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SUBJECT: MGT – Trip Report – Geophysical Assistance | 27 August 2014

TO: Juan Hernandez
State Conservationist, NRCS
Bangor, ME

File Code: 330-20-7

Purpose:
Introductory ground-penetrating radar (GPR) training was provided to Greg Granger and Nicholas Butler.

Participants:
Nicholas Butler, MLRA Office Leader, USDA-NRCS, Dover-Foxcroft, ME
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Greg Granger, Resource Soil Scientist, USDA-NRCS, Augusta, ME

Activities:
Training and field activities were completed during the period of 12 to 14 August 2014

Summary:

1. A ground-penetrating radar (GPR) was recently transferred from Durham, NH, to Augusta, ME, and Greg Granger was selected as the new radar operator. This was the initial contact training of Greg Granger by Jim Doolittle of the National Soil Survey Center. Training was provided on the setup of the radar system, conducting GPR surveys, and making interpretations of radar data obtained in the field. The setup and calibration of a survey wheel with encoder was also covered. Face-to-face, on-site training is essential with GPR; manuals and technical references do not provide adequate information on the setup, operation, and interpretations required to assess the highly complex and variable terrain and soil conditions that are experienced by NRCS GPR operators

2. Greg Granger is commended for his quick-start and novel use of GPR in soil technical assistance projects. Greg has already used GPR to verify the depth to bedrock for irrigation-water reservoir site recommendations in Aroostook County. He is the only GPR operator in NRCS that has an excavator (John Deere 35G Excavator) for digging soil pits to corroborate radar interpretations. This is most beneficial. The continuous subsurface imaging provided by GPR allows radar operators to select a minimal number of well-placed borings or excavations to confirm interpretations over an entire study site. The combined use of GPR and excavator reduces field time and provides greater confidence in site assessments. The National Soil Survey Center will look to Maine and Greg Granger for examples and guidance on expanding the role of GPR in technical soil services.

3. Signal processing is a requisite for improve GPR interpretations. Greg Granger has RADAN 6.0 software. However, he cannot install this software on his computer, and as a result, is at a serious disadvantage as he cannot effectively process, interpret, and display radar data. RADAN 6.0, while certified for use on NRCS computers using Windows NT, is not certified for use on computers using Windows 7. The RADAN 6.0 software has been succeeded by RADAN 7.0, which is certified for use on computers using Windows 7. Information Technology (IT) staffs are reluctant to pursue CCE certification for older programs that have been succeeded by newer programs. It is essential that Greg Granger has the ability to process, interpret, and exhibit radar

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data. The National Soil Survey Center will work with the Maine NRCS State Office Staff to satisfy this requirement. Presently, the upgrade of Maine's RADAN 6.0 processing software to RADAN 7.0 will cost $695.21[1].

4. Using the Interactive module of RADAN 7.0 signal processing software, a total of 148, 511 depth to bedrock measurements were determined based on the 12 radar traverses that were completed across 5 different soil map during the training exercises in Penobscot County. These measurements document the high spatial variability in the depth to bedrock both among and within each of the 7 map units traversed with GPR. This data will be used by the MLRA office to resolve soil depth, map unit composition (based on soil depth criteria), and map unit name issues. This data will be used to improve the information and interpretations of soil map units in the extensive revision to the Penobscot County Soil Survey.

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Director
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Attachment (Technical Report)

cc:
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[1] Geophysical Survey Systems Sales Quote Number 00012926 dated 8/26/2014.

GPR training and investigations in Penobscot County, Maine.
12 and 14 August 2014

Jim Doolittle

Background:

During the week of 11 August, soil scientists from the National Soil Survey Center, the Maine Soil Staff, and MLRA SSO 12-DFX (Dover-Foxcroft, ME) joined in ground-penetrating radar (GPR) training and field investigations in Penobscot County, Maine. A GPR system was recently relocated to Maine and a Soil Resource Specialist, Greg Granger, designated as the new primary radar operator for Maine and New Hampshire. Field exercises were conducted that covered the setup and calibration of the GPR, survey procedures, and interpretation of results. In soils formed in the tills of the Glaciated Soil Survey Region (SSR 12), soil mapping and investigations using soil augers and probes are challenging because of the large number of rock fragments that cause repeated and unwanted refusals. Here, GPR provides a fast and undemanding means to determine soil depth classes and measure the depths to bedrock, which can be highly variable and would otherwise require a large number of time-consuming and labor-intensive borings. The GPR data collected during the training exercises will be used by the Dover-Foxcroft MLRA office to resolve soil depth, map unit composition (based on soil depth criteria), and map unit name issues. This data will be used to improve the information and interpretations of soil map units in the extensive revision to the Penobscot County Soil Survey (Goodman et al., 1963).

Equipment:

The radar unit located in the Augusta Field Office 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. Jol (2009) and Daniels (2004) discuss the use and operation of GPR.

Figure 1. A 200 MHz antenna is used in an open-field (left), while a 400 MHz antenna is used along a footpath in a densely-wooded area (right).

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

Maine has two antennas: a 200 and a 400 MHz antenna (Figure 1). The depth of investigation (DOI) is governed by the physiochemical properties of the soil and the center frequency of the radar antenna. Signal attenuation increases and the DOI decreases with increases in clay, water, and soluble salt contents.

A dilemma with GPR is the inverse relationship between DOI and resolution of subsurface features. The DOI decreases with increasing antenna center frequency. However, the resolution of subsurface features improves as the antenna center frequency increases. As a general rule, the highest frequency antenna that will obtain the desired DOI should be selected. In general, the low clay and soluble salt contents of soils formed in glacial tills over most of Maine, favors the use of the 400 MHz antenna. Furthermore, the small size and portability of the 400 MHz antenna favors its use in many forested areas. However, the larger size and stability of the 200 MHz antenna favors this antennas use where a greater DOI is needed, in more conductive soil materials, and in areas where effective coupling of the antenna with the soil surface are concerns. Both antennas were used during training exercises (see Figure 1).

Presently, Greg Granger has no signal processing software to process, interpret, and display his radar data. This severely handicaps its effective use in Maine. The RADAN for Windows (version 7.0) software program (GSSI) was used by Jim Doolittle to process all radar records. Processing included: header editing, positioning the initial pulse to time zero, background removal, color table and transformation selection, horizontal high pass filtration, signal stacking, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

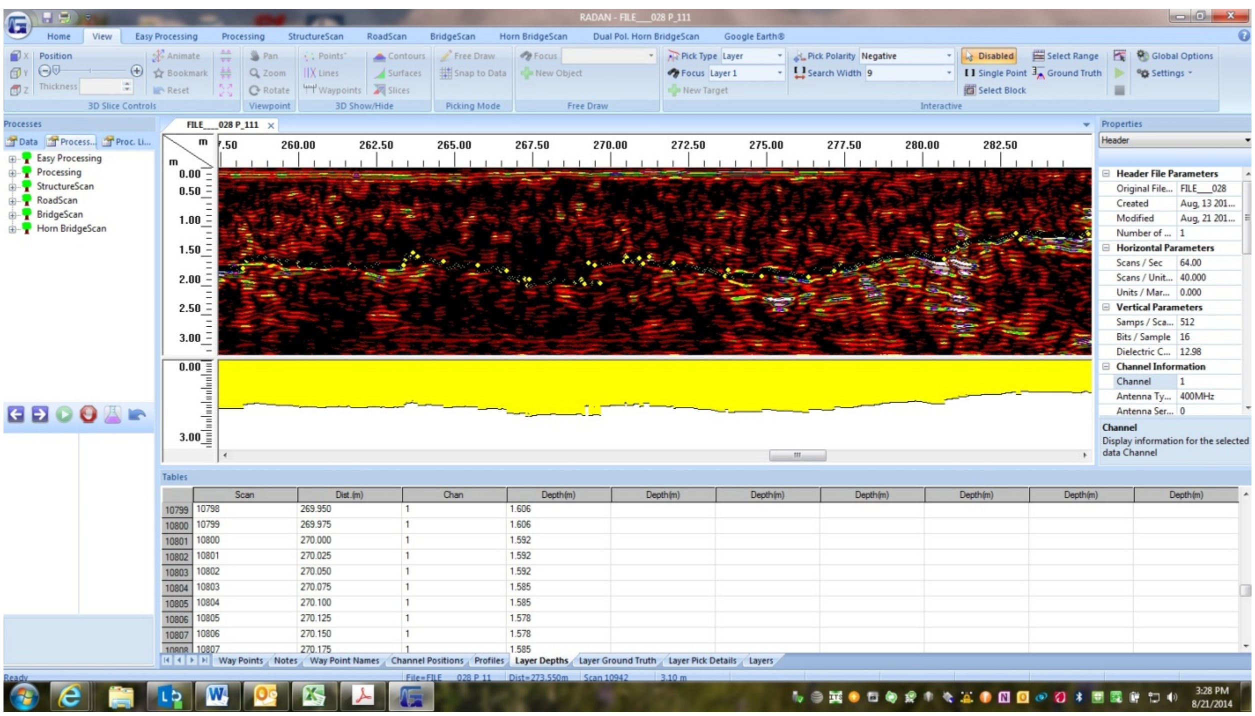

Figure 2. An example of the RADAN 7.0 interactive module window showing the radar record (top), depth profile (center), and layer file with the recorded depths. These depths been semi-automatically and quickly picked from the radar record.

Using the *Interactive Interpretation Module* of the RADAN7.0 signal processing software, depths to the soil/bedrock interface were quickly, semi-automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing positions along traverse line, depths to bedrock, and other useful data). Figure 2 is an example of the Interactive Module page of RADAN 7.0. With the interactive module, the depth to bedrock was recorded for each scan on the radar record. For the surveys in Penobscot County, the scanning rate was 64 scans/sec. This scanning rate provided an extremely large number of measurements that will be useful to document soil variability along each radar traverse line.

Survey Procedures:

Greg Granger does not have a signal data recorder. Without this device, he cannot geo-reference the radar data with a GPS receiver. This is a major disadvantage in this *digital, geo-spatial age*. Once equipped with GPS capabilities, Greg and the MLRA office can import geo-referenced GPR data into GIS for documentation, interpretation, and display purposes. As an example of this needed function, Figure 3 is a Google Earth image showing the locations of several radar traverses that were completed using a GPS. This data was recorded in an earlier study that was conducted in Aroostook County.

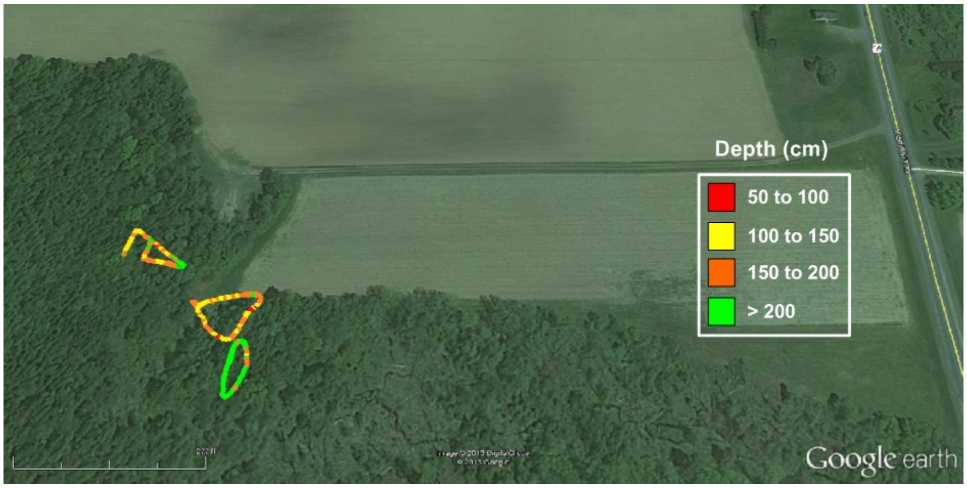

Figure 1. The locations of GPR traverses and soil-depth (depth to bedrock) classes are shown on this Google Earth image from a site in Aroostook County (see my report to Juan Hernandez dated November 4, 2013).

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 two-way 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 signal propagation (v) are described in equation [1] (after Daniels, 2004):

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

The velocity of propagation is most commonly determined using equation [1], the travel time, and the known depth to a subsurface feature appearing on a radar record. However, no soil borings were made during the training exercises to determine the velocity of signal propagation and to depth-scale the radar records. In this situation, a handy aid is to visually fit a modeled hyperbolic shape to the shape of a hyperbola that appears on a radar record. Hyperbolas are caused by point objects such as rocks in soils. This calibration procedure requires the RADAN processing software. By adjusting a model shape to match a hyperbola on the radar record, a close estimate of the velocity of signal propagation can be made and a depth scale established. Typically, this approach will yield a velocity that is slightly higher than the true velocity and, as a result, object depths will appear at a slightly deeper depth than reality (Tillard and Dubois, 1995).

Study Areas:
All sites are located within Penobscot County and near Bangor. Study Area 1 is located along a footpath within a forested area about 6.1 km north of Bangor and 6.4 km southwest of Orono. Radar traverses were begun near 68.7494º W longitude and 44.8664º N latitude and terminated near 68.7557º W longitude and 44.8623º N latitude. Soil map units traversed will be updated as Monarda-Telos complex, 0 to 8 % slopes (54B), and Chesuncook-Elliottsville association, 3 to 8 % slopes (56B). The poorly drained Monarda and somewhat poorly drained Telos soils are very deep to bedrock and shallow to dense glacial till. The moderately deep, well drained Elliottsville and the very deep, moderately well drained Chesuncook soils formed in glacial till. The underlying bedrock is generally slate, metasandstone, phyllite or schist.

Table 1. Taxonomic Classifications of the Named Soil Series.

Soil Series	Classification
Chesuncook	Coarse-loamy, isotic, frigid Aquic Haplorthods
Dixfield	Coarse-loamy, isotic, frigid Aquic Haplorthods
Elliottsville	Coarse-loamy, isotic, frigid Typic Haplorthods
Lyman	Loamy, isotic, frigid Lithic Haplorthods
Monarda	Loamy, mixed, active, acid, frigid, shallow Aeric Endoaquepts
Telos	Loamy, isotic, frigid, shallow Aquic Haplorthods
Tunbridge	Coarse-loamy, isotic, frigid Typic Haplorthods

Study Area 2 is located along a footpath within a forested area near the University of Maine’s Dairy Farm in Orono. Radar traverses were begun near 68.6651 º W longitude and 44.9196 º N latitude and terminated near 68.6665º W longitude and 44.9198 º N latitude. Soil map units traversed will be updated as Tunbridge-Lyman complex, 8 to 15 % slopes (82C). The shallow, somewhat excessively drained Lyman and the moderately deep, well drained Tunbridge soils formed in till. A transmission tower near the study area produced high levels of unwanted high frequency noise on most radar records. This noise caused unwanted clutter that masked desired reflections on radar records. The use of high-pass filtration and signal stacking techniques reduced the levels of this noise, improved the interpretability of radar records, and allowed the estimation of soil depths.

Study Area 3 is located along a trail within the University of Maine’s Forest near Taylor Road in Orono. Radar traverses were begun near 68.6509º W longitude and 44.9085º N latitude and terminated near 68.6532º W longitude and 44.9116º N latitude. The entire area traversed with GPR will be updated as Dixfield-Tunbridge complex, 0 to 8 % slopes (88B). The very deep, moderately well drained Dixfield soils formed in dense till.

Study Area 4 is located along a trail within the University of Maine’s Forest off of Seawall Road in Orono. Radar traverses were begun near 68.6780º W longitude and 44.9336º N latitude and terminated near 68.6763º W longitude and 44.9318º N latitude. The traversed area will be updated as Dixfield-Tunbridge complex, 0 to 8 % slopes (88B).

Results:

Study Area 1:

Traverse 7 was conducted in an area that will be updated as Monarda-Telos complex, 0-8% slopes, very stony (54B). Based on 8799 radar measurements, the average depth to bedrock along this traverse is 1.27 m with a range of 0.55 to 2.01 m. One-half of these measurements were between depths of 1.10 and 1.46 m. Traverse 8 was also conducted in an area that will be updated as map unit 54B. Based on 4115 radar measurements, the average depth to bedrock along this traverse is 1.15 m with a range of 0.17 to 2.23 m. One-half of these measurements were between depths of 0.92 and 1.40 m. Traverse 9 crossed areas that will be updated as map unit 54B and Chesuncook-Elliottsville association, 3 to 8 % slopes, very stony (56B). Based on 10700 radar measurements, the average depth to bedrock along this traverse is 1.11 m with a range of 0.0 to 2.05 m. One-half of these measurements were between depths of 0.73 and 1.52 m. Traverse 10 was conducted in an area that will be updated as map unit 56B. Based on 12685 radar measurements, the average depth to bedrock along this traverse is 0.87 m with a range of 0.16 to 1.57 m. One-half of these measurements were between depths of 0.72 and 1.02 m.

Study Area 2:

Traverses 18, 19 and 20 were conducted in an area that will be updated as Tunbridge-Lyman complex, 8 to 15 % slopes (82C). Based on 11273 radar measurements, the average depth to bedrock along traverse 18 is 0.81 m with a range of 0.22 to 1.86 m. One-half of these measurements were between depths of 0.63 and 0.89 m. Based on 9872 radar measurements, the average depth to bedrock along traverse 19 is 0.34 m with a range of 0.00 to 0.83 m. One-half of these measurements were between depths of 0.18 and 0.34 m. Based on 17429 radar measurements, the average depth to bedrock along traverse 20 is 0.74 m with a range of 0.00 to 2.60 m. One-half of these measurements were between depths of 0.47 and 0.91 m.

Study Area 3:

Traverses 24, 25 and 26 were conducted in an area that will be updated as Dixfield-Tunbridge complex, 0 to 8 % slopes (88B). Based on 9083 radar measurements, the average depth to bedrock along traverse 24 is 1.08 m with a range of 0.00 to 2.23 m. One-half of these measurements were between depths of 0.83 and 1.31 m. Based on 18055 radar measurements, the average depth to bedrock along traverse 25 is 1.75 m with a range of 0.65 to 3.98 m. One-half of these measurements were between depths of 1.37 and 1.98 m. Based on 14989 radar measurements, the average depth to bedrock along traverse 26 is 2.63 m with a range of 0.91 to 3.17 m. One-half of these measurements were between depths of 2.17 and 2.63 m.

Study Area 4:

Traverses 27 and 28 were conducted in an area that will be updated as Dixfield-Tunbridge complex, 0 to 8 % slopes (88B). Based on 15283 radar measurements, the average depth to bedrock along traverse 27 is 1.87 m with a range of 0.10 to 3.98 m. One-half of these measurements were between depths of 1.21 and 2.43 m. Based on 16228 radar measurements, the average depth to bedrock along traverse 28 is 1.11 m with a range of 0.00 to 3.16 m. One-half of these measurements were between depths of 0.61 and 1.56 m.

Depth to bedrock is one criteria used to define each soil. Table 2 summarizes the frequency distribution of the depth to bedrock for each of the 12 radar traverses conducted in Penobscot County during this training. Soil depth classes are: shallow (0 to 50 cm), moderately deep (50 to 100 cm), deep (100 to 150 cm) and very deep (> 150 cm). Noticeable differences are evident in the depth to bedrock both among and within each of the 7 map units traversed with GPR.

Table 2. Frequency distribution of the Depth to Bedrock along the Radar Traverses conducted in Penobscot County.

File	MU	OBS	Shallow	Mod Deep	Deep	V. Deep
7	91A	8799	0.00	0.22	0.64	0.14
8	54B	4115	0.06	0.30	0.54	0.16
9	54B	10700	0.21	0.20	0.50	0.30
10	56B	12685	0.08	0.66	0.26	0.00
18	82C	11273	0.11	0.73	0.11	0.05
19	82C	9872	0.79	0.21	0.00	0.00
20	82C	17429	0.28	0.52	0.12	0.08
24	88B	9083	0.08	0.34	0.48	0.10
25	88B	18055	0.00	0.03	0.35	0.62
26	88B	14989	0.00	0.01	0.06	0.93
27	88B	15283	0.03	0.15	0.25	0.57
28	88B	16228	0.19	0.38	0.17	0.26

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