State Historic Preservation Officer's Office want to confirm that the depths to the buried marsh sediments and associated archeological artifacts that may be disrupted by this project. Additionally, the environmental assessment of the site seeks to identify the nature and extent of buried materials that could potentially impact soil and groundwater quality, and to better understand existing soil and groundwater conditions.

Principal Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
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Olga Vargas, Soil Scientist, USDA-NRCS, Greenwich, NY
Dave Wick, CPESC, District Manager, Warren County SWCD, Warrensburg, NY

Activities:
All activities were completed on 15 July 2008.

Summary:
1. This brief visit allowed Olga Vargas and me to conduct field work together and discuss radar operations and interpretations. I provided Olga with an update on new advances in GPR technology, especially the integration of GPR with global positioning systems (GPS) and the use of the interactive module of RADAN software.

2. High rates of signal attenuation limited the effective profiling depth of the 200 MHz antenna to depths of less than 2 to 3 meters (6.5 to 9.8 feet) across most of the *West Brook Project* area. High rates of signal attenuation and restricted penetration depths were attributed to the high water content and the composition of different fill materials. While subsurface strata were evident in some areas to depths of 4.0 meters (13.1 feet), most reflectors were difficult to trace laterally with any degree of confidence. Without extensive excavations, the identities of these layers are unknown. The use of lower frequency antennas (70, 100, 120 MHz) could extend the depth of observation and possibly image the fill/original soil material interface. However, it is impractical to assume that small artifacts at these depths could be resolved and identified with any antenna. The use of GPR to identify deeply (>2 m) buried, small artifacts is considered unreasonable and inappropriate.

3. Ground-penetrating radar clearly imaged the water table in most traverse areas. In some areas, this interface was masked by reflections from other subsurface strata and features. However, the depth to the water table could be projected across these areas with reasonable confidence. Information was obtained with GPR on the depth to the water table and this was visually displayed using Goggle Earth. In general, at the time of this survey, the water table was largely at relatively shallow (< 2 feet) depths. Radar traverses were conducted in areas of Hinckley, Plainfield, and Oakfield soils. The water table should not occur at these shallow depths in these soils. Taking into consideration the recorded monitoring well and GPR data, it is recommended that the names of the soil polygons that have been mapped at this site be reevaluated.

4. For training, an exposure of the granitic gneiss atop Prospect Mountain was surveyed to document the affects of different lithologies on the performance of GPR.

It was my pleasure to work in New York and to be of assistance to you and Olga Vargas.

With kind regards,

James A. Doolittle
Research Soil Scientist
Soil Survey Research Staff
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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) discusses the use and operation of GPR. Antennas with a center frequency of 200 and 400 MHz were used in this study.

The RADAN for Windows (version 6.0) software program (GSSI; Salem, NH) was used to process the radar records.[1] Processing included: GPS option, header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (see Daniels (2004) for a discussion of these techniques).

A Trimble AG114 GPS receiver was used to collect position data. Position data were recorded at a rate of one measurement/sec with the AG114 GPS receiver. In RADAN, the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. In this study, the scanning rate was set to 64 scans/sec on the GPR control unit. As each scan of the radar is georeferenced, the integration of GPS with GPR results in incredibly large data sets. The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). Using the *Interactive Interpretation* module of the RADAN processing software, depths to the water table were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, and depths to water table, and other useful data).

Study Sites:
The *West Brook Project* area is located on either side of West Brook Road in the Village of Lake George, New York. The property on the north side of West Brook Road includes former structures to the "*Gaslight Village*" amusement park. The property on the south side of West Brook Road includes the "*Wax Life Museum*" or the "*Charlie's Saloon*" structure.

Historical information suggests that the site was once a wetland. West Brook once meandered across this former wetland. In the 1800s, the wetland was filled by the Delaware and Hudson Railroad in order to construct a barn and turn-around area for trains on a service line from Ft. Edward (Jarrett, 2007). During the late 1800s and early 1900s, several lumbermills/sawmills occupied portions of the site (Jarrett, 2007). In the early 1940s, a horse stable occupied some of this property. In the late 1950s, the land was purchased for commercial development and West Brook was rerouted to its present alignment along West Brook Road (Jarrett, 2007).

As part of the *West Brook Project*, six test pits were excavated at the site (Black, 2007). Layers of cinders, sawdust and wood were observed in these pits. Borings on the *north parcel* revealed that buried layers of organic soil materials were at depths greater than 10 feet (Jarrett, 2007). These layers are believed to represent original soil materials.

Figure 1 is a soil map of the *West Brook Project* area. Soils polygons identified within the site include: Hinckley-Plainfield complex, sloping (HpC), Oakville loamy fine sand, 3 to 8 percent slopes (OaB,) and Udorthents, smoothed (Ud). The very deep, excessively drained Hinckley and Plainfield soils formed in water-sorted sandy materials. Oakfield soils formed in sandy aeolian deposits. Hinckley soils contain large amounts of coarse fragments. Within the solum, rock fragments range from 5 to 50 percent gravel, 0 to 30 percent cobbles, and 0 to 3 percent stones. Plainfield soils contain less than 15 percent gravel. Oakville soils lack coarse fragments and

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

average more than 50 percent fine and very fine sand in the particle-size control section. The taxonomic classifications of these soils are listed in Table 1.

Figure 1. Soil map of the *West Brook Project* area from the Web Soil Survey.
Areas in green represent the *north* and *south parcels*.

Table 1 Taxonomic Classification of Soils Recognized in *West Brook Project* Area.

Soil Series	Taxonomic classification
Hinckley	Sandy-skeletal, mixed, mesic Typic Udorthents
Plainfield	Mixed, mesic Typic Udipsamments
Oakville	Mixed, mesic Typic Udipsamments

Udorthents are a miscellaneous land type. Slopes can range from 0 to 15 percent. Depths to root restrictive layer are greater than 60 inches. The natural drainage class of Udorthents is described as well drained. A seasonal zone of water saturation is described as being at 54 inches during winter and spring months.

Survey Procedures:
Three GPR traverses were completed across both the *north parcel* and *south parcel*. Traverses were conducted across open areas and were mostly aligned to have monitoring wells at their origins and/or end points. A 200 MHz antenna was used in these surveys. Scanning times of 100 and 120 ns were used for traverses conducted in the *north parcel* and *south parcels*, respectively. Each radar traverse was stored as a separate file. Radar records were reviewed in the field and the water table interface identified.

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., water table, 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 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 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 the E_r and *v*.

Based on measured depths and two-way pulse travel times to the water table, which were measured at five monitoring wells, the relative dielectric permittivity and the velocity of propagation through the upper part of the soil profile were estimated using equations [2] and [1]. An estimated E_r of 12 resulted in a *v* of 0.086 m/ns. A constant *v* of 0.086 m/ns was used to depth scale the radar records. A constant *v* provides an approximate depth scale for the radar records shown in this report, but is partially incorrect. This scale is only correct for depths above the water table. For deeper layers below the water table, because of the effects of water saturation, E_r will increase and *v* will decrease (below water table, the scaled depths should be reduced).

Results:
The locations of the six GPR traverse are shown in Figure 2. In Figure 2, each radar traverse is labeled and the direction of advance indicated by an arrow. Different colors show the relative depths to the water table along these lines. These depths were confirmed at five monitoring wells, which were the end points for five of the six GPR traverses. Reflections from the water table provided and identifiable interface that could be traced across each radar record with relative confidence. In Figure 2, the depths to water table are grouped into three depth classes: shallow (less than 50 cm (20 inches), red), moderately deep (50 to 100 cm (20 to 40 inches), orange) and deep (100 to 150 cm (40 to 60 inches), green).

One of the goals of this investigation was to use GPR to determine the thickness of fill. High rates of signal attenuation limited the effective profiling depth of the 200 MHz antenna to depths of less than 2 to 3 meters (6.5 to 9.8 feet) across most of the traversed areas. Variations in the rates of signal attenuation and depths of penetration were attributed to the high water content and the composition of the different fill materials. While subsurface strata were evident in some areas to depths as great as 4.0 meters (13.1 feet), these reflectors were generally low-amplitude and highly segmented. Consequently, these interfaces are difficult to trace laterally with any degree of confidence. Possibly, the use of a lower frequency antenna (70, 100, 120 MHz) could extend the depth of observation and image the fill/original soil material interface. However, it is doubtful that small archaeological features at these depths could be resolved and identified with any antenna. The use of GPR to identify deeply (>2 m) buried, small artifacts is considered inappropriate.

Ground-penetrating radar clearly imaged the water table in most traverse areas. In some areas, this interface was masked by other subsurface strata and features. In general, at the time of this survey, the water table was at relatively shallow (< 2 feet) depths. The water table should not occur at these shallow depths in areas of

Hinckley, Plainfield, and Oakfield soils. Taking into consideration the recorded monitoring well and GPR data, it is recommended that USDA-NRCS reevaluate the names of the soil polygons that have been mapped at this site. As areas of fill material are known to occur in the polygons of Hinckley-Plainfield complex, sloping (HpC), and Oakville loamy fine sand, 3 to 8 percent slopes (OaB,), these areas would be more appropriately mapped as Udorthents, smoothed (Ud).

Figure 2. Locations of GPR Traverse lines and depth to water table interpretations.

The radar records contained in this report depict highly variable subsurface materials. On most radar record, a continuous moderate to high amplitude subsurface planar reflector is evident. This interface varies in depth from about 1 to 3 meters (about 3.3 to 9.8 feet). While the identity of this interface is unknown, it may represent the contact of fill materials with the original soil materials. If so, the interpreted depths would be less than the observed depths reported in the site assessments. Differences in the depth of penetration and the graphic signatures in different portions of the *West Brook Project* area suggest the extent of different materials that could potentially impact soil and groundwater quality.

Figures 3 to 7 represent 3D images of the radar records collected in this study. In each images the depth and distance scales are in meters. The identities and locations of the traverse lines are shown in Figure 2. In addition, at the bottom of each 3D image, locations are identified by Universal Traverse Mercator (UTM) coordinates. Traverse lines 1 to 3 were conducted within a polygon of Hinckley-Plainfield complex, sloping (HpC), in the *north parcel*. Traverse lines 4 to 6 were conducted within a polygon of Oakville loamy fine sand, 3 to 8 percent slopes (OaB), in the *south parcel*.

Figure 3 is the radar record from traverse line 1. This relatively short traverse line trends in an east to west direction across the *north parcel*. The water table provides relatively high amplitude (white and grey colors) reflections that are easily traced across the upper part of this 3D image. Multiple, slightly wavy, horizontal reflectors suggest the presents of additional layers to depths of about 3 meters along this traverse. A prominent, deeper, unknown, continuous interface is evident across most of this 3D image. Near 604255 Easting, higher rates of signal attenuation suggest more attenuating materials (cinders or sawdust?) or possible contaminants in the groundwater.

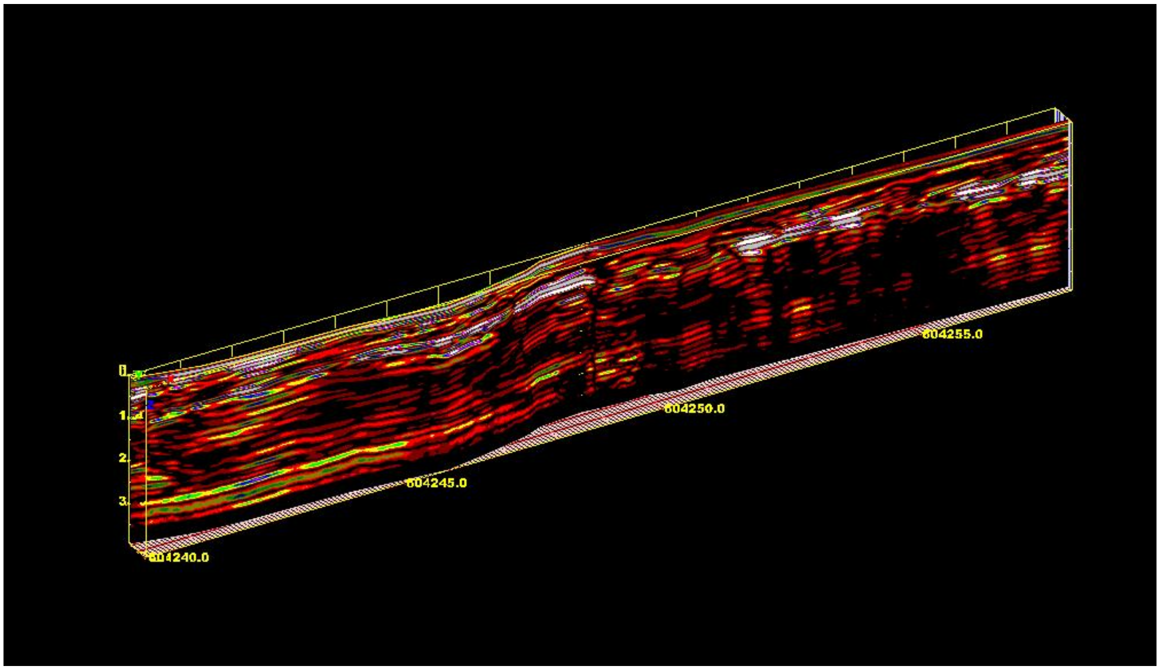

Figure 3. GPR traverse line #1. Direction of advance is from left to right.

Figure 4 contains the highly compressed radar record from traverse line 2. This relatively long traverse line trends in a west to east direction across the *north parcel*. The water table is more difficult to trace laterally across this 3D images as, in many segments, it is partially obscured by other subsurface reflectors. The greater complexity of radar signatures along these traverses suggests more contrasting and discontinuous layers of fill materials. Near 604250 Easting, higher rates of signal attenuation suggest more attenuating materials. This portion of the radar traverse crosses a paved area. The composition of the pavement or the presence of salts could be responsible for the observed higher rates of signal attenuation. Several, high-amplitude, narrow, vertical patterns are evident in this image. These patterns represent buried point anomalies; many are suspected to be buried utility lines (crossed at orthogonal to their long axis) or metallic objects. A cluster of shallowly buried (< 1 m), high amplitude reflections near 604325 Easting suggest the presence of a concentration of buried structural debris. Once again, deeper, more continuous interfaces that vary in signal amplitude can be traced laterally across the lower portions of the radar record.

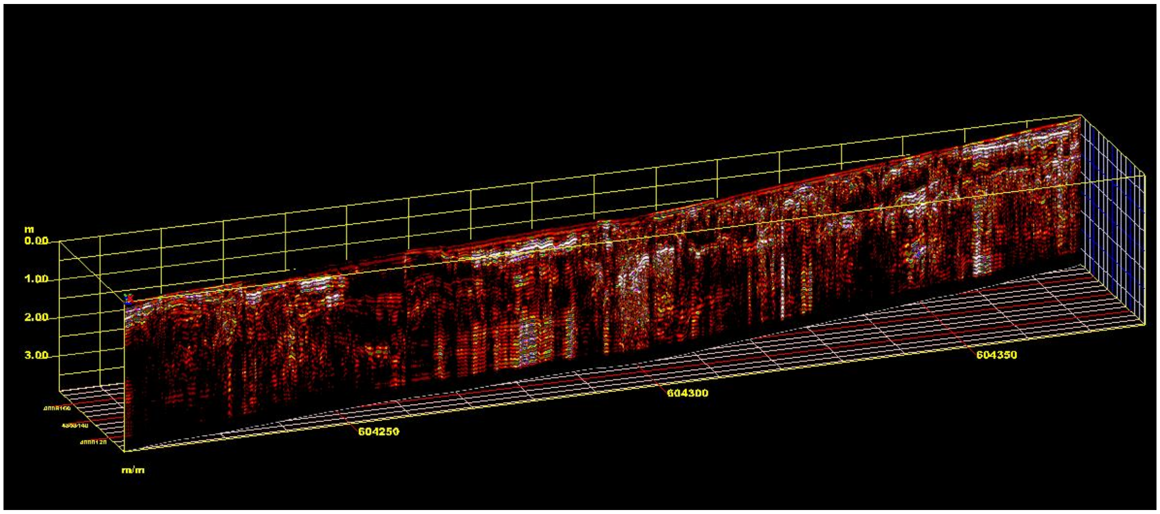

Figure 4. GPR traverse line #2. Direction of advance is from left to right.

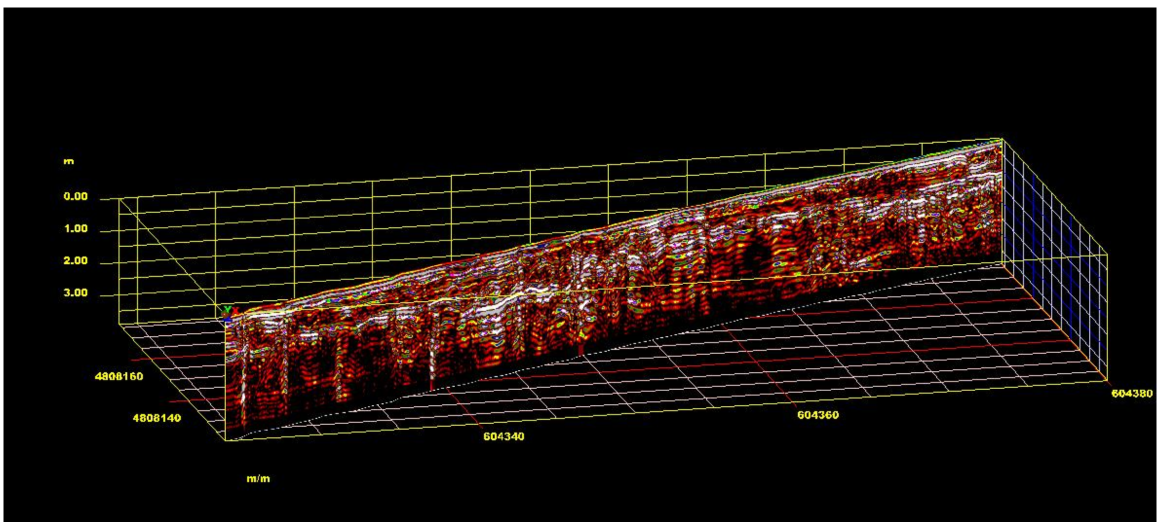

Figure 5. GPR traverse line #3. Direction of advance is from left to right.

Figure 5 is the radar record from traverse line 3. This relatively short traverse line trends in an east to west direction across the *north parcel*. The water table is more difficult to trace laterally across the upper part of this 3D images as, in many segments, it is partially obscured by other subsurface reflectors. The presence of several noticeable, high-amplitude, narrow, vertical reverberation patterns suggest the locations of buried utility lines (crossed at orthogonal to their long axis) or metallic objects. The radar record can be divided into several sections based on the arrangement and geometry of subsurface reflectors. These segments are suspected to represent different deposits of fill materials. An irregular, high-amplitude reflector can be traced laterally across this radar record at interpreted depths of about 70 to 170 cm (2.3 to 5.6 feet).

Figure 6 is the radar record from traverse line 4. This traverse line trends in an east to west direction across the *south parcel*. Two high-amplitude, narrow, vertical reverberation patterns (one near the beginning and one at the very end of the traverse line) suggest the locations of buried metallic artifact (the one near the very end of the traverse is side reflections off of a monitoring well casing). Across most of this image, the depth of maximum penetration is about 2 m. This relatively shallow depth suggest higher rates of signal attenuation and/or the absence of contrasting layers at lower soil depths. The radar record can be easily segmented into sections based on differences in the number, amplitude, and geometry of reflectors. These patterns are considered atypical for Oakfield soil and suggest the probable presence of disturbed or fill materials.

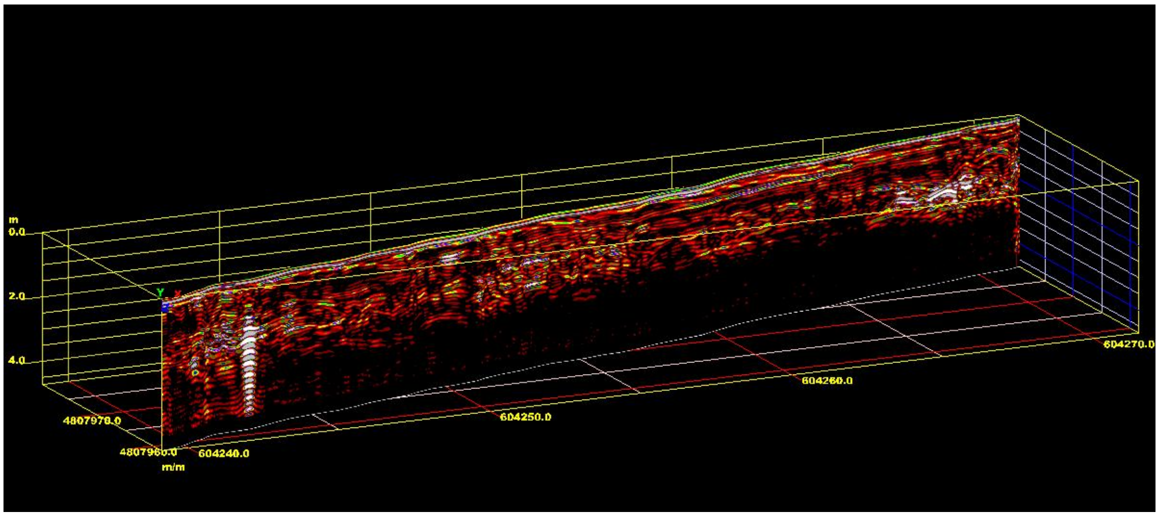

Figure 6. GPR traverse line #4. Direction of advance is from left to right.

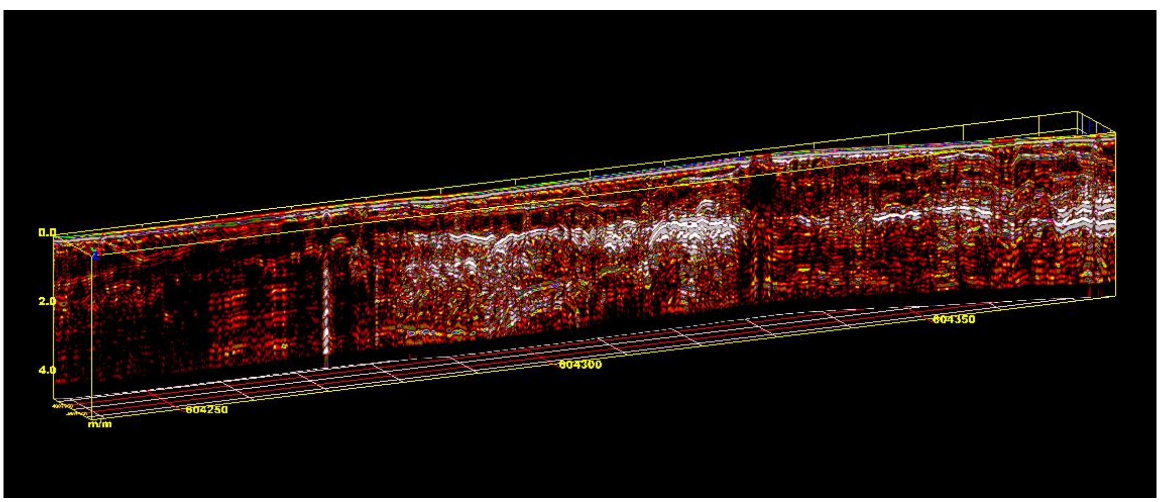

Figure 7. GPR traverse line #5. Direction of advance is from left to right.

Figure 7 is the radar record from traverse line 5. This traverse line trends in a general west to east direction across the *south parcel*. Other than western-most segment (left-hand portion of image), depths of penetration are greater than 4 m across most of the radar record. This suggests the presences of more transparent, less attenuating soil materials. The water table is partially obscured by both the surface pulse and subsurface reflections, and is difficult to trace laterally across the radar record. A major subsurface interface can be traced laterally across this radar record between interpreted depths of 2 to 3.2 meters (6.6 to 10.5 feet). The continuity and clear expression of this interface suggest a major stratigraphic layer and perhaps, the base of disturbed or fill materials.

Figure 8 is the radar record from traverse line 6. This traverse line trends in a south to north direction across the *south parcel*. The jagged appearance of this traverse line represents less accurate GPS positioning. A major subsurface interface can be traced laterally across this radar record between interpreted depths of 1.1 to 2.4 meters (3.6 to 7.9 feet). The continuity and clear expression of this interface suggest a major stratigraphic layer. Other less distinct and continuous interfaces are evident below this interface in the lower part of the radar record.

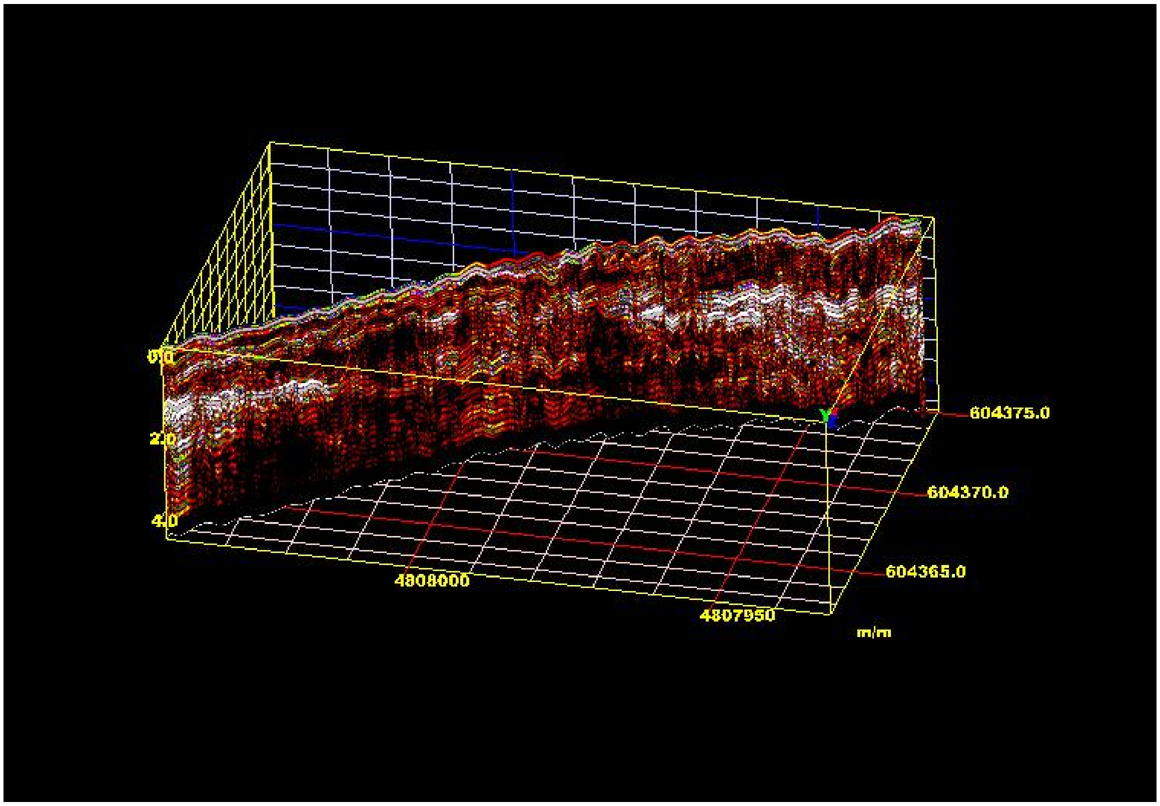

Figure 8. GPR traverse line #6. Direction of advance is from left to right.

Bedrock Investigation on Prospect Mountain:
Prospect Mountain, at an elevation of 2,030-feet, forms the western background to the village of Lake George, New York. It consists of Precambrian granitic gneiss. The granitic gneiss is characterized by large amounts of hornblende and garnet crystals and has prominent horizontal joints or cracks, presumably the result of exfoliation and/or glacial rebound. An exposure of the granitic gneiss (42.422861 N. Latitude, 73.747439 W. Longitude) atop Prospect Mountain was selected to document the affects of different lithologies on the performance of GPR.

The photograph in Figure 8 shows a radar traverse being conducted with a 400 MHz antenna near the face of the exposed granitic-gneiss outcrop. Horizontal cracks are evident in this photograph. Narrow, vertically inclined fractures were noticeable on the face of this exposure. In general, vertical fractures are markedly narrower and less obvious than the horizontal joints or cracks.

Figures 9 and 10 contain 3D radar records that were collected with the 200 and 400 MHz antennas, respectively. The granitic gneiss bedrock is transparent and well suited to GPR. Both antennas capture the horizontal fracture planes of the bedrock caused by exfoliation or glacial rebound. In both radar records, hyperbolas and multiple scattering reflections suggest the probable locations of some more vertically-inclined joints and fractures.

Figure 9. Conducting a radar traverse with the 400 MHz antenna across an exposure of granitic gneiss on Prospect Mountain.

Differences in the geometry, separation, and contents of fractures and bedding planes affect detection with GPR. Because of scattering losses, attenuation, wave length-scale heterogeneities, and geometric constraints, the number of fractures interpreted from radar data is generally considered an order of magnitude less than the number observed in outcrops (Lane et al., 2000). Closely spaced bedding and fracture planes are poorly defined as they often produce multiple, superimposed reverberations on radar records. Fractures and bedding planes with large dip-angles and/or irregular or rough interface surfaces can result in substantial scattering of the reflected wave front away from an antenna. Vertical interfaces reflect very little energy towards the antenna and are therefore difficult to detect with GPR. In addition, fractures and bedding planes with dip-angles greater than about 45 degrees are affected by spatial aliasing distortion and are not accurately imaged with GPR (Buursink and Lane 1999; Ulriksen, 1982).

In bedrock, variations in electrical properties are associated with changes in water content (Davis and Annan, 1989). Abrupt changes in water content produce radar reflections. In crystalline bedrock, saturated fractures have higher amplitude reflections than air-filled or unsaturated fractures (Lane et al., 2000). However, not all fractures are detectable with GPR. GPR is generally insensitive to fractures with smaller widths (less than ½ to ¼ of the propagated wave length).

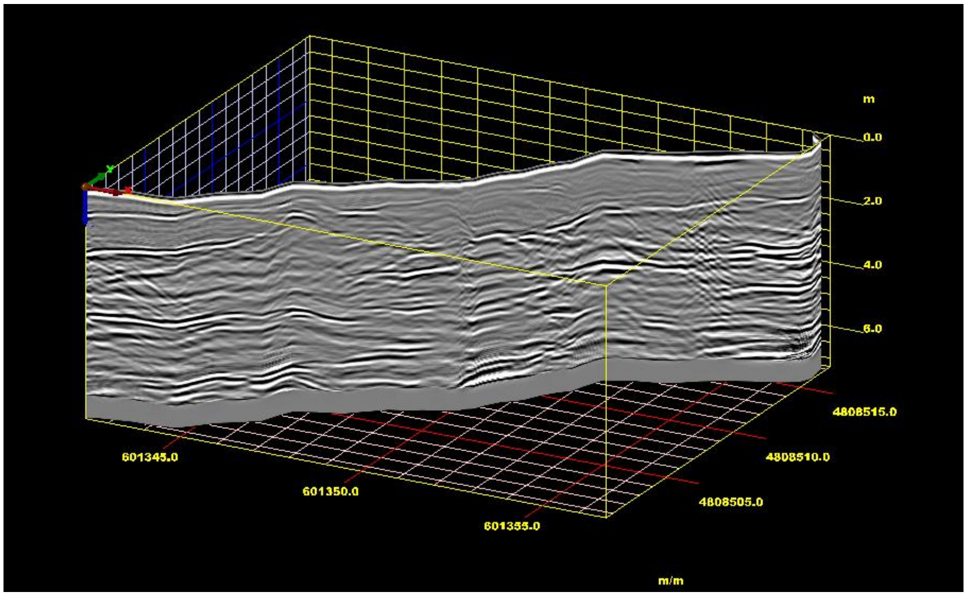

Figure 10. This geo-referenced 3D radar record, from the exposures of granitic gneiss on Prospect Mountain, was collected with the 200 MHz antenna.

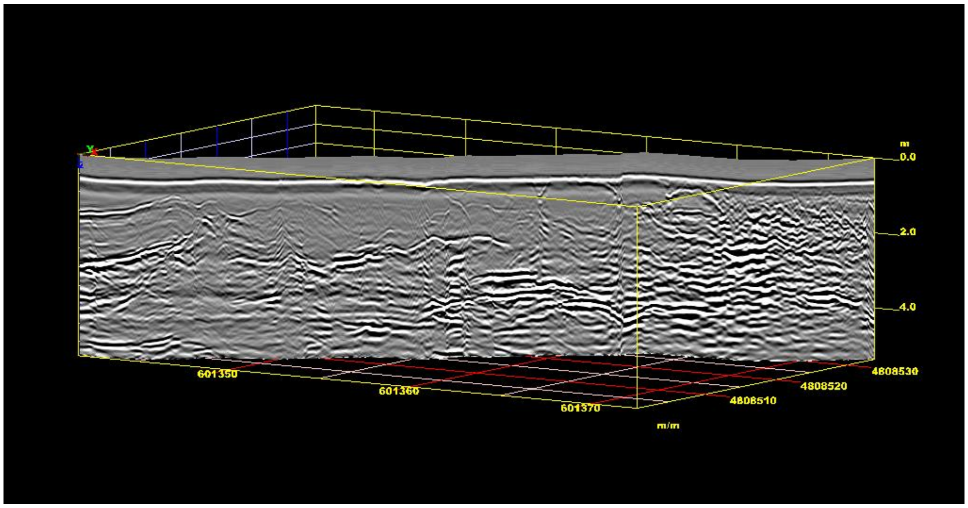

Figure 10. This geo-referenced 3D radar record, from the exposures of granitic gneiss on Prospect Mountain, was collected with the 400 MHz antenna.

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