United States Department of Agriculture | Natural Resources Conservation Service | 11 Campus Boulevard, Suite 200 Newtown Square, PA 19073

Subject: SOI -- Geophysical Assistance --

Date: 21 December 1999

To: Bruce Thompson,
State Soil Scientist/MLRA Office Leader
USDA-NRCS,
451 West Street
Amherst, MA 01002-2995

PURPOSE:
The purpose of this investigation was to use ground-penetrating radar (GPR) to determine the depths to bedrock in selected map units within Franklin County, Massachusetts. Data will be used to document the composition of soil map units. In addition, while collecting soil information in Franklin and Plymouth counties, Jim Turenne was provide training on the use of the new SIR System-2000 radar unit

PARTICIPANTS:
Al Averill, Soil Survey Project Leader, USDA-NRCS, Greenfield, MA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Shawn Finn, SDQS-Database Manager, USDA-NRCS. Amherst, MA
Astrid Martinez, Soil Scientist, USDA-NRCS, Amherst, MA
Jim Turenne, Soil Survey Project Leader, USDA-NRCS, W. Wareham, MA
Andrew Williams, SDSQ-Correlations, USDA-NRCS, Amherst, MA

ACTIVITIES:
All field activities were completed during the period of 13 to 15 December 1999.

EQUIPMENT:
The radar unit was the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. The models 3110 (120 mHz) and 5103 (400 mHz) antennas were used in this investigation. A 12-volt battery powered the radar system. Scanning time of 60 to 100 nanoseconds and a scanning rate of 32 scans/sec were used.

FIELD PROCEDURES:
Radar surveys were completed by pulling an antenna through areas of selected map units in Franklin and Plymouth counties. Although, GPR provides a continuous profile of subsurface conditions, interpretations were restricted to observation points. In Franklin County and for most traverses, these points were spaced at uniform intervals (about 30 feet) along traverse lines. Traverses were confined to mapped soil delineations. These traverses varied in length and contain different numbers of observations. At each observation point, the radar operator impressed a dashed, vertical line on the radar profile. This line identified an observation point on the radar record.

---

[1] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

Each radar traverse was stored as a separate file on a hard disc. Later, the radar file was reviewed and the subsurface interfaces were identified. In Franklin County, at each observation point, the depth to bedrock was determined. This determination was based on the identification of the soil/ bedrock interface on radar profiles and the results of calibration trials.

CALIBRATION:
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., soil horizon, stratigraphic layer, 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 the following equation (Morey, 1974):

$$v = 2d/t$$

The velocity of propagation is principally affected by the dielectric constant (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2$$

Where c is the velocity of propagation in a vacuum (1 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric constant of soil materials.

The radar was calibration during fieldwork. During calibration, the dielectric constant and velocity of propagation were determined. These values were used to establish a depth scale for the radar imagery.

At two sites in Franklin County, a metallic shovel blade was used to determine the dielectric constant and velocity of propagation. This information was used to scale (depth) the radar imagery and to estimate the depths to bedrock. The shovel blade was buried at a depth of about 16 and 20 inches. Based on the round-trip travel time to this buried reflector, the averaged velocity of propagation was estimated to be 0.09908 m/ns and 0.09310 at sites 1 and 3, respectively. The associated dielectric constant was estimated to be 9.17 and 10.38 at sites 1 and 3, respectively. At Site 1, based on an average velocity of propagation of 0.09908 m/ns and a scanning time of 100 ns, the 200 mHz antenna provided a maximum observation depth of about 4.95 meters. At the other sites, based on an average velocity of propagation of 0.09310m/ns and a scanning time of 60 ns, the 400 mHz antenna provided a maximum observation depth of about 2.79 meters.

During the bog investigation in Plymouth County, a soil probe was used to determine the thickness of organic materials at several observation points. This information was used to scale the radar imagery.

A basic assumption of this survey was that soil materials were rather uniform and that large differences in the velocity of propagation did not exist among the observation points. Unquestionably, slight discrepancies exist in the depth measurements. While the actual measurements are considered close approximations, the grouping of observation points into relative soil depth classes (shallow, moderately deep, deep, and very deep) is more accurate and is preferred.

RESULTS (Franklin County):
During an abbreviated two day period, a total of twenty-three transects were completed in mapped delineations of eleven different soil mapping units. However, because of poor interpretive qualities, two of these transects were discarded and are not reported. Depths to bedrock were interpreted at 384 observation points.

Site 1
This site was located within the town of Bernardston. Three transects were completed at this site. Map unit traversed with the GPR included areas of Dutchess-Cardigan complex, 8 to 15 percent slopes, and Cardigan-Nassau complex, 3 to 8 percent slopes. These soils formed in till on glaciated uplands. The moderately deep, well drained Cardigan and the very deep, well drained Dutchess soils are members of the coarse-loamy, mixed, mesic Typic Dystrochrepts family. The shallow, somewhat excessively drained Nassau soil is a member of the loamy-skeletal, mixed, active, mesic Lithic Dystrochrepts family. Appendix 1 lists the interpreted depths to bedrock for each transect. For each transect, a summary of the frequency of observations within each depth class is provided in Table 1.

Site 2

This site was located within the town of Bernardston. Nine transects were completed at this site. Map unit traversed with the GPR included areas of Macomber-Taconic complex, 15 to 25 percent slopes; Dutchess-Cardigan complex, 3 to 8 percent slopes; Dutchess-Cardigan complex, 15 to 25 percent slopes; and Cardigan-Nassau complex, 8 to 15 percent slopes. These soils formed in till on glaciated uplands. The moderately deep, well drained Macomber soil is a member of the loamy-skeletal, mixed, frigid, Typic Dystrochrepts family. The shallow, somewhat excessively drained Taconic soil is a member of the loamy-skeletal, mixed, frigid Lithic Dystrochrepts family. Appendix 1 lists the interpreted depths to bedrock for each transect. For each transect, a summary of the frequency of observations within each depth class is provided in Table 1.

Table 1
GPR Interpretations of the
Depth to Bedrock within Selected Map Units

Frequency of observations in each Depth Class (inches)
(values are expressed as percentages)

		Depth Classes			
Site	**Map Unit**	**0-20**	**20-40**	**40-60**	**>60**
1	141C	0	44	23	33%
1	142B	23	23	46	8%
1	141C	12	50	38	0%
2	152D	6	82	12	0%
2	152D	13	80	7	0%
2	152D	21	65	14	0%
2	152D	16	72	12	0%
2	152D	6	83	11	0%
2	141B	0	0	93	7%
2	142C	6	33	61	0%
2	116B	0	0	92	8%
2	141D	0	9	91	0%
3	116B	0	21	79	0%
3	116E	29	39	32	0%
3	116D	57	43	0	0%
3	116E	10	70	20	0%
3	117C	38	62	0	0%
3	117C	20	80	0	0%
3	117C	24	62	14	0%
3	116D	35	65	0	0%
4	113C	0	12	65	24%
4	113D	5	54	8	42%

Site 3

This site was located within the town of Shelburne. Eight transects were completed at this site. Map unit traversed with the GPR included areas of Millsite-Westminster complex 3 to 8 percent slopes, rocky; Millsite-Westminster complex 15 to 25 percent slopes, rocky; Millsite-Westminster complex 25 to 50 percent slopes, rocky; and Westminster-Millsite complex, 8 to 15 percent slopes, rocky. These soils formed in till on glaciated uplands. The moderately deep, somewhat excessively drained Millsite soil is a member of the coarse-loamy, mixed, frigid, Typic Dystrochrepts family. The shallow, somewhat excessively drained Westminster soil is a member of the loamy, mixed, frigid Lithic Dystrochrepts family. Appendix 1 lists the interpreted depths to bedrock for each transect. For each transect, a summary of the frequency of observations within each depth class is provided in Table 1.

Site 4
This site was located within the town of Shelburne. Two transects were completed at this site. Map unit traversed with the GPR included areas of Charlton-Chatfield complex 8 to 15 percent slopes, and Charlton-Chatfield complex 15 to 25 percent slopes. These soils formed in till on glaciated uplands. The very deep, well drained Charlton soil is a member of the coarse-loamy, mixed, active, mesic, Typic Dystrochrepts family. The moderately deep, well drained Chatfield soil is a member of the coarse-loamy, mixed, superactive, mesic Typic Dystrochrepts family. Appendix 1 lists the interpreted depths to bedrock for each transect. For each transect, a summary of the frequency of observations within each depth class is provided in Table 1.

RESULTS (Plymouth County):
During the morning of 15 December, GPR surveys were conducted in an area of ice-contact deposits. The purpose of this investigation was learn the graphic signatures associated with different glacial drift deposits. The area had been mapped as a complex of Montauk and Barnstable soils. Montauk is a member of the coarse-loamy, mixed, subactive, mesic Oxyaquic Dystrochrepts family. Barnstable is a member of the coarse loamy over sandy or sandy skeletal, mixed, active mesic Typic Dystrochrepts family.

During the afternoon of 15 December, GPR surveys were conducted in a bog. The purpose of this investigation was to provide the landowner with a map showing the depth of organics within the bog. The dominant soil was Berryland. This very deep, very poorly drained soil formed in marine sediments and is a member of the sandy, siliceous mesic Typic Alaquods family. Included in mapping are small areas of Swansea soil. The very deep, very poorly drained Swansea soil is a member of the sandy or sandy-skeletal, mixed, dysic, mesic Terric Medisaprists family. As the SIR2000 system is backpack portable, the survey was quickly and effortlessly completed. All radar data were turned over to Jim Turenne for analysis.

RECOMMENDATION:
Massachusetts has soils that are well suited to ground-penetrating radar. The GPR unit presently being used in Massachusetts has become outdated and obsolete. At the end of this calendar year, their manufacturer, Geophysical Survey System, Inc, (GSSI) will no longer support the SIR System-3 radar unit. In addition, the manufacturer can no longer provide repair services or parts for this older radar unit nor supply graphic paper or stylus belts for its printers. Unless the radar unit presently being used by NRCS in Massachusetts is replaced, the GPR program and services in Massachusetts will suffer dire consequences and may possibly end.

A new vintage of more affordable radar units and antennas has been developed. New radar units are smaller and backpack portable with real-time color display and data processing capabilities to improve interpretations and presentations. The most recently developed GPR unit is the Subsurface Interface Radar (SIR) System-2000. During the coarse of this field assignment, the SIR System-2000 was found to be highly suited to the wooded and steeply sloping upland terrains of Massachusetts. The purchase of this unit by the MLRA office is recommended.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
A. Averill, Soil Survey Project Leader, USDA-NRCS, Greenfield, MA
J. Culver, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
J. Turenne, Soil Survey Project Leader, USDA-NRCS, 15 Cranberry Highway, W. Wareham, MA 02576

References
Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. p. 212-232. *IN:* Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Appendix

Site 1

Transect #1
M.U. 141C - Dutchess-Cardigan complex 8-15% slopes

Obs.	Depth (in)
1	36.9
2	30.8
3	36.9
4	55.4
5	48.0
6	73.8
7	76.3
8	80.0
9	36.9

Transect #2
M.U. 142B - Cardigan-Nassau complex 3-8% slopes

Obs.	Depth (in)
1	39.4
2	51.7
3	40.6
4	116.9
5	40.6
6	19.7
7	33.2
8	14.8
9	51.7
10	46.8
11	9.8
12	35.7
13	40.6

Transect #3
M.U. 141C - Dutchess-Cardigan complex 8-15% slopes

Obs.	Depth (in)
1	41.8
2	28.3
3	9.8
4	28.3
5	29.5
6	40.6
7	36.9
8	41.8

Site 2

Transect #1
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
1	42.1
2	39.3
3	22.1
4	33.8
5	24.1
6	22.8
7	21.4
8	26.2
9	24.1
10	42.1
11	34.5
12	33.1
13	29.0
14	15.2
15	25.5
16	25.5
17	26.2

Transect #2
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
1	27.6
2	29.0
3	21.4
4	31.0
5	33.8
6	41.4
7	26.2
8	6.2
9	28.3
10	24.8
11	21.4
12	5.5
13	22.8
14	33.1
15	24.8

Transect #3
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
1	41.4
2	42.1
3	30.3
4	22.1
5	21.4
6	37.9
7	29.7
8	22.1
9	19.3

Transect #3
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
10	22.8
11	15.2
12	24.8
13	18.6
14	26.9

Transect #4
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
1	51.7
2	14.5
3	37.2
4	28.3
5	23.4
6	30.3
7	35.2
8	42.8
9	48.3
10	22.8
11	25.5
12	29.7
13	25.5
14	15.2
15	20.7
16	31.0
17	23.4
18	20.7
19	39.3
20	32.4
21	16.6
22	36.6
23	30.3
24	16.6
25	22.1

Transect #5
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
1	25.5
2	27.6
3	23.4
4	44.8
5	17.2
6	45.5
7	29.0
8	33.1
9	26.9
10	22.1
11	39.3

Transect #5
M.U. 152D - Macomber-Taconic 15-25% slopes

Obs.	Depth (in)
12	20.7
13	21.4
14	22.8
15	33.1
16	24.8
17	25.5
18	39.3

Transect #6
M.U. 141B - Dutchess-Cardigan complex 3-8% slopes

Obs.	Depth (in)
1	53.1
2	55.2
3	52.4
4	50.3
5	44.1
6	44.8
7	52.4
8	44.1
9	67.6
10	44.1
11	50.3
12	49.0
13	51.0
14	47.6
15	53.1

Transect #7
M.U. 142C - Cardigan-Nassau complex 8-15% slopes

Obs.	Depth (in)
1	48.3
2	54.5
3	44.1
4	44.8
5	47.6
6	39.3
7	44.8
8	24.8
9	26.2
10	57.2
11	46.2
12	29.0
13	46.2
14	50.3
15	55.2
16	17.9
17	30.3
18	40.0

Transect #8
M.U. 116B - Dutchess-Cardigan complex 15-25% slopes

Obs.	Depth (in)
1	46.9
2	51.7
3	54.5
4	46.9
5	43.4
6	47.6
7	49.7
8	50.3
9	51.7
10	53.1
11	60.7
12	53.8
13	51.0

Transect #9
M.U. 141D - Dutchess-Cardigan complex 15-25% slopes

Obs.	Depth (in)
1	46.2
2	46.9
3	58.6
4	51.7
5	55.2
6	53.1
7	41.4
8	53.1
9	59.3
10	48.3
11	50.3

Transect #9
M.U. 141D - Dutchess-Cardigan complex 15-25% slopes

Obs.	Depth (in)
12	53.1
13	41.4
14	37.9
15	45.5
16	34.5
17	46.9
18	42.8
19	48.3
20	41.4
21	44.8
22	49.7

Site 3

Transect #1
M.U. 116B - Millsite-Westminster complex, 3-8% slopes, rocky

Obs.	Depth (in)
1	41.4
2	34.5
3	35.9
4	40.0
5	49.7
6	44.8
7	55.2
8	48.3
9	43.4
10	31.7
11	41.4
12	24.1
13	41.4
14	34.5
15	44.8
16	53.1
17	46.2
18	46.2
19	41.4
20	50.3
21	51.0
22	46.2
23	42.1
24	49.0
25	51.0
26	43.4
27	48.3
28	51.7

Transect #2
M.U. 116E - Millsite-Westminster complex, 25-50% slopes, rocky

Obs.	Depth (in)
1	42.8
2	34.5
3	41.4
4	44.1
5	46.2
6	51.0
7	50.3
8	44.1
9	45.5
10	39.3
11	33.1
12	45.5
13	39.3
14	22.1
15	38.6
16	39.3
17	27.6
18	17.2
19	19.3

Transect #2
M.U. 116E - Millsite-Westminster complex, 25-50% slopes, rocky

Obs.	Depth (in)
20	24.1
21	24.8
22	15.9
23	17.2
24	22.8
25	13.8
26	13.1
27	15.9
28	19.3

Transect #3
M.U. 116B - Millsite-Westminster complex, 3-8% slopes, rocky

Obs.	Depth (in)
1	13.8
2	16.6
3	17.2
4	20.7
5	33.8
6	20.7
7	23.4
8	24.1
9	13.8
10	24.8
11	18.6
12	0.0
13	14.5
14	15.2

Transect #4
M.U. 116E - Millsite-Westminster complex, 25-50% slopes, rocky

Obs.	Depth (in)
1	50.3
2	26.2
3	33.8
4	35.9
5	55.2
6	29.0
7	21.4
8	34.5
9	31.0
10	20.7
11	48.3
12	29.0
13	35.9
14	41.4
15	26.9
16	34.5
17	13.8
18	15.9
19	24.8
20	21.4

Transect #5
M.U. 117C - Westminster-Millsite complex, 8-15% slopes, rocky

Obs.	Depth (in)
1	37.9
2	22.8
3	35.9
4	24.1
5	21.4
6	13.8
7	10.3
8	13.8
9	11.7
10	37.2
11	22.1
12	20.0
13	25.5
14	22.1
15	19.3
16	30.3

Transect #6
M.U. 117C - Westminster-Millsite complex, 8-15% slopes, rocky

Obs.	Depth (in)
1	25.5
2	26.9
3	29.0
4	25.5
5	18.6
6	36.6
7	20.0
8	30.3
9	38.6
10	40.0
11	24.1
12	18.6
13	12.4
14	32.4
15	29.0

Transect #7
M.U. 117C - Westminster-Millsite complex, 8-15% slopes, rocky

Obs.	Depth (in)
1	36.6
2	29.0
3	44.8
4	26.9
5	21.4
6	25.5
7	37.9
8	40.0
9	23.4
10	18.6
11	29.0
12	15.9

Transect #7
M.U. 117C - Westminster-Millsite complex, 8-15% slopes, rocky

Obs.	Depth (in)
13	29.0
14	14.5
15	41.4
16	44.8
17	13.8
18	33.1
19	27.6
20	30.3
21	0.0

Transect #8
M.U. 116D - Millsite-Westminster complex, 15-25% slopes, rocky

Obs.	Depth (in)
1	27.6
2	25.5
3	31.7
4	24.8
5	31.0
6	20.7
7	18.6
8	13.8
9	12.4
10	20.0
11	23.4
12	22.8
13	19.3
14	31.0
15	22.1
16	0.0
17	22.1

Site 4

Transect #1

M.U. 113C - Charlton-Chatfield complex, 8-15% slopes

Obs.	Depth (in)
1	48.3
2	55.2
3	49.0
4	53.8
5	51.7
6	53.1
7	55.2
8	38.6
9	42.8
10	69.0
11	93.1
12	77.2
13	62.1
14	58.6
15	44.8
16	41.4
17	40.0

Transect #2

M.U. 113D - Charlton-Chatfield complex, 15-25% slopes

Obs.	Depth (in)
1	29.0
2	43.4
3	42.8
4	51.7
5	55.2
6	49.7
7	71.0
8	53.1
9	52.4
10	57.2
11	52.4
12	69.0
13	53.8
14	4.8
15	66.2
16	84.1
17	70.3
18	64.1
19	60.0
20	75.2
21	64.8