United States Department of Agriculture

NRCS

Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

Subject: Soils – Geophysical **Date:** 19 September 2012

To: Juan Hernandez
State Conservationist
USDA-Natural Resources Conservation Service
967 Illinois Avenue, Suite 3
Bangor, ME 04401

Purpose:
To determine the depth to bedrock in several soil map units in Penobscot County with ground-penetrating radar. Radar data will be used by the Dover MLRA staff to document map unit composition (based on soil depth classes), generate support information to justify recommendations for changes in soil survey legends, and improve interpretative data.

Principal Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Robert Evon, Soil Survey Office Leader, USDA-NRCS, Dover-Foxcroft, ME
Nicholas Butler, Soil Scientist, USDA-NRCS, Dover-Foxcroft, ME

Activities:
All activities were completed on 12 and 13 September 2012.

Summary:

1. Thirty-five GPR traverses of varying lengths were completed in seven soil map units in southern Penobscot County. Using the interactive module of RADAN for Windows, 188,724 soil depth measurements were semi-automatically *picked* and recorded. Tables included in this report summarize, for each radar traverse, the number of observations and the frequency distribution of soils into four soil depth classes.

2. An Excel spreadsheet containing all radar traverse data has been forwarded to Bob Evon.

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

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:

James Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, USDA-NRCS, Newtown Square, PA

Robert Evon, Soil Survey Office Leader, USDA-NRCS,42 Engdahl Drive, Dover-Foxcroft, ME 04426

Tony Jenkins, State Soil Scientist, USDA-NRCS 967 Illinois Avenue, Suite 3, Bangor, ME 04401

Wes Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, USDA-NRCS, Wilkesboro, NC

Larry West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Lincoln, NE

Michael Wilson, Research Soil Scientist/Liaison MO12, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Lincoln, NE

GPR investigation of the depth to bedrock in Penobscot County, Maine.
12 and 13 September 2012

Jim Doolittle

Purpose:
Traditional soil survey tools are increasingly being considered inadequate for soil-depth determination in soils that contain large amounts of rock fragments. Rock fragments limit the depth and number of observations that can be made with spades and augers. As a consequence, transect data collected with these traditional soil survey tools are limited in depth, extent, and number. Ground-penetrating radar can provide large, georeferenced data sets that can help overcome issues of data insufficiency and incorrectness, and validate differences in depths to bedrock. The purpose of this investigation was to conduct multiple GPR traverses in several soil map units in southern Penobscot County. The GPR data will be used as support information to justify recommendations for changes in soil survey legends and improve interpretative data.

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 200 MHz antenna was used in the investigations.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high pass filtration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). The *Interactive 3D Module* of RADAN was used to semi-automatically "*pick*" the depths to the interpreted bedrock surface on radar records. The picked data were exported to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to bedrock).

The SIR-3000 system contains a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows was 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. [1] Position data were recorded at a rate of one reading per second. The scanning rate of the GPR was 40 scan/sec.

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., soil horizon, bedrock surface) 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):

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

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

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 light in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest affect on the E_r and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in substantial increases in the relative permittivity of soils (Daniels, 2004). Using a 100 MHz antenna, Daniels (2004) observed that the relative dielectric permittivity of most dry mineral soil materials is between 2 and 10, while for most wet mineral soil materials, it is between 10 and 30. At the time of this investigation, soils were dry.

A small pit was excavated to bedrock in an area of Telos-Chesuncook complex, 3 to 8 % slopes, very stony (M.U. 22B). The bedrock was exposed at a depth of 28 cm. This depth to bedrock was used to depth scale the radar imagery. A radar traverse was conducted adjacent to this pit. Based on the measured depth and the two-way pulse travel time to the exposed bedrock, the velocity of propagation and the relative dielectric permittivity through the upper part of a soil profile were estimated using equations [1] and [2]. With the 400 MHz antenna, the estimated E_r was 8.3. The estimated v was 0.1041 m/ns. However, both v and E_r will vary spatially across landscapes and with depth. This variability will affect the accuracy of soil depth measurements.

Study Sites:
Thirty-five radar traverses were conducted across 7 different soil map units in southern Penobscot County. Table 1 lists the names of the map units that were traversed with GPR. Table 2 list the taxonomic classification of the named soils.

Table 1 Map Units traversed with GPR

Symbol	***Map Unit Name***
22B	Telos-Chesuncook complex, 3 to 8% slopes, very stony
22C	Chesuncook-Telos complex, 8 to 15% slopes, very stony
56B	Elliottsville-Chesuncook complex, 3 to 8% slopes, very stony
304C	Danforth-Thorndike complex, 3 to 15% slopes, very stony
502C	Becket -Tunbridge-Dixfield association, 8 to 15% slopes, very stony
502D	Becket -Tunbridge association, 15 to 30 % slopes, very stony
507C	Monadnock -Tunbridge association, , 8 to 15% slopes, very stony

Table 2 Taxonomic Classification of Soils

Series	***Taxonomic Classification***
Becket	Coarse-loamy, isotic, frigid Oxyaquic Haplorthods
Chesuncook	Coarse-loamy, isotic, frigid Aquic Haplorthods
Danforth	Loamy-skeletal, isotic, frigid Typic Haplorthods
Dixfield	Coarse-loamy, isotic, frigid Aquic Haplorthods
Elliottsville	Coarse-loamy, isotic, frigid Typic Haplorthods
Monadnock	Coarse-loamy over sandy or sandy-skeletal, isotic over mixed, frigid Typic Haplorthods
Telos	Loamy, isotic, frigid, shallow Aquic Haplorthods
Thorndike	Loamy-skeletal, isotic, frigid Lithic Haplorthods
Tunbridge	Coarse-loamy, isotic, frigid Typic Haplorthods

All soils formed in stony till on glaciated uplands. The very deep, well drained Becket soils formed in a loamy mantle overlying dense, sandy till derived principally from granite, gneiss, and schist. Becket soils are moderately deep to a densic contact. The very deep, moderately well drained Chesuncook soils formed in dense till derived mainly from slates and other dark colored sedimentary and metamorphic rocks. The very deep, well drained Danforth soils formed in till derived from slate and fine grained metasandstone and lesser amounts of granite, gneiss or schist. The very deep, moderately well drained Dixfield soils formed in dense till derived mainly from mica schist, granite, phyllite, and gneiss. The moderately deep, well drained Elliottsville soils formed in till derived mainly from slate, metasandstone, phyllite or schist. The very deep, well drained Monadnock soils formed in a loamy mantle overlying sandy till derived mainly from schist, granite, gneiss, and quartzite. The very deep, somewhat poorly drained Telos soils formed in till derived mainly from slate and other dark colored sedimentary and metamorphic rocks. Telos soils are shallow to dense till. The shallow, somewhat excessively drained Thorndike soils formed in till derived principally from slate, phyllite, or calcareous metasedimentary rock. The moderately deep, well drained Tunbridge soils formed in loamy till derived mainly from micaceous schist, gneiss, and phyllite.

Survey Procedures:
At each site, multiple, GPR traverses were completed by pulling the 400 MHz antenna along the ground surface. Radar traverse were conducted along gravel access roads that had limited cut and fill manipulations and along footpaths thru the woods. Each radar traverse was stored as a separate file. Where overlying vegetation was sparse and open, the GPS option was used with the GPR and all radar scans were georeferenced.

Results:
Beckett, Dixfield and Tunbridge soils form principally over mica schist, phyllite, granite, and gneiss. Chesuncook, Danforth, Elliottsville, Telos and Thorndike soils form principally over dark-gray, fine-grained quartzite, slate, phyllite and calcareous sandstone. Different soils and parent rocks should produce different reflection patterns on radar records.

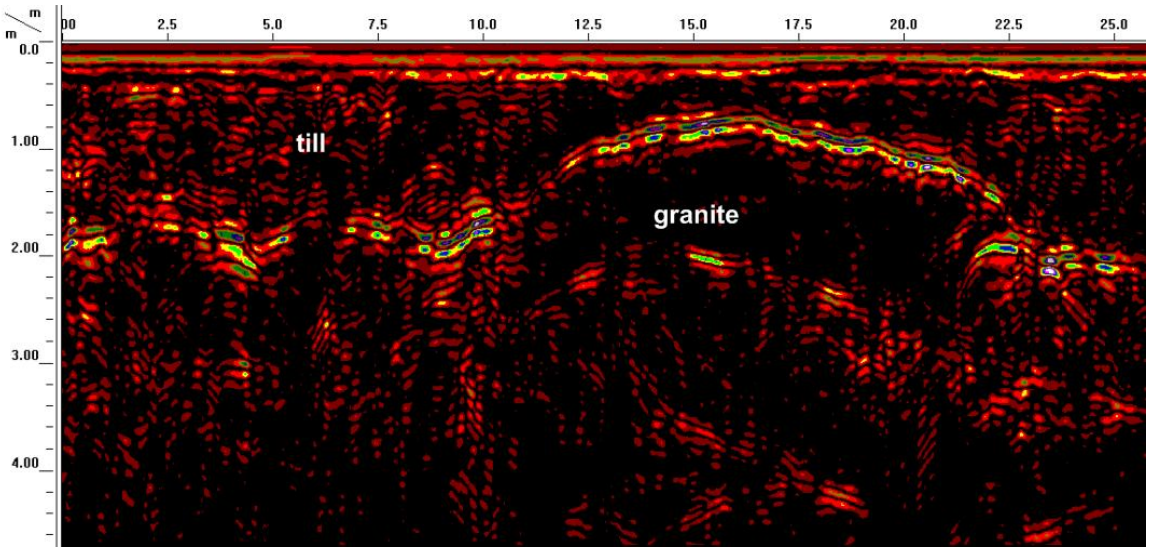

Figure 1. This representative radar record is from an area of Beckett-Tunbridge-Dixfield association, 8 to 15 % slopes, very stony. The underlying bedrock is assumed to be granite. The undulating soil/bedrock interface is easily traced across this record.

Figure 1 is a representative radar record from an area of Beckett-Tunbridge-Dixfield association, 8 to 15 % slopes, very stony. On this radar record all scales are expressed in meters. Though not observed, the

underlying bedrock is assumed to be granite. The soil/granite interface provides a rather smooth, high-amplitude, undulating reflecting surface that can easily be traced on most radar records. Inhomogeneities and fracture planes within the granite produce low- and medium-amplitude reflections.

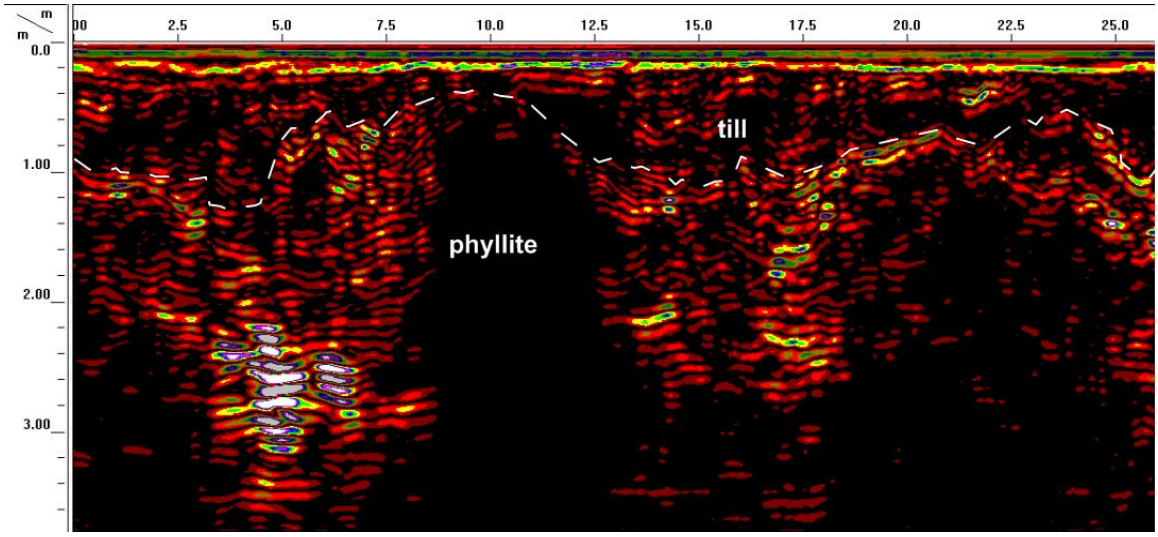

Figure 2. This radar record is from an area of Danforth-Thorndike complex, 3 to 15 % slopes, very stony. The underlying bedrock is assumed to be phyllite. The soil/bedrock interface appears discontinuous and is difficult to trace laterally.

Figure 2 is a representative radar record from an area of Danforth-Thorndike complex, 3 to 15 % slopes, very stony. On this radar record all scales are expressed in meters. Though not observed, the underlying bedrock is assumed to be phyllite. In Figure 2, a segmented white-colored line has been used to approximate the interpreted bedrock surface. Compared with the graphic signature of granite shown in Figure 1, the phyllite consists of multiple, highly irregular and segmented interfaces, which vary considerably in signal amplitude. The soil/bedrock interface lacks continuity and is often difficult to trace laterally across radar records because of the large number of rock fragments in the overlying till and the segmented and varying reflection patterns within the bedrock, which creates ambiguities.

Figure 3 is a representative radar record from an area of Telos-Chesuncook complex, 3 to 8 % slopes, very stony. On this radar record all scales are expressed in meters. Though not observed, the underlying bedrock is assumed to be phyllite or metasedimentary rock. In Figure 3, a segmented white-colored line has been used to approximate the interpreted bedrock surface. The soil/bedrock interface lacks continuity and is difficult to trace laterally across the radar record. The bedrock consists of numerous, segmented, inclined reflectors that vary in amplitude. These reflectors are believed to represent bedding and cleavage planes, and other inhomogeneities within the bedrock. In Figure 3, the soil/bedrock interface has been interpreted as the shallowest, high to moderate amplitude, linear reflections that can be traced across the radar record.

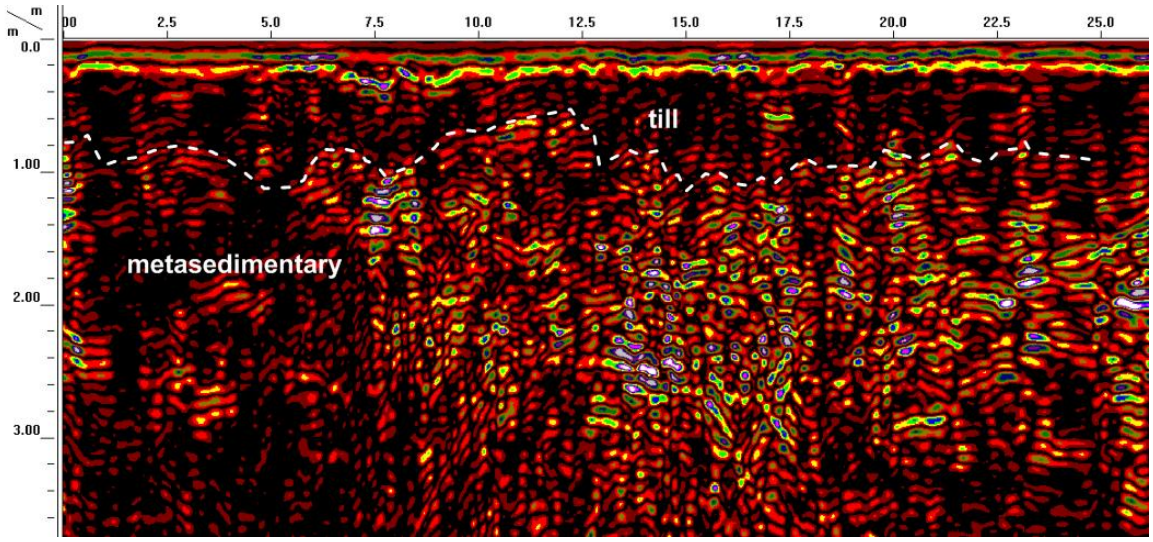

Figure 3. A representative radar record from an area of Telos-Chesuncook complex, 3 to 8 % slopes. The underlying bedrock is assumed to be slate or metasedimentary rock. The soil/bedrock interface is indistinct and difficult to trace laterally with confidence.

Table 3 and 4 respectively list the number and frequency of observations based on soil depth classes along the traverse lines.

References:

Cassidy, N.J. 2009. Electrical and magnetic properties of rocks, soils, and fluids. In *Ground Penetrating Radar: Theory and Applications*, ed. H. M. Jol, 41-72 pp. Elsevier Science, Amsterdam, The Netherlands.

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.

Table 3. Number of measurements falling into each soil depth class for the radar traverses conducted in the two study areas.

M.U.	*File*	*Shallow*	*Mod Deep*	*Deep*	*V. Deep*	*Total*
304C	12	1963	1938	2073	244	6218
304C	13	0	202	2402	3480	6084
304C	14	0	0	432	5043	5475
304C	15	941	2138	1071	760	4910
304C	16	265	3325	1822	327	5739
304C	17	142	3004	2006	0	5152
502C	18	0	0	1758	3534	5292
502C	19	558	3007	1480	1016	6061
502C	20	785	3376	1869	156	6186
502C	21	566	5277	269	112	6224
507C	22	0	2793	2818	244	5855
507C	23	569	3807	1751	21	6148
507C	24	0	3721	2267	84	6072
507C	25	288	2610	2820	592	6310
502D	26	23	2625	408	0	3056
502D	27	0	485	925	1403	2813
502D	28	0	1177	1649	59	2885
502D	29	1114	1654	2	0	2770
502C	30	1170	1110	554	0	2834
502C	31	1474	1429	370	0	3273
502C	32	548	1328	1377	0	3253
502C	33	339	610	1936	94	2979
22B	36	1963	1938	2073	244	6218
22B	37	0	202	2402	3480	6084
22B	39	0	0	432	5043	5475
22C	40	941	2138	1071	760	4910
22C	41	22	3752	3604	0	7378
56B	42	646	3295	1123	0	5064
56B	43	1294	2361	652	429	4736
56B	44	418	2949	1606	89	5062
56B	45	0	575	1877	0	2452
56B	46	1144	2383	888	0	4415
56B	47	2277	2395	386	0	5058
56B	48	1912	2491	547	0	4950
56B	49	0	5377	1485	0	6862
56B	50	1618	5305	855	0	7778
56B	51	5196	1077	420	0	6693

Table 4. Frequency distribution according to soil depth classes for the radar traverses conducted in the two study areas.

M.U.	*File*	*Shallow*	*Mod Deep*	*Deep*	*V. Deep*
304C	12	0.32	0.31	0.33	0.04
304C	13	0.00	0.03	0.39	0.57
304C	14	0.00	0.00	0.08	0.92
304C	15	0.19	0.44	0.22	0.15
304C	16	0.05	0.58	0.32	0.06
304C	17	0.03	0.58	0.39	0.00
502C	18	0.00	0.00	0.33	0.67
502C	19	0.09	0.50	0.24	0.17
502C	20	0.13	0.55	0.30	0.03
502C	21	0.09	0.85	0.04	0.02
507C	22	0.00	0.48	0.48	0.04
507C	23	0.09	0.62	0.28	0.00
507C	24	0.00	0.61	0.37	0.01
507C	25	0.05	0.41	0.45	0.09
502D	26	0.01	0.86	0.13	0.00
502D	27	0.00	0.17	0.33	0.50
502D	28	0.00	0.41	0.57	0.02
502D	29	0.40	0.60	0.00	0.00
502C	30	0.41	0.39	0.20	0.00
502C	31	0.45	0.44	0.11	0.00
502C	32	0.17	0.41	0.42	0.00
502C	33	0.11	0.20	0.65	0.03
22B	36	0.32	0.31	0.33	0.04
22B	37	0.00	0.03	0.39	0.57
22B	39	0.00	0.00	0.08	0.92
22C	40	0.19	0.44	0.22	0.15
22C	41	0.00	0.51	0.49	0.00
56B	42	0.13	0.65	0.22	0.00
56B	43	0.27	0.50	0.14	0.09
56B	44	0.08	0.58	0.32	0.02
56B	45	0.00	0.23	0.77	0.00
56B	46	0.26	0.54	0.20	0.00
56B	47	0.45	0.47	0.08	0.00
56B	48	0.39	0.50	0.11	0.00
56B	49	0.00	0.78	0.22	0.00
56B	50	0.21	0.68	0.11	0.00
56B	51	0.78	0.16	0.06	0.00