United States Department of Agriculture

NRCS

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SUBJECT: SOI – Geophysical Assistance

August 25, 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 limestone bedrock (Trenton formation) in areas that were formerly mapped as shallow and moderately deep phases of Nellis soils in Lewis County. The radar data will be used to improve the estimation of soil map unit compositions and interpretations.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Delvin Fanning**,** Professor Emeritus, Department of Environmental Science & Technology, University of Maryland, College Park, MD
Travis Ganter, Soil Conservationist, Environmental Division, USA, Fort Drum, NY
Barry Hunyadi, Soil Scientist, USDA-NRCS, Lowville, NY
Amy Langner, Soil Scientist, USDA-NRCS, Lowville, NY

Activities:
Field activities were completed on 16 and 17 August 2011.

Summary:

- Over 120,000 geo-referenced radar scans were collected during the course of this investigation. This data will be used by the MLRA Soil Survey Office to assess the classification of soils and document the composition of two map units based on soil depth criteria. The data collected during this visit can be imported into NASIS and used to improve soil interpretations.

- Areas that were formerly mapped as of Nellis loam, shallow, 0 to 8 % slopes (NbB) and Nellis loam, moderately deep, 2 to 8 % slopes (NcB) have been renamed as Farmington loam, 0 to 8 % slopes (NbB) and Galway loam, 2 to 8 % slopes (NcB), respectively. Based on the radar interpreted data gathered along seventeen transect lines, soils within these two map units are dominantly moderately deep (70.2%) and shallow (29.6 %) to bedrock with a very meager amount of very deep (0.02%) inclusions. In the areas investigated with GPR, no significant difference in the average depth to bedrock was observed between these two units (56.5 cm (NbB) and 57.5 cm (NcB)). MLRA soil scientists may decide to combine these two soil consociations into one soil complex.

- An Excel worksheet containing the geo-referenced, radar interpreted measurements have been delivered to Barry Hunyadi in Lowville, NY.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
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cc: See attached list

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Technical Report on Ground-Penetrating Radar (GPR) Investigations conducted in Lewis County on 16 and 17 August 2011.

James A. Doolittle

This study was initiated by observations that were made by Fanning et al. (2010) on intersecting linear patterns of differing plant vigor and growth in areas of Nellis soils. The vegetal pattern (Figure 1) is the result of the influence of intersecting joints or crack in the underlying limestone bedrock on plant rooting depths and available soil moisture. The presence of these intersecting patterns, while considered common, is more evident in plants grown in areas of shallow (0 to 50 cm) and moderately deep (50 to 100 cm) soils than deep (100 to 150 cm) and very deep (>150 cm) soils. Fanning et al. (2010) noted that these joint patterns may need to be considered in the design and interpretations of map units.

Figure 1. Differing patterns of alfalfa vigor and growth are evident in an area of Nellis loam, shallow, 0 to 8 % slopes, in Lewis County, New York (photograph by S. Carlisle and from Fanning et al., 2010).

As a consequence of the observations made by Fanning et al. (2010), ground-penetrating radar (GPR) was used to chart the depth to limestone bedrock (Trenton formation) in areas that were formerly mapped as shallow and moderately deep phases of Nellis soils in the *Soil Survey Report of Lewis County* (Pearson et al., 1960). The Nellis series (coarse-loamy, mixed, superactive, mesic Typic Eutrudepts) is presently recognized as being very deep (>152 cm) to limestone bedrock. In the 1960 *Soil Survey Report of Lewis County*, the depth to limestone bedrock was reported to range from "15 inches [38 cm] to many feet" in areas of Nellis soils.

Study Sites:

All study sites are located in the Black River Valley, which separates the Tug Hill Plateau from the Adirondacks in Lewis County. The selected sites are underlain at relatively shallow depths by the

Ordovician Trenton limestone. Intersecting patterns of more vigorous plant growth are more commonly observed in areas that were formerly mapped as shallower phases of the Nellis soils (map units NbB and NcB) than those mapped as deeper phases. In the soil survey report, the reported depths to limestone bedrock were 10 to 24 inches (~25 to 60 cm) in areas of Nellis loam, shallow, 0 to 8 %slopes (NbB); and 24 to 40 inches (~60 to 100 cm) in areas of Nellis loam, moderately deep, 2 to 8 % slopes (NcB). No depth to bedrock estimation was provided for the Nellis loam, ledgy, 3 to 15 % slopes (NfC) map unit (which was also traversed (negligibly) with GPR).

Figure 2. Soil maps from the Web Soil Survey of the GPR study sites in Lewis County, New York.[1] *Map unit symbols only identify the soil delineations traversed with GPR.*

All sites are located in cultivated fields or hay lands. Site 1 is located to the immediate north of Number Three Road in Lewis County (~75.5571 W Longitude, ~43.8351 N Latitude). This site includes delineations that were mapped as Nellis loam, shallow, 0 to 8 % slopes (NbB) and Nellis loam, moderately deep, 2 to 8 % slopes (NcB). The very deep, well drained Nellis soils formed in calcareous till. Areas formerly mapped and identified as shallow and moderately deep phases of Nellis soils have been reclassified as Farmington and Galway soils, respectively. The current names for these map units are listed in Table 1. These soils form in a thin layer of till that overlies mostly limestone, dolomite, or dolomitic limestone bedrock. Depths to bedrock are 25 to 50 cm for the shallow, well drained and somewhat excessively drained Farmington soils, and 50 to 100 cm for the moderately deep, well drained and moderately well drained Galway soils. The taxonomic classifications of these soils are listed in Table 2.

[1] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [August 23, 2011].

Table 1.
Updated Map Unit Names

Symbol	Name
NbB	Farmington loam, 0 to 8 % slopes
NcB	Galway loam, 2 to 8 % slopes
NfC	Rock Outcrop-Farmington complex, 3 to 15 % slopes

Table 2
Taxonomic Classification of the Named Soil Series

Soil Series	Taxonomic Classification
Galway	Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts
Farmington	Loamy, mixed, active, mesic Lithic Eutrudepts
Nellis	Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts

Site 2 is located to the immediate north of Halifax Road in Lewis County (~75.6187 W Longitude, ~43.8998 WN Latitude). This site includes delineations that were mapped as Nellis loam, shallow, 0 to 8% slopes (NbB) and Nellis loam, moderately deep, 2 to 8 % slopes (NcB).

Site 3 is located off of Roberts Road in Lewis County (~75.6444 W Longitude, ~43.9172 N Latitude). This site includes a delineation that was mapped as Nellis loam, shallow, 0 to 8% slopes (NbB).

Site 4 is located between Battle and Gardner Roads in Lewis County (~75.5137 W Longitude, ~43.7791 N Latitude). This site includes delineations that were mapped as Nellis loam, shallow, 0 to 8% slopes (NbB) and Nellis loam, ledgy, 3 to 15% slopes (NfC).

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. The 400 MHz antenna was used in this study.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[2] Processing included: header editing, setting 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).

Recent technical developments allow the integration of GPR and 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). Following data collection, 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 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 second. The scanning rate of the GPR was set at 42 scan/sec.

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

Using the *Interactive 3D Module* of the RADAN, depths to the soil/bedrock interface were semi-automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including longitude, latitude, and depth to bedrock data).

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 equation [1] (after Daniels, 2004):

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

The velocity of propagation is mainly 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 (0.299 m/ns). The velocity of pulse propagation is most 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 a known subsurface reflector (buried metal plate), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated using equations [1] and [2]. At the time of these studies, soils were moist. The estimated E_r was 8.4. The estimated v was 0.1035 m/ns.

GPR Survey Procedures:
In areas formerly mapped as Nellis soils, multiple traverses were completed with r a 400 MHz antenna. The 400 MHz antenna provided good resolution of subsurface features and satisfactory penetration depths. Each radar traverse was stored as a separate file. Poor satellite reception resulted in some traverses being corrupted and omitted from this study.

Results:
Figure 3 is a representative radar record from Site 1 (an area that is presently identified as Farmington loam, 0 to 8 % slopes (NbB)). This radar record has been minimally processed. Processing procedures used include: header editing, setting the initial pulse to time zero, color table and transformation selection, and signal stacking. In Figure 3, all scales are expressed in meters.

On the radar profile shown in Figure 3, the upper 35 cm contains the surface pulse and its multiples. These bands provide little information to this study and are a source of unwanted noise. The first major subsurface interface is the soil/bedrock boundary. On this record, the depth to the soil/bedrock interface ranges from about 40 to 60 cm. This slightly wavy, horizontal reflector is punctuated by several minor breaks, which have been identified with arrows. These breaks represent larger cracks or joints that are filled with soil materials. The bedrock is identified by multiple, sub-parallel linear reflectors that represent bedding planes. At depths ranging from about 130 to 160 cm, higher amplitude (colored in shades of white, grey, blue, and green), highly segmented, linear reflectors represent an abrupt and highly contrasting change in lithology.

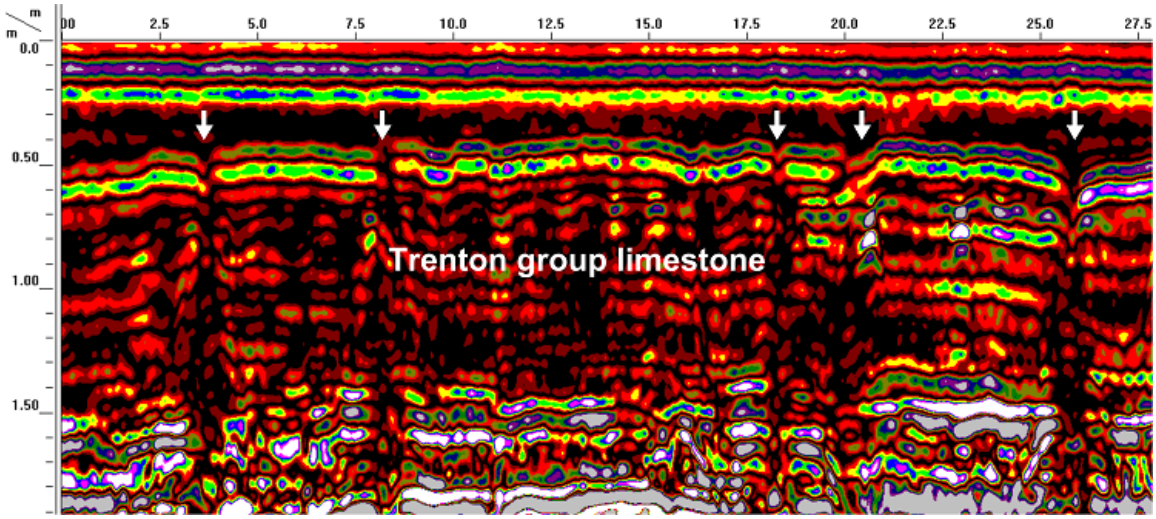

Figure 3. Representative radar record from an area of Nellis loam, shallow, 0 to 8 % slopes. All scales are expressed in meter. Arrows indicate larger joints in the underlying bedrock surface.

Figure 4 is a three-dimensional presentation of one of the radar traverses (Transect 13). In this three-dimensional block image all scales are in meters. The coordinate system is UTM. The radar record seen in Figure 4 has been subjected to more intense signal processing (horizontal high-pass filtration and migration) than the one shown in Figure 3. These additional processing procedures were used to remove or reduce incoherent signal and instrument noises, diffraction tails, distortion, dip displacement and out-of-line reflections. Inclined, alternating beds of limestone layers are evident in this presentation. The beds appear slightly wavy and segmented with noticeable vertical fractures and joints.

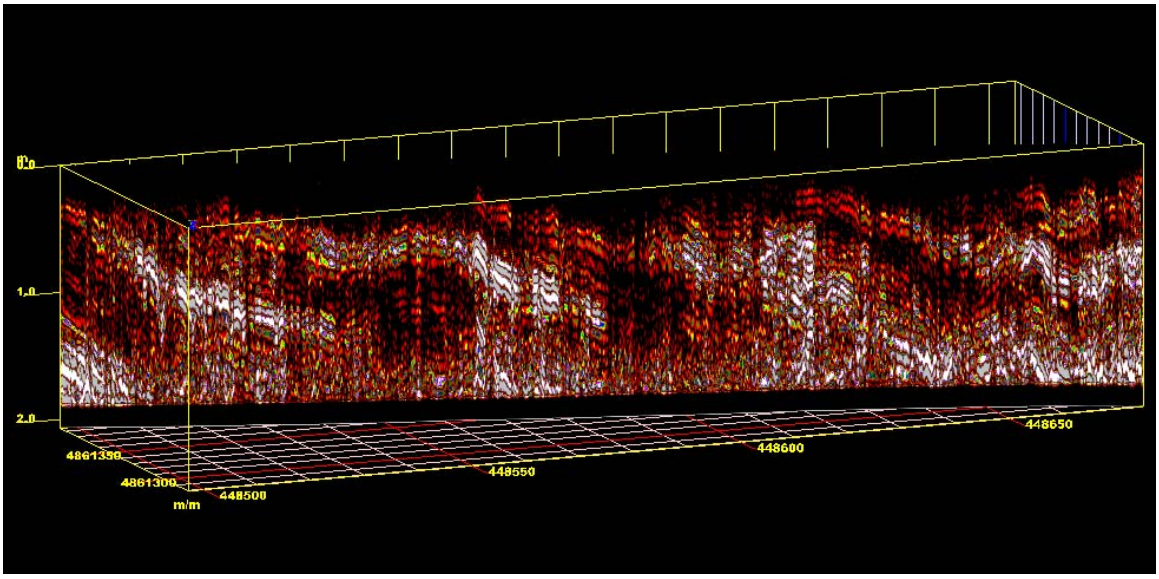

Figure 4. Alternating, inclined layers of limestone bedrock are evident in this three-dimensional cube presentation of transect 13.

Tables 3 to 6 summaries the basic bedrock statistics for each transect within the four study sites. At site 1, transect lines 2 thru 4 were mostly restricted to map unit NcB; transects 5 thru 7 traversed mostly map unit NbB. Basic bedrock statistics appears closely similar for these two map units. At site 2, transect lines 8 and 9 traversed map unit NcB; transects 10 contains portions of both map units NbB and NcB.

Once again, basic bedrock statistics appears similar for the two units. At Sites 3 and 4, transects were conducted in map unit NbB.

Table 3. Basic Statistics for the Depth to Bedrock within Site 1
(Data expressed in meters)

	2	3	4	5	6	7
Number	3974	8298	5889	7315	5418	1970
Minimum	0.336	0.221	0.336	0.404	0.226	0.445
25%-tile	0.453	0.513	0.554	0.550	0.530	0.615
75%-tile	0.594	0.619	0.695	0.635	0.695	0.741
Maximum	0.995	0.813	0.950	0.801	0.978	0.877
Mean	0.553	0.555	0.617	0.593	0.609	0.675
Std. Dev.	0.136	0.102	0.114	0.067	0.134	0.082

Table 4. Basic Statistics for the Depth to Bedrock within Site 2
(Data expressed in meters)

	8	9	10
Number	6187	12818	7767
Minimum	0.194	0.299	0.204
25%-tile	0.473	0.655	4.33
75%-tile	0.57	0.845	0.615
Maximum	0.801	1.249	1.164
Mean	0.472	0.740	0.520
Std. Dev.	0.113	0.157	0.140

Table 5. Basic Statistics for the Depth to Bedrock within Site 3
(Data expressed in meters)

	13	14	15	17
Number	8558	3440	4976	8339
Minimum	0.15	0.186	0.267	0.194
25%-tile	0.315	0.323	0.469	0.538
75%-tile	0.477	0.445	0.623	0.699
Maximum	1.257	0.679	0.869	1.079
Mean	0.400	0.391	0.549	0.605
Std. Dev.	0.111	0.093	0.118	0.146

Table 6. Basic Statistics for the Depth to Bedrock within Site 4
(Data expressed in meters)

	22	23	24	25
Number	14860	5859	8314	6060
Minimum	0.190	0.251	0.121	0.129
25%-tile	0.522	0.538	0.388	0.505
75%-tile	0.740	0.732	0.598	0.708
Maximum	1.286	1.023	0.881	0.942
Mean	0.635	0.629	0.495	0.598
Std. Dev.	0.155	0.137	0.136	0.148

Tables 7 and 8 summaries the frequency distribution by soil depth classes for each GPR transect that were completed within Sites 1 and 2, and Sites 3 and 4, respectively. Collectively, soils are dominantly moderately deep (70.2%) and shallow (29.6 %) with a very meager amount of very deep (0.02%) inclusions.

Table 7. Frequency Distributions by Soil Depth Classes along GPR Traverse Lines completed at Sites 1 and 2.

	2	3	4	5	6	7	8	9	10
0-50 cm	**0.41**	**0.21**	**0.17**	**0.09**	**0.22**	**0.02**	**0.09**	**0.10**	**0.46**
50-100 cm	**0.59**	**0.79**	**0.83**	**0.91**	**0.78**	**0.98**	**0.91**	**0.90**	**0.54**
100-150 cm	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 8. Frequency Distributions by Soil Depth Classes along GPR Traverse Lines completed at Sites 3 and 4.

	13	14	15	17	22	23	24	25
0-50 cm	**0.83**	**0.87**	**0.37**	**0.22**	**0.21**	**0.19**	**0.53**	**0.24**
50-100 cm	**0.17**	**0.13**	**0.63**	**0.78**	**0.77**	**0.81**	**0.47**	**0.76**
100-150 cm	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	**0.00**	**0.00**

Figure 5 contains four *Goggle Earth* images of the areas surveyed with GPR. In these images, the locations of the GPR traverse lines are shown. Each traverse line is colored-coded based on the interpreted depth to the soil/bedrock interface. The estimated depths are based on an average *v* of 0.1035m/ns and an *Er* of 8.4.

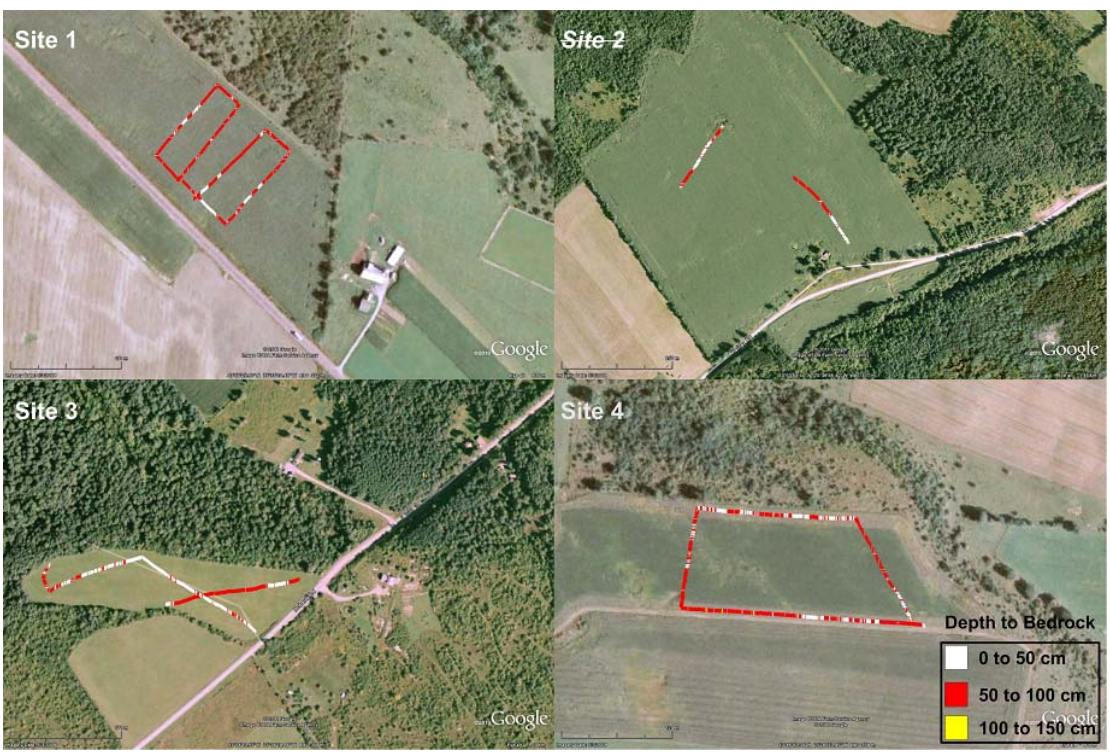

Figure 5. These four Google Earth images show the locations of GPR traverse lines that were conducted across four sites in Lewis County. Different colors are used to show differences in soil depths along each traverse line (These Google images of radar data are courtesy of Brian Jones of GSSI).

References:

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