United States Department of Agriculture	**Natural Resources Conservation Service**	**c/o USDA Forest Service 11 Campus Boulevard Suite 200 Newtown Square, PA 19073** (610) 557-4233; FAX: (610) 557-4200

Subject: SOI -- Geophysical Assistance -- **Date:** 16 August 2004

To: Francis M. Keeler
State Conservationist
USDA-NRCS
356 Mountain View Drive
Colchester, VT 05446

Purpose:
Ground-penetrating radar (GPR) was used in an attempt to locate burials of the Missisquoi /Mazipskoik Abenaki Tribe along the north bank of the Missisquoi River near the town of Swanton, Vermont.

Participants:
Scott Dillion, Archaeologist, Vermont State Historic Office, Montpelier, VT
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Raymond Godfrey, Resource Inventory Coordinator, USDA-NRCS, Colchester, VT
Matt Lachet, Volunteer, University of Vermont, Burlington, VT
Peter Lossmann, Soil Conservation Technician, USDA-NRCS, Middlebury, VT
Reed Sims, GIS Specialist, USDA-NRCS, Colchester, VT
Randy Stearns, Soil Conservation Technician, USDA-NRCS, Middlebury, VT
Dave Skinas, Archaeologist, USDA-NRCS, Berlin, VT

Activities:
All field activities were completed during the period of 19 to 22 July 2004.

Summary:

1. Five, high intensity ground-penetrating radar surveys were completed near Swanton, Vermont. Although GPR provided satisfactory penetration depths and resolution for archaeological investigations, the identification of burials, if present, was problematic. Stratification (differences in soil particle sizes) created high levels of background noise that complicated radar records and, if present, masked the identification of burials.

2. The interpretation of two-dimensional radar records and three-dimensional radar imagery led to the identification of several suspected locations within the Fournier and Spaulding sites. These locations were marked and will be examined by an archaeologist.

3. Although several suspected locations were identified, no burial was explicitly recognized.

4. The survey at the Monument Site provides useful information for the interpretation of similar sites in Vermont. Monument Site has had a long history of known occupation and use by Native Americans. It has been repeatedly disturbed. Radar records and images from this site showed that high amplitude reflections do not increase monotonously with depth. Otherwise, the radar record from this site is similar to the other sites. Three-dimensional time-slice analysis appears ill suited for the identification of Native American burial grounds in Vermont.

5. While it is doubtful that individual burial were identified with GPR, areas of intense and historic disturbances were differentiated.

As always, it was my pleasure to work in Vermont and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
S. Gourley, State Soil Scientist, USDA-NRCS, 69 Union Street, Winooski, VT 05404
C. Olson, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
D. Skinas, Archaeologist, USDA-NRCS, 617 Comstock Road, Suite 1, Berlin, VT 05602-8927
B. Thompson, MO Team Leader, USDA-NRCS, 451 West Street Amherst, MA 01002-2995
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room G08, 207 West Main Street, Wilkesboro, NC 28697

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-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 System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. The 400 MHz antenna was used in this study. The use and operation of GPR are discussed by Daniels (1996).

The RADAN for Windows (version 5.0) software developed by Geophysical Survey Systems, Inc, was used to process the radar records. [1] Processing included setting the initial pulse to time zero, color table and transformation selection, marker editing, distance normalization, and range gain adjustments. In addition all radar records were migrated to remove hyperbola diffractions and to correct the geometry of steeply dipping layers. Radar records were processed into a three-dimensional image using the 3D QuickDraw for RADAN Windows NT software developed by Geophysical Survey Systems, Inc. [1] Once processed, arbitrary cross sections and time slices were viewed and selected images attached to this report.

Background:
At the time of historic contact (about 1600) a large Missisquoi /Mazipskoik Abenaki village extended along the lower reaches of the Missisquoi River. This village was fairly permanent, dating from about 2800 YBP to the early 19th Century. A Jesuit Mission was established at this village in 1744 and lasted until 1790. Although four "known" burial grounds have been documented, unmarked burials and burial grounds are common throughout this area. Graves are typically 60 and 150 cm deep, but some are as shallow as 40 cm. Until the 19th Century, corpses were interred in the ground without coffins. In the 19th Century, corpses were commonly interred in wooden coffins.

An agreement has been obtained with the Missisquoi /Mazipskoik Abenaki Tribe that allows residential development in this area of cultural and historic significance. Prior to development a detailed archaeological investigation is required at each site. It has been recommended that these investigations be accompanied by a

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

detailed ground-penetrating radar survey.

Study Sites:
Study sites are located in residential lots along Monument Road in Swanton, Vermont. Monument Road is located to the north and northwest of the town. The road parallels the north bank of the Missisquoi River. Most investigated sites are located in areas that have been mapped as Windsor loamy fine sand, 0 to 3 percent slopes (Flynn and Joslin, 1979). The Monument Site is located in an area of Au Gres loamy fine sand, 0 to 6 percent slopes (Flynn and Joslin, 1979). The very deep, excessively drained Windsor soil forms in sandy glacial fluvial deposits. Windsor is a member of the mixed, mesic, Typic Udipsamments family. The very deep, somewhat poorly drained Au Gres soil forms in sandy glacial drift on stream terraces and outwash plains. Au Gres is a member of the sandy, mixed, frigid Typic Endoaquods family.

Figure 1 is a representative radar record from an area of Windsor loamy fine sand, 0 to 3 percent slopes. In Figure 1, the vertical scale is in meters. The white vertical lines at the top of the radar record represents equally spaced (1-m) reference points along the radar traverse line. With the exception of the Bhs horizon in Au Gres soil, both Au Gres and Windsor soils produced similar radar records.

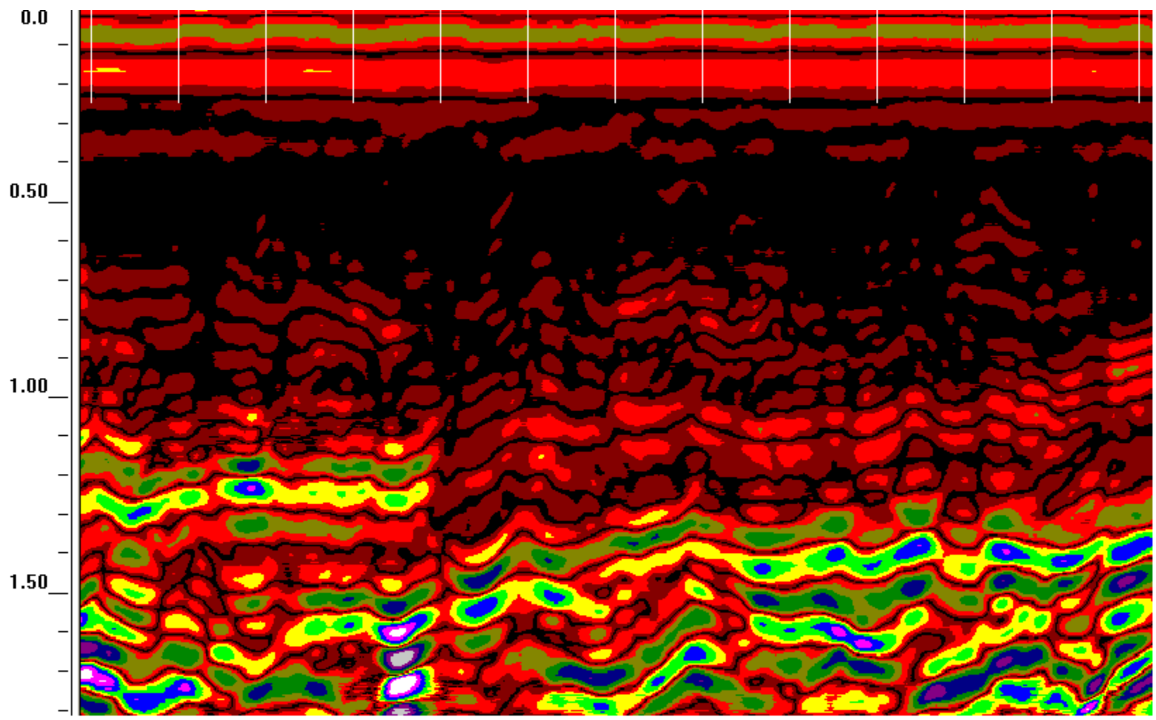

Figure 1. Representative radar record from an area of Windsor loamy fine sand, 0 to 3 percent slopes

Windsor soil has a solum that ranges in thickness from about 25 to 90 cm. The solum is loamy fine sand or loamy sand in the upper part and loamy fine sand, loamy sand, fine sand, and/or sand in the lower part. In Figure 1, the solum is about 90 cm thick and is relatively free of reflections in the upper part. In the lower part of the solum, low amplitude, linear reflections indicate layers composed of slightly dissimilar grain-size materials. Windsor soil has substrata that consist of stratified layers of gravel, coarse sand and/or loamy coarse sand. In Figure 1, moderate to high amplitude linear reflectors below a depth of about 1 m indicate these contrasting strata. Rock fragments, range from 0 to 10 percent by volume in the solum and from 0 to 15 percent in the substratum. In the lower part of the radar record, high amplitude point reflectors are believed to represent larger rock fragments.

Survey Procedures:

Prior to field work, each site was walked and reviewed with an archaeologist, and the most desirable study area(s) selected. To expedite field work, two equal length and parallel lines were established at each site. These two parallel lines defined a rectangular grid area. Survey flags were inserted in the ground at equal intervals (50 cm) along each of these two lines. For positional accuracy, surveys were completed by stretching and sequentially moving a reference line between similarly numbered flags on the two parallel grid lines.

Pulling the 400 MHz antenna along a reference line that was stretched between similarly numbered flags on the two parallel survey lines completed a GPR traverse. Along the reference line, marks were spaced at 1-m intervals. As the antenna was towed passed each reference point, a vertical mark was impressed on the radar record. Walking, in a back and forth manner, along the reference line, which was moved between similarly numbered flags on the two parallel survey lines, completed the GPR survey.

Use of GPR for Archaeological Investigations:
A favorable feature of GPR is its ability to detect soil disturbances and the intrusion of foreign materials. GPR is therefore a useful tool for locating burials (Bevan, 1991; Gracia et al., 2000; King et al., 1993; and Vaughan, 1986). However, results vary with soils. In some soils, rates of signal attenuation are so severe that GPR cannot profile to the required depths. Even under favorable site conditions (i.e. dry, coarse-textured soils) the detection of a burial is never guaranteed with GPR. The detection of burials is affected by (i) the electromagnetic gradient existing between the feature and the soil, (ii) the size, depth, and shape of the buried feature, and (iii) the presence of scattering bodies within the soil (Vickers et al., 1976).

The amount of energy reflected back to an antenna from a burial is a function of the dielectric gradient that exists between the buried feature and the undisturbed soil. The greater or more abrupt the difference in electromagnetic properties between the buried feature and the undisturbed soil, the greater the amount of energy that is reflected back to the antenna, and the more intense will be the amplitude of the reflection recorded on the radar record.

Burials with electromagnetic properties similar to the surrounding soil matrix are poor reflectors of electromagnetic energy and are difficult to detect on radar records (Vaughan, 1986; Bevan, 1991). Most burials initially contrast with the surrounding soil matrix. Biological tissues have high electrical conductivity that severely attenuates the radar signal (Hammon et al., 2000). This results in a zone of no or low amplitude reflections directly beneath recently buried cadavers. With the passage of time, corpses decay and become less attenuating and electrically contrasting with the surrounding soil matrix. The preservation of a corpse depends upon the length of burial, soil type, moisture content, temperature, flora and fauna (Killam, 1990). Corpses deteriorate more rapidly in highly acidic soils than in neutral or alkaline soils (Mellett, 1992). As most unmarked Native American burials along the Missisquoi River are greater than 200 years old, corpses have deteriorated to such an extent that they are electrically similar to the soil.

Corpses may be buried in sacks, body bags, or in wooden, fiberglass, composite, or metal caskets. Metallic or lead coffins and burial vaults provided large and contrasting interfaces that produce strong, recognizable radar reflections. If a coffin is intact, an air-filled void exists, which is generally detectable with GPR. Bevan (1991) was successful in detecting burials that consisted of intact coffins, but not burial that consisted of collapsed, soil-filled coffin or bones alone.

At many sites, the most distinctive feature of a grave is the disturbed soil materials that fill and cover the grave shaft (Bevan, 1991). Bevan (1991) noted that it is more likely that GPR will detect the disturbed soil within a grave shaft, a partially or totally intact coffin, or the chemically altered soil materials, which directly surrounds a burial rather than the bones themselves. Refilled excavations contain disturbed soil materials that are mixed and have electrical properties that contrast with the surrounding, undisturbed soils (Bevan, 1991; Miller, 1996). Often, investigators rely on the presence of soil disturbance to identify burials. However, in soils that lack contrasting horizons or geologic strata, the detection of disturbances or grave shafts is improbable. In addition, with the passage of time, the signs of disturbances are erased by natural soil-forming processes.

The depth and size of a burial affect detection. Burials may range in depth from shallow (<50 cm) to very deep (>150 cm). Large, electrically contrasting features reflect more energy and are easier to detect than small, less contrasting features. Small, deeply buried features are more difficult to discern on radar records. Bones are generally too small to be distinguished with GPR (Killam, 1990; Bevan, 1991). In addition, bones are electrically similar to dry soil materials and rock fragments (Davis et al., 2000).

The shape and orientation of a subsurface anomaly may suggest its identity. Subsurface anomalies that are narrow and linear may suggest burials. Burials may be uniformly spaced or aligned in a particular direction. Bartel (1982) observed burials aligned with the orientation of the solar traverses. Multiple elongated subsurface anomalies occurring at a common depth suggest burials.

In soils such as the Au Gres and Windsor, burials are difficult to distinguish because of the presence of stratified or segmented soil layers and occurrence of rock fragments, tree roots, and animal burrows. Vaughan (1986) and Bevan (1991) found graves identification complicated by rock fragments, which introduced unwanted clutter and complicate the interpretation of radar records.

In the search for burials with GPR, success is never guaranteed. Even under ideal site and soil conditions, burials will be missed with GPR. The usefulness of GPR for site assessment purposes depends on the amount of uncertainty or omission that is acceptable.

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 (Morey, 1974):

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

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

$$E_r = (C/V)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.3 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 E_r of a material.

The velocity of propagation is spatially variable. In areas of Windsor and Au Gres soils, based on hyperbola-matching processing techniques (the shape of a hyperbole is dependent on signal velocity), the velocity of propagation decreased with increasing depth, but over the scanned depth averaged about 0.10 m/ns (E_r of 8.9). With a scanning time of 40 ns, the maximum penetration depth was about 2.0 m.

Results:
Radar Interpretations:
Figure 2 is a radar record from an area of Windsor loamy fine sand, 0 to 3 percent slopes. The vertical scale is in meters. The white vertical lines at the top of the radar record represents equally spaced (1-m) reference points along the radar traverse line. In this figure, the outline of a recently refilled soil pit has been enclosed in a box. The backfilled materials contain mixed materials that contrast with the surrounding solum. The contrast in grain size distributions and moisture contents provides reflective surfaces that are displayed on the radar record. The refilled soil materials provide reflections whose patterns contrast with the bounding undisturbed soil materials. The refilled soil materials are indicated by hyperbolas starting near the surface with some ringing in time (depth).

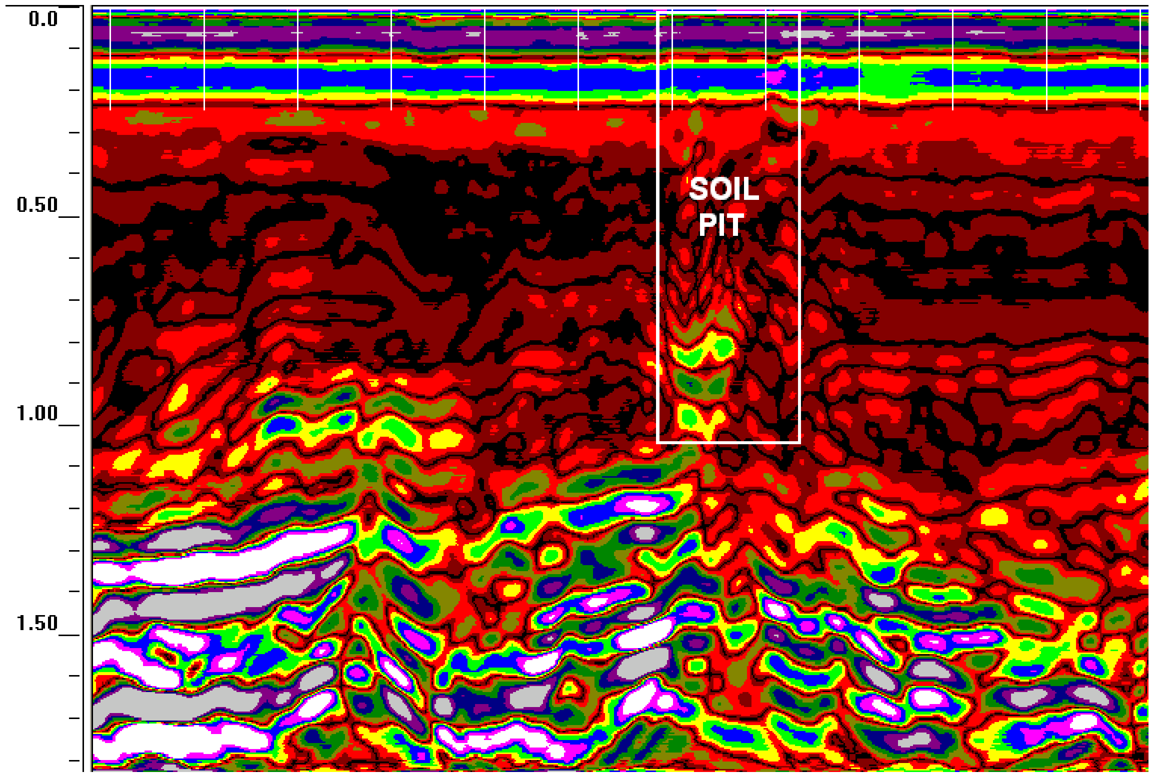

Figure 2. A recently refilled soil pit in an area of Windsor loamy fine sand, 0 to 3 percent slopes.

It is anticipated that burials may exhibit patterns similar to the recently refilled soil pit shown in Figure 2. However, reflected signal amplitudes will weaken and become indistinct on radar records with the passage of time and soil development.

<u>Three-Dimensional Interpretations of Radar Data:</u>
Three-dimensional (3D) images allow the rapid display of composite radar data from various viewing angles. To construct 3D images, a relatively small area is intensively surveyed with closely spaced (typically 0.2 to 0.5 m), parallel GPR traverse lines. The relatively dense network of traverse lines is necessary to resolve the geometries and sizes of different subsurface features and to prevent spatially aliasing of the data (Grasmueck and Green, 1996).

Three-dimensional interpretations of GPR data have been used to identify burials, middens, and other cultural features (Conyers and Goodman, 1997, Whiting et. al, 2000). In the past, the use of 3-D images has been restricted because only analog signals were recorded and the lack of suitable software. The recent use of digital signals and the development of sophisticated signal-processing software has enabled signal enhancement and improved pattern-recognition on radar records.

Results:
Fournier Site:
The site is located in a pasture. The dimensions of this grid were 34- by 26-m. Traverse lines were 34-m long, orientated in essentially an east-west direction, and spaced 50 cm apart. Pulling the 400 MHz antenna along 53 equally spaced (50-cm) survey lines completed the GPR survey. The origin (X=0, Y=0) of the grid was located in the northeast corner of the site.

Figure 3 contains four time-slice images of the Fournier Site. In Figure 3, all distance units are expressed in meters. The origin is located in the lower left-hand corner (northeast corner of grid area) of each slice. The three horizontal "time-slices" represent depths of about 0, 60, and 120 cm. These depths are based on an averaged signal propagation velocity of 0.10 m/ns through the soil. The width of each time-slice is about 25 cm.

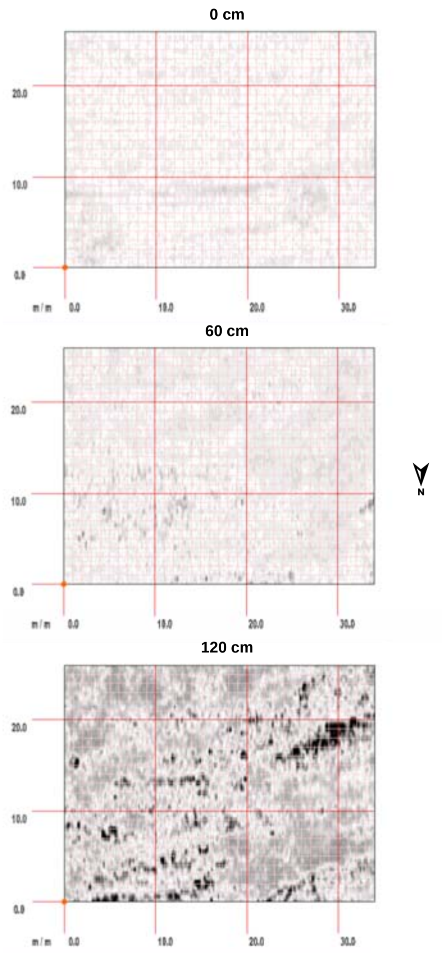

Figure 3. Time sliced images of the Fournier Site.

In Figure 3, the shallowest (0 cm) slice is nearly devoid of reflections. Reflections that appear in this slice are of very low amplitudes and indistinct. The absence of moderate to high amplitude signals in this slice indicate very similar soil properties (moisture, density, texture) at very shallow (< 10 inches) depth across this site. In the 60 cm slice, several anomalous areas of low and moderate amplitude reflections punctuate the pervasive very low amplitudes. These anomalies are most evident in the northern (lower) part of the site. The reflections are generally dispersed throughout this area, and assume crude southwest to northeast alignments. Because of these alignments, amplitude anomalies are assumed to principally represent the stratified and contrasting layers of the substratum. The 150 cm slice contains a greater abundance of higher amplitude reflections that are believed to represent cobbles and dissimilar stratigraphic layers in the underlying materials.

Several anomalies with radar signatures suggesting refilled pits and/or possible burials were identified on the radar records and located in the grid. This area will be investigated by an archaeologist.

Spaulding Site:
The site is located in the lawn of the Spaulding residence. The dimensions of this grid were 19- by 14-m. Traverse lines were 19-m long, orientated in essentially a north-south direction, and spaced 50 cm apart. Pulling the 400 MHz antenna along 29 equally-spaced (50-cm) survey lines completed the GPR survey. The origin (X=0, Y=0) of the grid was located in the southeast corner of the site.

Figure 4 contains three time-slice images of the Spaulding Site. In Figure 4, all distance units are expressed in meters. The origin is located in the lower left-hand corner (southeast corner of grid area) of each slice. The three horizontal "time-slices" represent depths of about 30, 80, and 120 cm. These depths are based on an averaged signal propagation velocity of 0.10 m/ns through the soil. The width of each time-slice is about 25 cm.

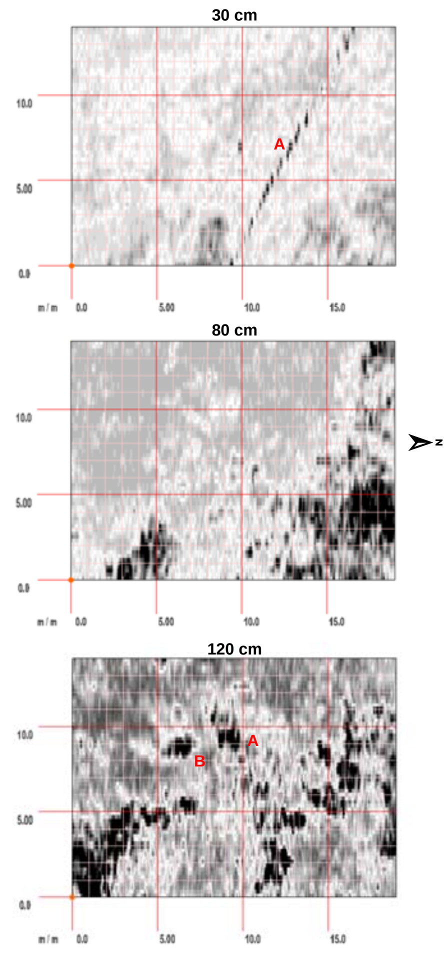

Figure 4. Time sliced images of the Spaulding Site.

In Figure 4, the 30 cm slice shows a linear feature (A) that was identified as a buried propane gas line. The broad, patchy areas of high amplitude reflections in the lower east-central portion and the northeast corner of this slice are believed to represent contrasting strata in the lower part of the Windsor profile. These areas expand in size and increase in amplitude in the 80 cm slice. A general northwest to southeast alignment in these reflections is evident in this slice. In the 120 cm slice, the two broad, patchy areas of high amplitude reflections appear to have shifted to the south. This trend suggests inclined strata and subtle changes in the elevation. Two conspicuous anomalies (*A* and *B*) have been identified in this slice. *A* corresponds with a planted shrub. The identity of *B* is unknown, but will be investigated by an archaeologist. No features on radar profiles or time-sliced images can be unambiguously identified as a burial. Excessive levels of background noise from soil horizons and subsurface strata complicate radar records and, if present, mask the identification of burials.

Taylor Site:

The site is located in the lawn of the Taylor residence in the area immediately south of Monument Road. The dimensions of this grid were 30- by 7-m. Traverse lines were 30-m long, orientated in essentially an east-west direction, and spaced 50 cm apart. Pulling the 400 MHz antenna along 15 equally-spaced (50-cm) survey lines completed the GPR survey. The origin (X=0, Y=0) of the grid was located in the southwest corner of the site. Monument Road parallels the northern (upper) boundary of each slice.

Figure 5 contains four time-slice images of the Taylor Site. In Figure 5, all distance units are expressed in meters. The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The four horizontal "time-slices" represent depths of about 0, 50, 100 cm, and 150 cm. These depths are based on an averaged signal propagation velocity of 0.10 m/ns through the soil. The width of each time-slice is about 25 cm.

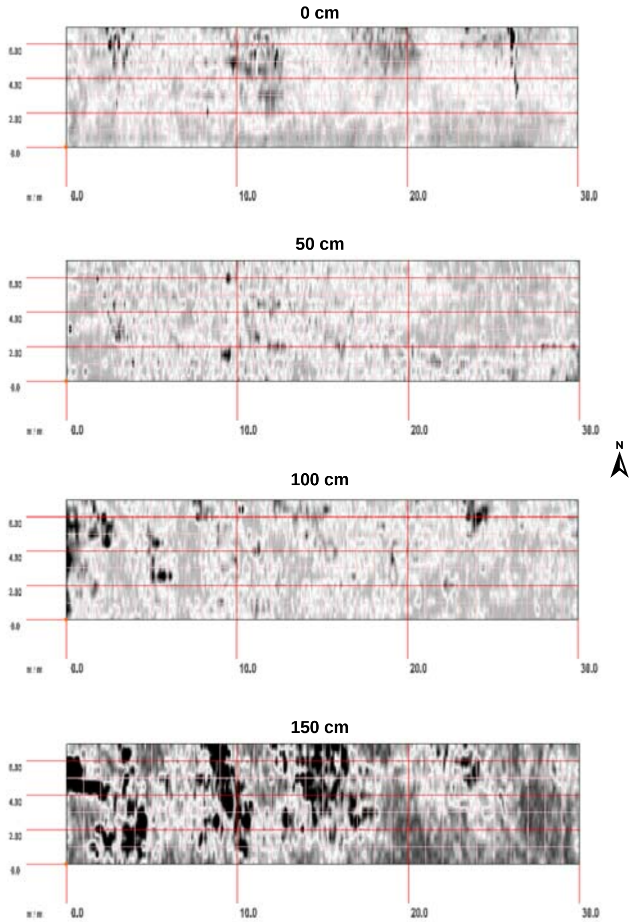

Figure 5. Time sliced images of the Taylor Site.

In Figure 5, the 0 cm slice contains several broad, moderate to high amplitude linear features that are assumed to represent differences in fill materials, soil moisture, and/or density. The number and dimensions of areas with high amplitude reflections increase with increasing soil depths (see 50, 100, and 150 cm slices). Once again, though several features are suspected, no single feature on radar records or time-sliced images was unambiguously identified as a burial. Excessive levels of background noise from soil horizons and subsurface strata complicate radar records and, if present, mask the identification of burials.

Holbrook Site:

The site is located in the lawn of the Holbrook residence in the area immediately south of Monument Road. The dimensions of this grid were 21- by 6-m. Traverse lines were 21-m long, orientated in essentially an east-west direction, and spaced 50 cm apart. Pulling the 400 MHz antenna along 13 equally-spaced (50-cm) survey lines completed the GPR survey. The origin (X=0, Y=0) of the grid was located in the southwest corner of the site.

Figure 6 contains four time-slice images of the Holbrook Site. In Figure 6, all distance units are expressed in meters. The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The four horizontal "time-slices" represent depths of about 0, 50, 100 cm, and 150 cm. These depths are based on an averaged signal propagation velocity of 0.10 m/ns through the soil. The width of each time-slice is about 25 cm.

The Holbrook Site adjoins the Taylor Site. Similar interpretations can be applied to each site. In Figure 6, the 0 cm slice contains several broad, moderate to high amplitude linear features that are assumed to represent differences in fill materials, soil moisture, and/or density. The number and dimensions of areas with high amplitude reflections increase with increasing soil depths (see 50, 100, and 150 cm slices). In the 50 and 100 cm slices, two areas with high amplitude linear reflectors extend into the grid. These areas have been labeled *A* and *B* in the 50 cm slice, and *A* in the 100 cm slice. Though linear, the lengths of these amplitude anomalies appear too long to suggest burials. Their lengths do suggest buried utilities. Once again, though several features are suspected, no single feature on radar records or time-sliced images was unambiguously identified as a burial. Excessive levels of background noise from soil horizons and subsurface strata complicate radar records and, if present, mask the identification of burials

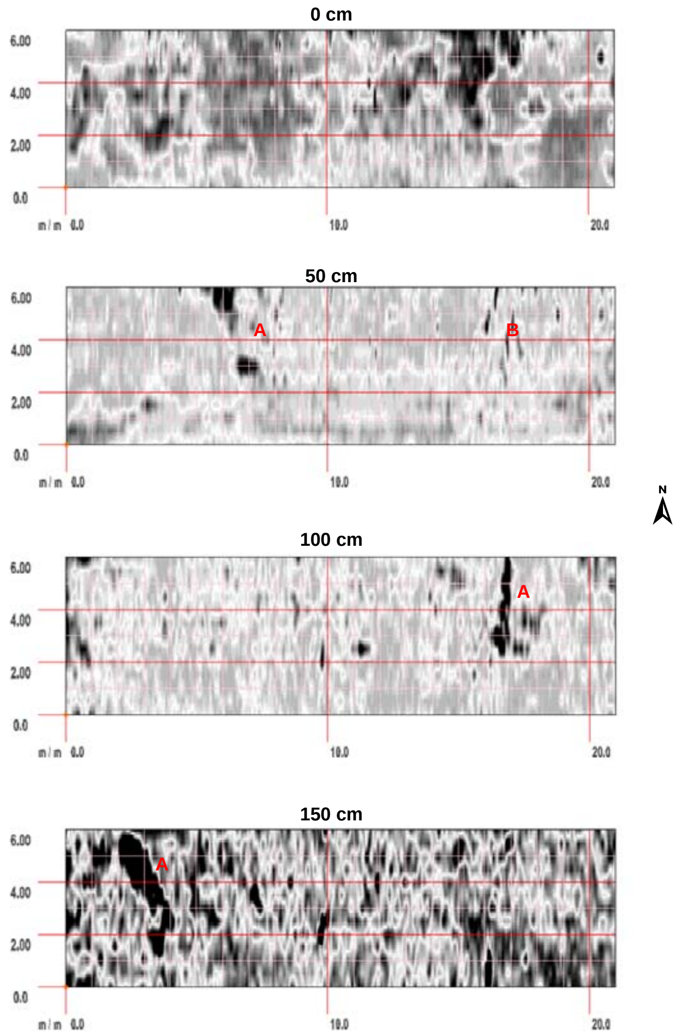

Figure 6. Time sliced images of the Holbrook Site.

Monument Site:

The site is located to the immediate east of the *Monument* to the Missisquoi /Mazipskoik Abenaki Tribe on Monument Road. This site contains known artifacts and burials. Grid dimensions were 20- by 14-m. Traverse lines were 20-m long, orientated in essentially an east-west direction, and spaced 50 cm apart. Pulling the 400 MHz antenna along 29 equally-spaced (50-cm) survey lines completed the GPR survey.   The origin (X=0, Y=0) of the grid was located in the southwest corner of the site.

Figure 7 contains three time-slice images of the Monument Site. In Figure 7, all distance units are expressed in meters.   The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The three horizontal “time-slices” represent depths of about 50, 100 cm, and 150 cm. These depths are based on an averaged signal propagation velocity of 0.10 m/ns through the soil. The width of each time-slice is about 25 cm.

The survey of the Monument Site provides radar records and 3D imagery from an area with known Native American artifacts and burials. The time-sliced images in Figure 7 are basically similar to the images seen in figures 3, 4, 5, and 6. Monument Site has a long history of occupation and use. It has been repeatedly disturbed. In Figure 7, moderate to high amplitude reflectors do not increase monotonously with depth. However, patterns remain broad and patchy suggesting undisturbed materials at greater soil depths. Three-dimensional time-slice analysis appears ill suited for the identification of Native American burial grounds in Vermont.

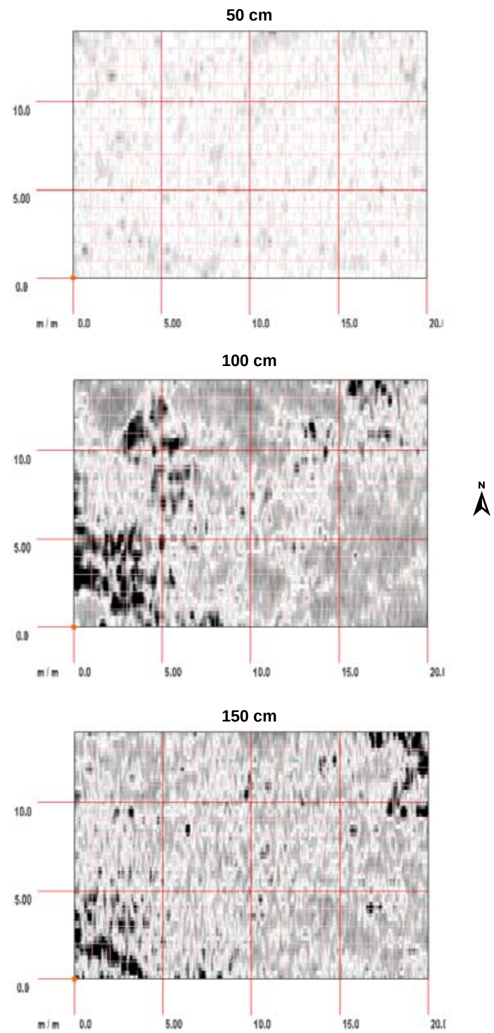

Figure 7. Time sliced images of the Monument Site.

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