United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

October 4, 2011

TO: Astor F. Boozer
State Conservationist
NRCS, Syracuse, New York

File Code: 330-7

Purpose:
Ground-penetrating radar (GPR) was used to chart the depth to serpentinite bedrock in areas of Wotalfs and Todthill soils on Staten Island. The radar data will be used to improve interpretations and document the composition of soil map units. In addition, GPR was used to locate buried utility lines, identify different subsurface layers of anthropogenic materials, and ascertain the presence and depth to bedrock in the Bronx.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Franco Montalto, Associate Professor, Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, PA
Richard Shaw, Resource Soil Scientist, USDA-NRCS, Staten Island, NY
Elizabeth Troop, Sr. Engineer/Project Manager, eDesign Dynamics, New York, NY
Olga Vargas, Resource Soil Scientist, USDA-NRCS, Greenwich, NY

Activities:
Field activities were completed during the period of 12 to 14 September 2011.

Summary:

1. In the "urban canyons" of Bronx, New York, the accuracy of GPS positioning was seriously impaired by multipathing and satellite shading. It is recommended that for future radar surveys of similar urban sites, grid should be laid out and systematic grid survey conducted with GPR. During the bedrock investigations on Staten Island, the GeoXT GPS receiver failed to communicate with the SIR3000 and signal data recorder. As a consequence, no position data were recorded and the radar signals cannot be georeferenced.

2. At the Bronx site, GPR interpretations suggest that the underlying bedrock, if present, occurs at depths greater than 1.75 m (about 5.7 ft) beneath most areas. An area with anomalous, higher-amplitude subsurface radar reflections (at depths of less than 1.2 m) was identified. These reflections could represent either layers of contrasting fill materials or bedrock. To confirm these interpretations, ground-truth core observations are needed.

3. Based on the Bronx study, the 400 MHz antenna is recommended for future studies conducted in New York City in areas that are underlain by till.

4. In the highlands of Staten Island, based on fourteen GPR traverses and over 63,000 semi-automatically picked depths, soils are dominantly moderately deep (67 %) and shallow (25 %). Deep and very deep soils make up only 5 and 3 % of the picked observations, respectively. The

use of map unit complexes for the soils and the landscape covered is recommended.

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

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc: See attached list

cc:
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Technical Report on Ground-Penetrating Radar (GPR) Investigations conducted in Staten Island, New York on 12 and 14 September 2011.

James A. Doolittle

Background:

A reconnaissance site investigation was conducted with ground-penetrating radar (GPR) in the Bronx. The purpose of this survey was to provide additional subsurface information and evaluate the suitability of GPR to locate buried utility lines, identify different subsurface layers of anthropogenic materials, and ascertain the presence and depth to bedrock. Ground-penetrating radar was used on Staten Island to chart the depth to serpentinite bedrock in areas of shallow Wotalfs and moderately deep Todthill soils. The radar data will be used to improve interpretations and to document the composition of soil map units.

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).[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 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 400 MHz antenna was used this study.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[1] Processing included: header editing, positioning the initial pulse to time zero, color table and transformation selection, signal stacking, migration, horizontal high pass filtration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). In this report, three-dimensional (3D) imaging methods, which are contained in the RADAN software, were used to exhibit some radar records.

Recent technical developments allow the integration of GPR and global positioning system (GPS) data. The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). During data processing, a subprogram within RADAN is 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. A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) with Hurricane antenna was used to georeferenced data collected with the SIR-3000 system.[1]

For the data that were collected on Staten Island, the *Interactive 3D Module* of RADAN was used to semi-automatically picked the depths to the soil/bedrock interface. The picked data were outputted to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to bedrock data). Data have been forwarded to Richard Shaw under a separate cover letter.

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., bedrock, 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 (after Daniels, 2004):

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[1] Trade names are used for specific references and do not constitute endorsement.

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

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

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

Where C is the velocity of propagation in a vacuum (0.299 m/ns). The velocity of pulse propagation is commonly 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 the measured depth and the two-way pulse travel time to known subsurface reflector (bedrock surface), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated at several sites on Staten Island using equations [1] and [2]. At the time of this study, soils were moist. The estimated E_r varied between 6.3 and 6.7. The estimated *v* ranged from 0.1198 to 0.1158 m/ns. No ground-truth core observations were taken in the Bronx. An average E_r (6.5) and *v* (0.1178 m/ns) were used to provide a rough estimate of the exploration depths for this urban investigation.

GPR Survey Procedures:

At each site, multiple traverses were completed with a 400 MHz antenna. The 400 MHz antenna provided good resolution of subsurface features and suitable penetration depths. Each radar traverse was stored as a separate file. Poor satellite reception and multipathing resulted in the corruption of the position data recorded with GPS. The lack of processing software produced additional position inaccuracies.

Discussion and Results:

Stratford Street, Bronx, New York

The site is located on Stratford Ave between E 172nd and 174th Streets in Bronx, New York (Figure 1). Ground-penetrating radar traverses were completed along Stratford Ave., the adjoining sidewalks and parking areas. In addition, radar traverses were also completed along the sidewalk located on the south side of E 174th Street between Stratford and Manor Avenues.

Initially, a 200 MHz antenna was used for the GPR site investigation of Stratford Avenue. The 200 MHz antenna provided ample penetration depth, but could not adequately resolve many of the buried utility lines that were known to exist beneath Stratford Ave. The 400 MHz antenna provided suitable penetration depths (1.5 to 2 m) and, compared with the 200 MHz antenna, greater resolution of subsurface features. Based on the results of this investigation, the 400 MHz antenna is recommended for future studies conducted in New York City in areas underlain by till.

Figure 2 is a representative portion of a radar record that was collected along Stratford Ave. In Figure 2, the vertical (depth) scale is expressed in meters. The horizontal scale is expressed in latitude and longitude values based on the WGS 84 geodetic system. Several point anomalies, all believed to be buried utilities and pipe lines, are evident on this radar record. These buried features were traversed orthogonal to their long axis and, as a result, produced distinct hyperbolic patterns on the radar record. When the antenna traverse is located immediately above and parallel with the long axis of these features, elongated, planar reflectors are produced on radar records. The clarity of these features is affected by their orientation, size and depth, and the soil moisture and clay contents.

On the radar record shown in Figure 2, the approximate depth of exploration is about 1.75 m (5.7 ft). Buried utility lines appear at depths ranging from 0.75 to 1.25 m (2.5 to 4.1 ft). Other than these features, there are no major subsurface reflections, such as bedrock, visible within depths of 1.75 m.

Figure 1. The Bronx study site is located principally along Stratford Ave between W 173rd and E 174th Streets. Multiple radar traverses were completed within the area defined by the yellow-colored lines. Imagery courtesy of Brian Jones of GSSI.

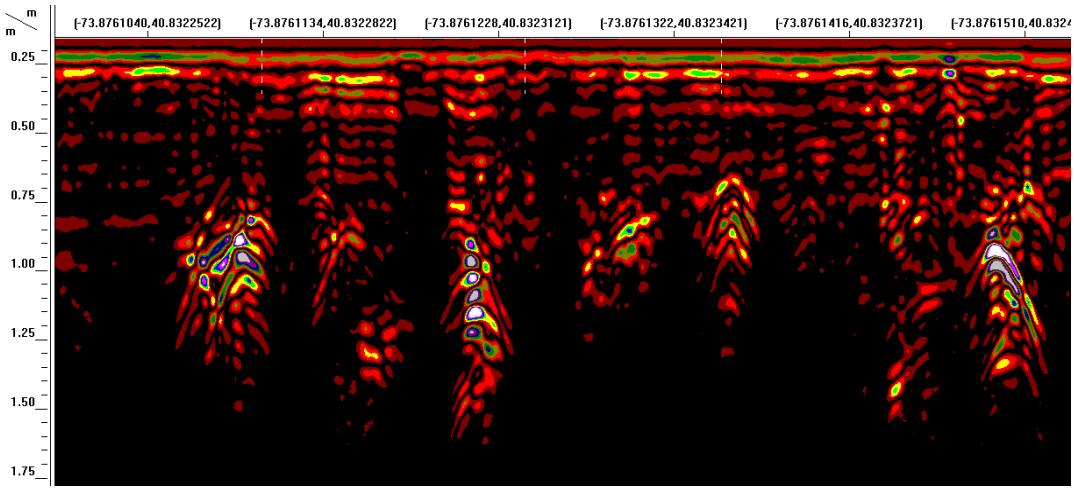

Figure 2. Hyperbolic reflections from buried utilities and pipe lines, which were crossed over (orthogonally to their long axes) by the radar antenna, are clearly evident in this radar record from Stratford Ave.

Figure 3 is a portion of a radar record also collected along Stratford Ave. In Figure 3, the vertical (depth) scale is expressed in meters. The horizontal scale is expressed in latitude and longitude values based on

the WGS 84 geodetic system. In Figure 3, features interpreted as two refilled trenches have been outlines by yellow-colored lines. The chaotic reflection patterns consisting of numerous point reflectors that are evident on this radar record are characteristic of glacial till. No subsurface reflectors that suggest a lithologic feature or the soil/bedrock interface are clearly expressed or evident on this radar record.

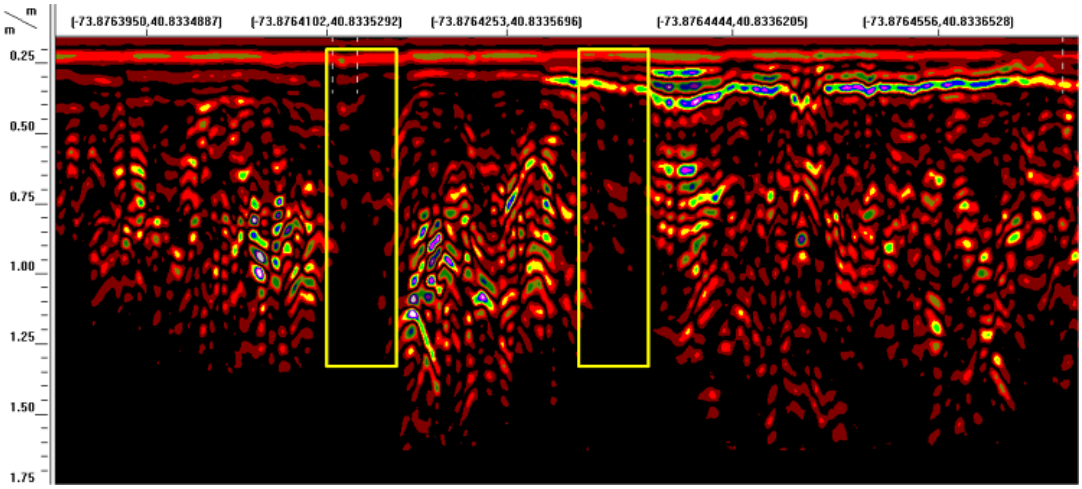

Figure 3. The rectangles formed by yellow-colored lines are believed to represent refilled trenches that were excavated into the underlying glacial till.

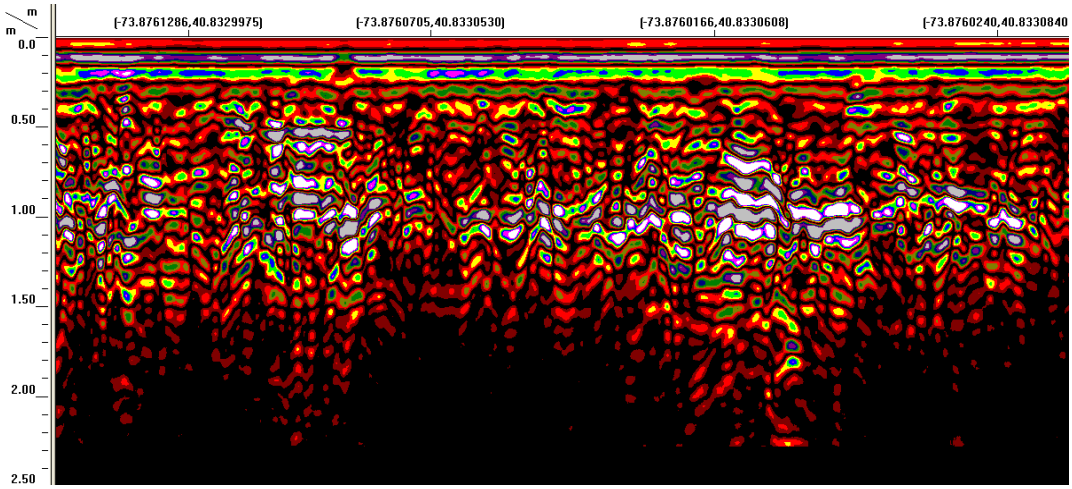

Figure 4. This rather unique radar record was collected in an area that was suspected to be underlain by bedrock at relatively shallow depths. The high-amplitude, segmented, linear reflector that occurs at depths ranging from 60 to 120 cm may represent the soil/bedrock interface.

Oral history and the presence of high-rise buildings suggest the likely presences of bedrock at relatively shallow depths within a portion of the study site. Figure 4 is a portion of a radar record that was collected in a parking area that is believed to be underlain by bedrock at relatively shallow depths (for location, see "A" in Figure 1). Higher amplitude (signified by white, pink and grey colors), segmented, planar reflector appears to pass across this radar record between depths of about 60 to 120 cm (about 2.0 to 3.9 ft). This reflector identifies a more contrasting (in terms of dielectric properties) interface. For the radar record shown in Figure 4, the depth of exploration was set to a slightly higher range and the gain settings

were slightly higher than for the radar record shown in Figure 3. The reflection patterns in these figures are similar and vary only in amplitude (the record settings were slightly higher on the radar record shown in Figure 4). If the subsurface features on these radar records are in fact the same, the refilled excavation pits in Figure 3 show that the subsurface layer has been breached. While the identity of this interface cannot be confirmed by radar interpretations alone, it could represent layers of contrasting fill materials or bedrock. To confirm these interpretations, ground-truth core observations are needed.

During the survey of Stratford Ave., real-time GPS was enabled on the GPR system. The program generates an *ASCII* plot file in which the GPS coordinates are associated with radar trace numbers. Under favorable conditions, GPR/GPS integration provides for the relatively accurate positioning of radar data and its importation into geographical information systems (GIS). During the course of the radar survey along Stratford Ave., problems occasionally occurred with the GeoXT GPS receiver failing to lock onto a sufficient number of satellites (the GPS Option of the GPR requires a minimum of 4 to 6 satellites). The radar system, however, provided no indication of poor satellite geometry or insufficient numbers of satellites, and sub-meter accuracy was assumed.

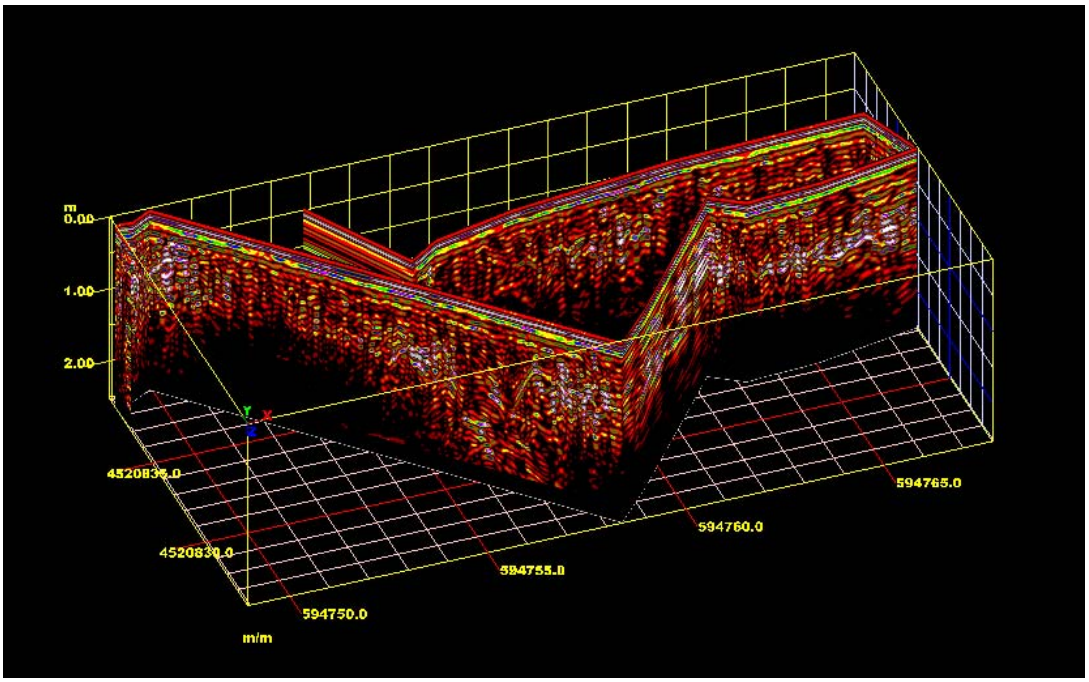

Figure 5. This 3D GPR pseudo-image is from a radar traverse that consisted of three, straight-line segments, which formed a U-shaped pattern. Excessive distortion caused by multipathing and satellite shading makes this imagery unsuitable for use.

Following the radar survey the RADAN software was used to merge the GPR and GPS data. Figure 5 is a representative 3D GPR pseudo-image of a radar record from the Stratford Ave site. The radar traverse consisted of three line segments that formed a U-shaped pattern. It is evident in this pseudo-image that excessive distortion has occurred. The distortion is mostly likely the result of multipathing and satellite shading caused by adjoining high-rise buildings. These inaccuracies, which were not evident at the time of the survey, persist on all radar records. As a consequence, the GPS ground-control is considered inappropriate for use in this setting. For future studies in similar urban settings, a higher grade GPS

receiver with base station and signal processing software should be used, or a properly measured and recorded grid needs to be established across survey sites.

Todt Hill highlands, Staten Island, New York:

The highlands of Staten Island are underlain by serpentinite. Serpentinite is a dense, greenish-colored, greasy rock composed of the mineral serpentine. Serpentine rarely occurs in soils, except in those formed from serpentinite. Soils formed in materials weathered from serpentinite are considered relatively infertile. Infertility is attributed to the soil's chemical properties (high magnesium to calcium ratio, and high levels of certain trace metals, especially nickel and chromium). Most plants cannot tolerate these conditions, and the serpentine "barrens" of Staten Island are characterized by its unique plant communities.

Dominant soils on the Todt Hills highland include Cheshire (coarse-loamy, mixed, semiactive, mesic Typic Dystrudepts), Todthill (coarse-loamy, mixed, superactive, mesic Dystric Eutrudepts), and Wotalfs (loamy-skeletal, mixed, superactive, mesic Lithic Eutrudepts) series. These well drained soils formed in a loamy mantle of ablation till overlying serpentinite bedrock. Depth to bedrock is shallow (0 to 50 cm) for Wotalfs, moderately deep (50 to 100 cm) for Todthill, and very deep (>150 cm) for Cheshire soils.

Study Sites:

No digital soil data is presently available for the GPR study sites on Staten Island. Figure 6 contains three Google Earth images that include the locations of the five study sites. Site 1 is located on a steeply sloping, forested slope to the immediate north of Old Mill Road. Two traverses were conducted in a down slope direction across this site. Rock outcrops were more evident along traverse line 1 (~74.1506 W Longitude, ~40.5731 N Latitude) than along traverse line 2 (~74.1495 W Longitude, ~40.5733 N Latitude). The second traverse line was divided into two parts: an upper and a lower slope component.

Four GPR traverses were completed across Site 2 (~74.1292 W Longitude, ~40.5973 N Latitude), which is located on a partially cleared summit area just south of Brielle Ave. Two GPR traverses were conducted along two intersecting trails at Site 3 (~74.1310 W Longitude, ~40.58833 N Latitude), which is located in a wooded area. The first traverse (line 8) was conducted essentially orthogonal to the slope contours; the second line (line 9) was conducted parallel with the slope contours.

Three GPR traverses were completed across Site 4 (~74.0912 W Longitude, ~40.6306 N Latitude), which is located on grassy areas of Silver Lake Park near the intersection of Forest Ave. and Victory Blvd. The first traverse (line 10) across this site descended from a summit area along Forest Ave. into a depressional area. Traverse lines 11 and 12 were completed in a sloping, tree-covered area located in the extreme northeastern corner of Silver Lake Park. Two GPR traverses (lines 13 and 14) were completed across Site 5 (~74.0878 W Longitude, ~40.6304 N Latitude), which is located on grassy, tree covered areas within Hero Park near the intersection of Victory Blvd and Louis Street.

Interpretations of Radar Records:

Figures 7 and 8 are representative radar records that were collected in the highlands of Staten Island and in areas that are underlain by serpentinite bedrock. Typically, a diffuse, ill-defined zone, which consists of chaotically arranged, low to medium amplitude (in Figure 7, colored in shades of red and yellow) point reflectors overlies a prominent layer of higher amplitude (in Figure 7, colored in shades of white, grey, purple and green), segmented and inclined, linear reflectors. The upper zone may represent a layer of more highly weathered and fractured serpentinite. The point reflectors in this portion of the radar record

are caused by local inhomogeneities: more resistant and less weathered rock fragments, areas of intact bedrock separated by fractures. In Figure 7, a prominent, high-amplitude, segmented interface is evident at depths ranging from 80 to 100 cm (2.6 to 3.3 ft). In Figure 8, the diffuse, overlying zone is thinner and the higher-amplitude, segmented interface is within depths of 1 m (3.3 ft). On the radar records shown in Figures 7 and 8, the serpentinite presents similar interfaces and radar facies. Radar facies are "groups of radar reflections whose parameters (configuration, amplitude, continuity, frequency, interval velocity, attenuation, dispersion) differ from adjacent groups" (Baker, 1991). In both radar records, a thin, diffuse zone of lower-amplitude point reflectors overlies a higher-amplitude, segmented interface. In both radar records, the serpentinite facies consists of higher-amplitude, highly segmented, inclined, and contorted mostly linear reflectors with a lesser number of point reflectors.

Figure 6. Google Earth Images of the five GPR study sites on Staten Island. Numbers are used to identify each site. Imagery was provided courtesy of Brian Jones of GSSI.

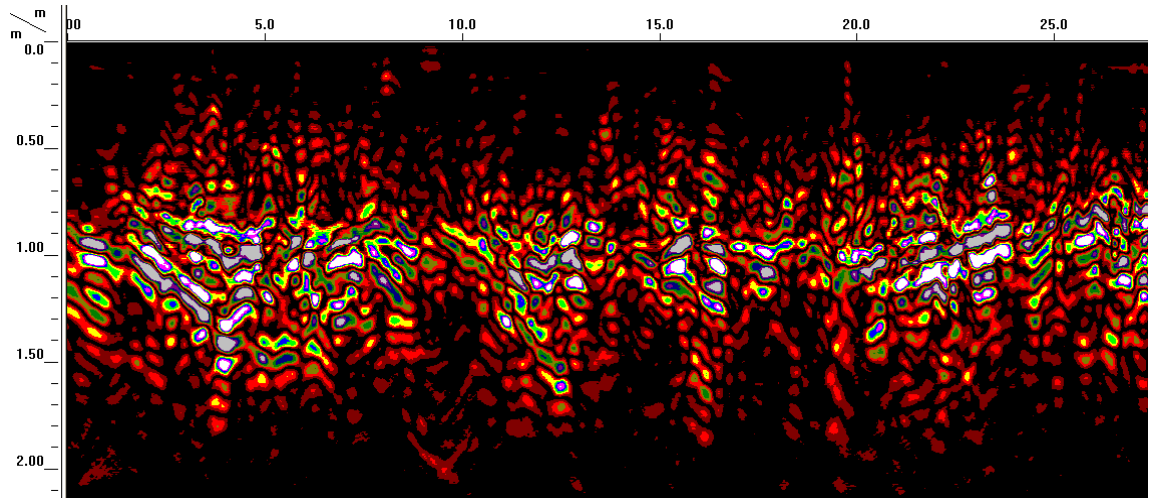

Figure 7. In this radar record, a fairly broad, upper, diffuse zone of lower-amplitude reflectors overlies a narrower, well-defined, layer consisting of segmented higher-amplitude reflectors that is believed to represents the interface separating relatively weathered from unweathered serpentinite.

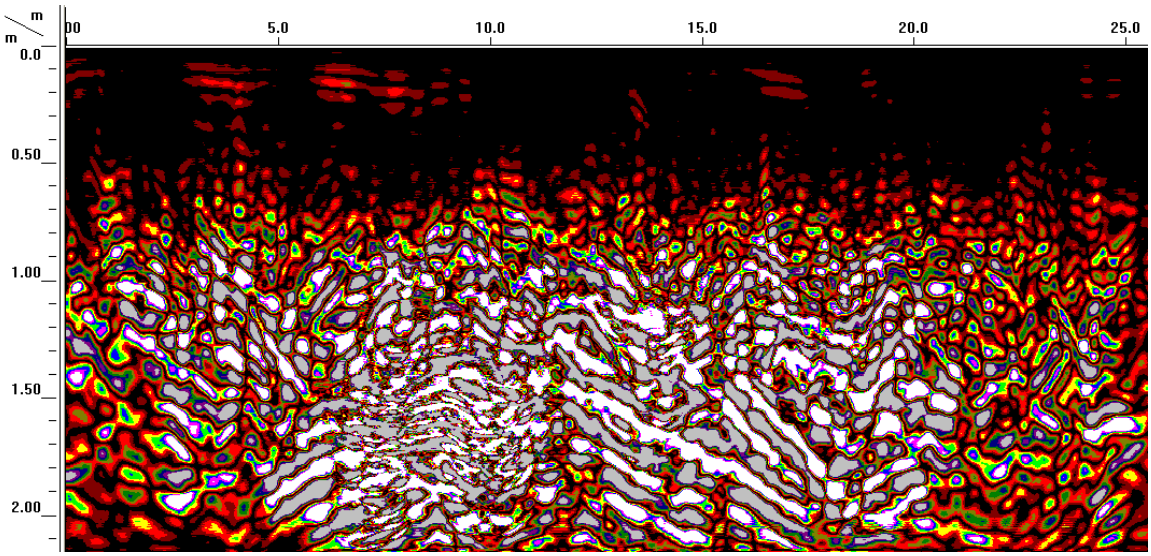

Figure 8. In this radar record, a thin, upper, diffuse zone of lower-amplitude reflectors overlies a broad, well-defined, layer of segmented, inclined, higher-amplitude reflectors that is believed to represents the unweathered serpentinite.

Results:

Site 1:

Two long traverses were conducted in a down slope direction across this steeply-sloping, forested area. Based on 5270 semi-automatically picked observations, the average depth to bedrock is 23 cm with a range of 0 to 68 cm along Line 1. The second traverse was broken into two segments, Line 2 (up-slope) and Line 3 (down-slope). Based on 2915 observations, the average depth to bedrock is 58 cm with a range of 0 to 110 cm along Line 2. Based on 2608 observations, the average depth to bedrock is 66 cm

with a range of 27 to 100 cm along Line 3. Table 1 summarizes the composition of each line based on soil-depth criteria. Soils are dominantly shallow along Line 1, and moderately deep along Lines 2 and 3.

Table 1. Frequency Distribution of GPR Observations made at Site 1 based on Soil Depth Classes.

	1	2	3
shallow	0.93	0.31	0.14
mod deep	0.07	0.66	0.86
deep	0.00	0.03	0.00

Site 2:

Four traverses were conducted across a nearly-level summit area of idle land at Site 2. Based on 5716 semi-automatically picked observations, the average depth to bedrock is 57 cm with a range of 22 to 93 cm along Line 4. Based on 6808 picked observations, the average depth to bedrock is 66 cm with a range of 24 to 105 cm along Line 5. Based on 5278 picked observations, the average depth to bedrock is 75 cm with a range of 19 to 124 cm along Line 6. Based on 1792 picked observations, the average depth to bedrock is 55 cm with a range of 21 to 86 cm along Line 7. Line 7 was conducted along a more sloping trail that descends the summit. Table 2 summarizes the composition of each line based on soil-depth criteria. Soils are dominantly moderately deep to serpentinite along all four traverse lines at Site 2.

Table 2. Frequency Distribution of GPR Observations made at Site 2 based on Soil Depth Classes.

	4	5	6	7
shallow	0.29	0.12	0.07	0.30
mod deep	0.71	0.88	0.86	0.70
deep	0.00	0.00	0.07	0.00

Site 3:

Two traverses were conducted along two trails that crossed this sloping area. Based on 3433 semi-automatically picked observations, the average depth to bedrock is 62 cm with a range of 6 to 129 cm along Line 8 (orientated orthogonal to slope contours). Based on 6059 picked observations, the average depth to bedrock is 47 cm with a range of 13 to 105 cm along Line 9 (orientated parallel to slope contours). Table 3 summarizes the composition of the two lines based on soil-depth criteria. Soils are dominantly shallow and moderately deep to serpentinite at Site 3.

Table 3. Frequency Distribution of GPR Observations made at Site 3 based on Soil Depth Classes.

	8	9
shallow	0.61	0.43
mod deep	0.39	0.48
deep	0.00	0.08

Site 4 (Silver Lake Park):

Three traverses were conducted across a lawn area in Silver Lake Park. Based on 7190 semi-automatically picked observations, the average depth to bedrock is 1.15 cm with a range of 3 to 217 cm along Line 10 (included a less sloping area surrounding a depression). Based on 6653 picked

observations, the average depth to bedrock is 78 cm with a range of 28 to 143 cm along Line 11. Based on 3366 picked observations, the average depth to bedrock is 68 cm with a range of 31 to 115 cm along Line 12. Table 4 summarizes the composition of the three lines based on soil-depth criteria. Soils are dominantly moderately deep to serpentinite at Site 4. Line 10, however, contains a significant portion of soils that are deep and very deep to bedrock.

Table 4. Frequency Distribution of GPR Observations made at Site 4 based on Soil Depth Classes.

	10	11	12
shallow	0.04	0.09	0.24
mod deep	0.60	0.79	0.69
deep	0.07	0.12	0.08
very deep	0.29	0.00	0.00

Site 5 (Hero Park):
Two traverses were conducted across a lawn area of Hero Park. Based on 3719 semi-automatically picked observations, the average depth to bedrock is 69 cm with a range of 43 to 95 cm along Line 13. Based on 2501 picked observations, the average depth to bedrock is 72 cm with a range of 33 to 107 cm along Line 14. Table 5 summarizes the composition of the two lines based on soil-depth criteria. Soils are dominantly moderately deep to serpentinite at Site 5.

Table 1. Frequency Distribution of GPR Observations made at Site 5 based on Soil Depth Classes.

	13	14
shallow	0.02	0.03
mod deep	0.98	0.94
deep	0.00	0.03

References:

Baker, P.L., 1991. Response of ground penetrating radar to bounding surfaces and lithofacies variations in sand barrier sequences. *Exploration Geophysics* 22: 19-22

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.