United States Department of Agriculture

NRCS

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Subject: Soils – Geophysical Investigations **Date:** 21 September 2010

To: Juan Hernandez
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Purpose:
A study of the Caribou soil catena in MLRA 146 (*Aroostook Area*) has been initiated by the soil staff in Maine. Caribou is a benchmark soil series and occupies a key position in the soil classification system. The Caribou catena is significant because it is the most intensively farmed soil catena in Maine. As part of this soil characterization project, ground-penetrating radar is being used to determine the depths to bedrock with mapped areas of the Caribou catena.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Greg Granger, Soil Resource Specialist, USDA-NRCS, Dover-Foxcroft, ME

Activities:
All field activities were completed on 14 and 15 September 2010.

Summary:

1. Soils of the Caribou catena are interpreted as being very deep to bedrock. Base on twelve radar traverses conducted in southern Aroostook County, soils were found to average about 12 % shallow, 71 % moderately deep, and 17 % deep to bedrock. Base on twenty radar traverses conducted in northern Aroostook County, soils were found to average about 13 % shallow, 66 % moderately deep, 19 % deep, and 2 % very deep to bedrock. Based on radar interpretations, moderately-deep soils dominate the selected traverse areas, which are mapped or associated with the Caribou catena.

2. Ground-penetrating radar interpretations provide estimates of soil depths. The results of this investigations are interpretive and do not substitute for direct ground-truth observations (soil core data), which are much more difficult to obtain and therefore significantly more limited in number. The use of GPR has resulted in a very large data set, with what is considered, very reasonably accurate interpretations of the depth to bedrock.

3. An Excel worksheet with all the interpreted radar data from this study has been forwarded to the principal participants (Tony Jenkins, Greg Granger, and Mary Jo Kimble).

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with and be of assistance to your fine soil staff in this study.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
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Technical Report on Geophysical Fieldwork completed in Maine on 14 and 15September 2010.

Jim Doolittle

Background:
The Caribou soil and catena are widespread in the *Aroostook Area* (MLRA 146). The Caribou catena is conceptualized as consisting of very deep, fine-loamy soils that formed in till. The Caribou catena is composed of the well drained Caribou, moderately-well drained Conant, and poorly drained Easton soils. Also associated with these soils is the well drained Mapleton soils. With the exception of Mapleton, soils of the Caribou catena have depths to bedrock greater than 60 inches. Mapleton soils are moderately deep to bedrock (20 to 40 inches). Caribou and Mapleton soils are on similar landscape positions. Conant and Easton soils are on lower landscape positions. The taxonomic classifications of these soils are listed in Table 1.

Table 1. Taxonomic classification of the soils of the Caribou Catena.

Soil Series	Classification
Caribou	Fine-loamy, isotic, frigid Typic Haplorthods
Conant	Fine-loamy, isotic, frigid Aquic Haplorthods
Easton	Fine-loamy, mixed, superactive, nonacid, frigid Aeric Endoaquepts
Mapleton	Fine-loamy, mixed, superactive, frigid Dystric Eutrudepts

The soils of Aroostook County were mapped in the 1950s using different field concepts and mapping procedures, and under a different soil classification scheme. Recent observations of Caribou soil have led to concerns over its classification in terms of the absence of a spodic horizon, presence of densic materials, and depth to bedrock. This GPR investigation is part of a project designed to improve the interpretations of this soil catena based on soil sampling and characterization data. The collected baseline data will be used to revise the concepts and improve the interpretations of map unts occurring on the Caribou catena.

The focus of this GPR investigation was to provide data on the depth to bedrock within the Caribou catena. One cannot drive thru Aroostook County without noticing the presence and impact of the underlying bedrock. Rock outcrops, low, seemingly bedrock-controlled knolls and ridges, and exposures in road cuts testify to the presence of bedrock. Many surfaces are punctuated by swells, low mounds, or ridges that are believed to be expressions of the underlying bedrock. Ground-penetrating radar was used to determine the depths to bedrock in different areas of the Caribou Catena.

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 this study.

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

The RADAN for Windows (version 6.6) software program (here after referred to as RADAN) developed by GSSI was used to process the radar records shown in this report.[2] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, migration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

A Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA) was used to georeferenced the GPR data.[2]

Survey Procedures:
Multiple, random radar traverses were completed across nine site located in Aroostook County. Pedestrian surveys were completed by walking with the SIR-3000 and pulling the 200 antenna across each site. Radar data were collected at a rate of 48 scans/sec. Using the *Interactive Interpretation* module of the RADAN, interpretations of the depth to the soil/bedrock interface were essentially made for each scan. This process produced very large data sets for each site. Each radar traverse was stored as a separate file. After interpretation of the depth to bedrock, measurements were stored as a layer file which was imported into an Excel spreadsheet.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the 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):

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

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (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 commonly expressed in meters per nanosecond (ns). In soils, the amount and physical state of water (temperature dependent) have the greatest effect on the E_r and v.

In both northern and southern Aroostook County, these parameters were determined by comparing the interpreted depth to a known, shallowly buried, metallic reflector (whose image was identified on a radar record) with the two-way travel time to this reflector on radar records. Based on the measured depth and the two-way travel time to the reflector, and equation [1], the velocity of propagation was estimated. The E_r of the near-surface soil layers was then determined using equation [2].

The relative dielectric permittivity and velocity of propagation is spatially and temporally variable. In a given field, these parameters will vary with soils, soil depths, and landscape positions. However, these parameters were estimated for all traverses conducted in southern and northern on the basis of a single measurement made in each region of the county. In southern Aroostook County, the estimated relative dielectric permittivity was 6.8 (v of 0.1150) while in northern Aroostook County it was 9.8 (v of 0.9583 m/ns). It was assumed that drier soil moisture conditions in southern Aroostook County were responsible for the lower E_r and higher v.

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

Study Sites:
All sites are located in Aroostook County and within cultivated fields that are presently planted to clover (potatoes-oats-clover rotation). Multiple, random GPR traverses were completed across each site using the 200 MHz antenna.

Sites 1 to 4 are located in southern Aroostook County. Site 1 (46.0212 N. Latitude, 67.8277 W. Longitude) is located off of Green Road about 2.4 miles northeast of Carey in Hodgdon Township. Areas of the field traversed with GPR are mapped as Thorndike shaly silt loam, 0 to 8 percent slopes (ThB). Thorndike formed in till weathered from slate, phyllite, or calcareous metasedimentary rocks and is commonly associated with the Caribou catena. The shallow, somewhat excessively drained Thorndike soils formed in till on uplands. Thorndike is a member of the loamy-skeletal, isotic, frigid Lithic Haplorthods soil taxonomic family.

Site 2 (46.1098 N. Latitude, 67.8928 W. Longitude) is located off of Porter Settlement road about 2.7 miles southwest of Houlton. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Caribou gravelly loam, 8 to 15 percent slopes (CgC).

Site 3 (46.2921 N. Latitude, 67.8316 W. Longitude) and Site 4 (46.2936 N. Latitude, 67.8116 W. Longitude) are located off of Hare Road about 0.4 and 1.4 miles east of US Highway 1, respectively, in Monticello. At Site 3, areas of the field traversed with GPR are mapped as Mapleton shaly silt loam, 0 to 8 percent slopes (MhB). At Site 4, areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Caribou gravelly loam, 8 to 15 percent slopes (CgC).

Sites 5 to 9 are located in northern Aroostook County. Site 5 (46.7657 N. Latitude, 68.1747 W. Longitude) is located off of Castle Hill Road about 1.5 miles southwest of Washburn. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB), Caribou gravelly loam, 8 to 15 percent slopes (CgC), and Conant silt loam, 2 to 8 percent slopes (CoB).

Site 6 (46.8071 N. Latitude, 68.1623 W. Longitude) is located off of Hines Road about 1.1 miles north of Washburn. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Conant silt loam, 2 to 8 percent slopes (CoB).

Site 7 (46.8670 N. Latitude, 68.1711 W. Longitude) is located off of Davis Road about 7.4 miles west of Caribou. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB).

Site 8 (46.8633 N. Latitude, 68.1650 W. Longitude) is located off of Davis Road about 7.1 miles west of Caribou. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Conant silt loam, 2 to 8 percent slopes (CoB).

Site 9 (46.9205 N. Latitude, 68.4077 W. Longitude) is located off of Watson Memorial Drive about 3.9 miles north-northwest of Caribou. Areas of the field traversed with GPR are mapped as Caribou gravelly loam, 2 to 8 percent slopes (CgB).

Results:
Southern Aroostook County:
The frequency distribution of radar interpreted estimates of the depth to bedrock for each traverse conducted in southern Aroostook County is listed in Table 2.

<u>Site 1:</u>

Four GPR traverses were conducted across a unit of Thorndike shaly silt loam, 0 to 8 percent slopes (ThB). These traverses produced a total of 48,728 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 7 % shallow (< 50 cm), 77 % moderately deep (50 to 100 cm), and 16 % deep (100 to 150 cm) to bedrock.

Table 2. Frequency distributions of the interpreted depths to bedrock along individual GPR traverse lines conducted in southern Aroostook County.

GPR File #	Site	Shallow	Mod-Deep	Deep	Very Deep
3	1	0.00	0.75	0.25	0.00
4	1	0.01	0.79	0.20	0.00
5	1	0.21	0.75	0.04	0.00
6	1	0.04	0.80	0.16	0.00
7	2	0.17	0.71	0.12	0.00
8	2	0.16	0.78	0.06	0.00
9	3	0.43	0.49	0.08	0.00
10	3	0.23	0.68	0.09	0.00
11	3	0.11	0.71	0.18	0.00
12	4	0.00	0.60	0.39	0.01
13	4	0.07	0.83	0.10	0.00
14	4	0.01	0.66	0.33	0.00

Site 2:
Two GPR traverses were conducted across units of Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Caribou gravelly loam, 8 to 15 percent slopes (CgC). These traverses produced a total of 20,558 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 17 % shallow, 74 % moderately deep, and 9% deep to bedrock.

Site 3:
Three GPR traverses were conducted across a unit of Mapleton shaly silt loam, 0 to 8 percent slopes (MhB). These traverses produced a total of 27,238 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 23 % shallow, 63 % moderately deep, and 11% deep to bedrock.

Site 4:
Three GPR traverses were conducted across units of Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Caribou gravelly loam, 8 to 15 percent slopes (CgC). These traverses produced a total of 32,200 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 3 % shallow, 70 % moderately deep, and 27% deep to bedrock.

Northern Aroostook County:
The frequency distribution of radar interpreted estimates of the depth to bedrock for each traverse conducted in northern Aroostook County is listed in Table 3.

Site 5:
Six GPR traverses were conducted across units of Caribou gravelly loam, 2 to 8 percent slopes (CgB), Caribou gravelly loam, 8 to 15 percent slopes (CgC), and Conant silt loam, 2 to 8 percent slopes (CoB). These traverses produced a total of 33,377 geo-referenced estimates of the depth to bedrock.

Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 14 % shallow, 70 % moderately deep, and 16 % deep to bedrock.

Table 3. Frequency distributions of the interpreted depths to bedrock along individual GPR traverse lines conducted in northern Aroostook County.

GPR File #	Site	Shallow	Mod-Deep	Deep	Very Deep
16	5	0.01	0.85	0.13	0.01
17	5	0.01	0.55	0.44	0.00
18	5	0.30	0.70	0.00	0.00
19	5	0.25	0.55	0.20	0.00
20	5	0.14	0.86	0.00	0.00
21	5	0.15	0.66	0.19	0.00
22	6	0.38	0.58	0.04	0.00
23	6	0.06	0.72	0.22	0.00
24	6	0.02	0.61	0.37	0.00
25	6	0.00	0.86	0.14	0.00
26	6	0.04	0.47	0.44	0.05
27	7	0.00	0.64	0.34	0.02
28	7	0.01	0.82	0.17	0.00
29	7	0.53	0.40	0.06	0.01
30	8	0.03	0.68	0.28	0.01
31	8	0.20	0.74	0.06	0.00
32	9	0.11	0.59	0.18	0.12
33	9	0.04	0.65	0.17	0.14
34	9	0.24	0.61	0.15	0.00
35	9	0.04	0.80	0.13	0.03

Site 6:
Five GPR traverses were conducted across units of Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Conant silt loam, 2 to 8 percent slopes (CoB). These traverses produced a total of 34,707 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 5 % shallow, 39 % moderately deep, 36 % deep, and 20 % very deep (> 150 cm) to bedrock.

Site 7:
Three GPR traverses were conducted across a unit of Caribou gravelly loam, 2 to 8 percent slopes (CgB). These traverses produced a total of 26,670 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 18 % shallow, 62 % moderately deep, 19 % deep, and 1 % very deep to bedrock.

Site 8:
Two GPR traverses were conducted across units of Caribou gravelly loam, 2 to 8 percent slopes (CgB), and Conant silt loam, 2 to 8 percent slopes (CoB). These traverses produced a total of 17,234 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 11 % shallow, 71 % moderately deep, and 17 % deep to bedrock.

Site 9:

Four GPR traverses were conducted across a unit of Caribou gravelly loam, 2 to 8 percent slopes (CgB). These traverses produced a total of 34,674 geo-referenced estimates of the depth to bedrock. Interpretations of the radar records collected at this site resulted in an averaged frequency distribution (according to soil depth criteria) of 11 % shallow, 67 % moderately deep, 15 % deep, and 7 % very deep to bedrock.

References:

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.