**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: MGT – Trip Reports – Delayed Reports

June 25, 2012

TO: Vicky Drew
State Conservationist
Natural Resources Conservation Service
Colchester, Vermont

File Code: 330-20-7

The enclosed trip report is being distributed much later than it should have been according to our policy. I am offering no excuses, but processing and distribution of the trip reports were delayed because of changes to administrative assistant duties following the transfer of one of our administrative assistants to another office. All blame for the delay belongs to me for not following up on the proper processing and distribution of these reports.

Please let me assure you the issue has been resolved, and trip reports will be prepared, processed, and distributed as expediently as possible in the future.

Sincerely,

LARRY T. WEST
National Leader
Soil Survey Research and Laboratory

**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) 437-5321

**SUBJECT**: SOI – Geophysical Assistance

June 5, 2012

**TO**: Vicky Drew
State Conservationist
Natural Resources Conservation Service
Colchester, Vermont

**File Code**: 330-20-7

**Purpose:**

The purpose of this study is to develop field methodologies and data analysis procedures for the rapid identification, classification, and delineation of subaqueous soils and landscapes from copious ground-penetrating radar (GPR) data sets collected over ice-covered water bodies. Radar data and terrain analysis procedures will be used to identify differences in substrates and distinguish different subaqueous soil-landscape units based on bathymetry, slope, landscape shape, sediment type, and geographical location.

**Participants:**

Jim Doolittle, Research Soil Scientist, NSSC, USDA-NRCS, Newtown Square, PA
David Frisque, Park Ranger, U.S. Fish and Wildlife Service, Missisquoi National Wildlife Refuge, Swanton, VT
Joshua Paul, Soil Scientist, USDA-NRCS, Paul Smiths, NY
Gerald Smith, MLRA Soil Survey Office Leader, USDA-NRCS, Paul Smiths, NY
Thomas Villars, Resource Soil Scientist, USDA-NRCS, White River Jct, VT

**Activities:**

On February 14 and 15, personnel from the National Soil Survey Center (NSSC), the Vermont NRCS Soil Resource Staff, MLRA 142 Office, and U.S. Fish and Wildlife Service's Missisquoi National Wildlife Refuge (NWR) used a mobile GPR platform to compile more than 53 km (33 miles) of continuous, geo-referenced GPR data recordings across ice-covered portions of Missisquoi and Maquam Bays in northwestern Vermont.

**Summary:**

1. In a two day period, more than 50 kilometers of geo-referenced GPR data was compiled across Missisquoi and Maquam Bays. This effort resulted in more than 510,500 geo-referenced water-depth measurements that were semi-automatically picked from the radar records using processing software. The northeastern portion of Missisquoi Bay was surveyed to the Canadian border. Using a velocity of propagation of 0.0335 m/ns (dielectric permittivity of 80) and based on 374,444 radar picks, in the traversed areas of Missisquoi Bay, the average water depth was 4.44 m with a range of 0.52 to 6.43 m. The northern portion of Maquam Bay was also surveyed. Here, based on 136,085 radar picks, in the traversed areas, the average water depth was 3.03 m with a range of 0.31 to 9.92 m.

2. We greatly appreciate the help of Reed Sims, GIS Specialists, Colchester, Vermont, in assisting with this project and digitizing the outlines of both Missisquoi and Maquam Bays.

3. This year, as the areas traversed on Missisquoi and Maquam Bays with GPR are deeper than those traversed last year on Missisquoi Bay, a lower frequency 120 MHz antenna was used. Energy transmitted from this antenna was less rapidly attenuated than energy transmitted from the higher frequency, 200 MHz antenna, which was used last year. The 120 antenna provided excellent imagery with low levels of background noise to depths as great as 9 meters (27 feet).

4. Survey work was halted by antenna problems on the second day before the completion of all the planned survey work. Water from melting snow had flowed thru a gasket and onto the 705DA transreceiver board on the 120 MHz antenna, shorting the circuit board and causing the stoppage of signals to the SIR3000. The unit will be returned to manufacturer for repairs.

5. As part of this study, Dr. Zamir Libohova (Research Soil Scientist, Soil Survey Research & Laboratory, NSSC) will use GPR data and terrain analysis techniques to quantify terrain parameters (e.g., slope and landform units). This methodology will be used to identify subaqueous soil-landscape units, which can be used to partition submersed areas into more homogenous map units.

6. All interpreted radar data have been forwarded in Excel worksheet formats to Thomas Villars and Dr. Zamir Libohova.

It is the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance to your staff in this study.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

Attachment (Technical Report)

cc:
David Clausnitzer, Acting State Soil Scientist/MLRA Office Leader, USDA-NRCS, Amherst, MA
James Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Newtown Square, PA
Zamir Libohova, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
John Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Wilkesboro, NC
Thomas Villars, Resource Soil Scientist, NRCS, White River Jct., VT
Larry West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Michael Wilson, Research Soil Scientist/Liaison MO12, Soil Survey Research & Laboratory, NSSC, MS 41, Lincoln, NE
Gerald Smith, MLRA Office Leader, NRCS, Paul Smiths MLRA Soil Survey Office, Paul Smiths, NY

**Technical Report on Subaqueous Soil Pilot Mapping Project: Missisquoi and Maquam Bays, Vermont, on February 14 and 15, 2012**

**Jim Doolittle**

**Background:**

> "The concept that sediments in shallow water environments undergo soil forming processes, are capable of supporting rooted plants, and meet the definition of soil according to the criteria defined in Soil Taxonomy has been moving soil scientists into a new frontier of soil survey – mapping subaqueous soils." (Jim Turenne, Soil Scientist, USDA-NRCS, Rhode Island; http://nesoil.com/sas/sasinfo.htm).

Subaqueous soils occur under both fresh and salt waters. These soils have the ability to support rooted plants in natural environments. The maximum water depth limit for subaqueous soils is presently set at 2.5 meters. This depth limit is assumed to represent the "*normal*" maximum depth below which most emergent vegetation will not grow. However, in some areas, emergent vegetation is known to grow at deeper depths.

In order to document, map, and classify subaqueous soils, it is important to have knowledge of water depths, bottom topography, sediment types and thickness, and subaqueous processes. Over open water, acoustical fathometers and acoustic sub-bottom profilers (SBP), and radio-frequency ground-penetrating radar (GPR) have proven to be effective in providing information on water depths, bottom topography, sediment types and thickness (Feurer et al., 2008). However, over open-water these methods, because of drift, often suffer from imprecise positioning with adverse implications to subsequent ground-truth verification of interpretations and the selection of core sites (Moorman and Michael, 1997). In northern latitudes, GPR can also be used on ice, which provides a more stable platform for the more accurate positioning of core sites and the completion of traverses (Hunter et al., 2003).

Ground-penetrating radar has been used extensively for bathymetric surveys of fresh water lakes (Doolittle et al., 2010; Fischer et al., 2007; O'Driscoll et al., 2006; Buynevich and Fitzgerald, 2003; Hunter et al., 2003; Moorman, 2001; Moorman and Michel, 1997; Mellett, 1995; Sellmann et al., 1992; Izbicki and Parker, 1991; Truman et al., 1991; Haeni et al., 1987) and rivers (Sambuelli et al., 2009; Feurer et al., 2008; Spicer et al., 1997; Kovacs, 1991; Annan and Davis, 1977). In these studies, GPR provided continuous, highly detailed, two-dimensional records of subbottom-sediment type, thickness, and topography. These studies illustrate how GPR can provide more comprehensive coverage of bottom and subbottom conditions than possible from core data alone. Traditional coring methods are labor intensive, and have very high cost/area ratios (Feurer et al., 2008). As a consequence of these high costs, the number of cores is limited. Limited measurements and observations can result in an oversimplification of relatively complex subaqueous environments (Stevens et al, 2009). Ground-penetrating radar can provide copious, continuous records of subaqueous substrates, soils, and landforms. Acceptable radar interpretations, however, require a small, but still sufficient number of cores for verification.

In reported studies conducted in low-conductivity waters, GPR has been used to identify the water / bottom-sediment interface to depths as great as 22 to 25 m, and provide accurate and detailed bathymetric cross-sections and contour-maps (Moorman and Michel, 1997; Delaney et al. 1992; Sellmann et al., 1992). Moorman and Michel (1997) reported an accuracy of ± 3% for GPR measurements of lake bottoms to depths as great as 19 m. However, in conductive waters, GPR is greatly restricted. The use of

GPR in brackish or salt waters is impractical because of their high electrical conductivity and attenuation rates, which severely restricts penetration.

The purpose of this investigation is to obtain data with GPR on water depths, bottom topographies, and sediment types within the eastern portion of Missisquoi Bay and the northern portion of Maquam Bay, Vermont. This information will be used to develop field methodology and data processing techniques for the rapid assessment and mapping of subaqueous soils in bodies of fresh water.

**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 9 lbs (4.1 kg) and is backpack portable. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 120 MHz antenna was used in this study.

Recent technical developments allow the integration of GPR and GPS data. The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be geo-referenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows (version 6.6) software program (GSSI) can be 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.[1] 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 time interval of one second along GPR traverse lines. The scanning rate of the GPR was set at 24 scan/sec.

The RADAN for Windows (version 6.6) software program was used to process the radar records. Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). Using the *Interactive 3D Module* of the RADAN, depths to the water/bottom-sediment interface were semi-automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including latitude, longitude, depths to interface or layer, and other useful data).

**Field Methods:**
Mobile GPR surveys were conducted across the ice-covered portions of Missisquoi and Maquam Bays. A 4x4 wheel drive, Kawasaki *Mule* (Figure 1) was used as a mobile platform to rapidly complete the GPR surveys.[1] The 120 MHz antenna was towed behind the ATV. Over a 2 day period, more than 31.6 km (19.6 miles) and 22 km (13.7 miles) of continuous, geo-referenced GPR data were recorded over Missisquoi and Maquam Bays, respectively. During these surveys, no ground-truth core observations were taken to confirm interpretations and scale the radar imagery. Depth scales and radar interpretations are based on information gathered during the February 2011 survey of Missisquoi Bay. Average ice thickness was estimated to be 50 and 36 cm (20 and 14 inches) at the times of the February 2011 and 2012 surveys, respectively.

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

*Figure 1. This mobile GPR platform was used to survey portions of Missisquoi and Maquam Bays.*

**Calibration:**
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, stratigraphic layer, lake bottom) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to the 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 (Daniels, 2004):

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

The velocity of propagation is dependent upon the relative dielectric permittivity ($E_r$) of the profiled material(s). Relative dielectric permittivity is a dimensionless, complex number. The relationship between $E_r$ and $v$ is embedded in the large dielectric contrast between water (~80) and air (~1) and is expressed in the equation (Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In earthen materials, the amount and physical state (temperature dependent) of water have the greatest effect on the $E_r$ and $v$.

Estimating $E_r$ and $v$ over variable hydrothermal structures is a challenging task. Ground-truth core data had been collected at several *reference* or *calibration points* along GPR traverse lines in February 2011. Based on data from 10 calibration points, the average $v$ though a column of snow, ice, and shallow water was 0.0476 m/ns, but actual values ranged from about 0.0355 to 0.0776 m/ns. The average $E_r$ through this column was 48.6, but actual values ranged from about 15 to 71.3. At some core sites, there was essentially no water column and the probe went from ice directly into subaqueous soil materials. The velocity of propagation increases and the dielectric permittivity decreases as the water column shallows and the relative thickness of the ice column increases (compared with underlying water column). Ice has an $E_r$ that ranges from 3.5 to 8 (Kovacs and Morey, 1990); water has an $E_r$ of about 80.1 at 20 ° C, but is frequency and temperature (its 88 at 0 ° C) dependent (Daniels, 2004). The $E_r$ of ice decreases and the $v$ increases with increasing snow and ice thickness (Kovacs and Morey, 1990). The dielectric permittivity of the snow cover is a function of its density and unfrozen liquid water content (Lundberg et al., 2000). The dielectric permittivity of dry snow ranges from 1 to 2, while values for wet snow have been reported to be as high as 7 (Sand and Bruland, 1998).

At the 10 calibration sites (February 2011), a high correlation ($r^2 = 0.959$) was determined between the measured two-way pulse travel time (ns) and the measured depth (m) to bottom sediments (Figure 2). A linear predictive equation was developed and used to estimate the depth to bottom sediments on radar records. This predictive equation is:

$$\text{Depth} = 0.0156*(\text{travel time}) + 0.377 \qquad [3]$$

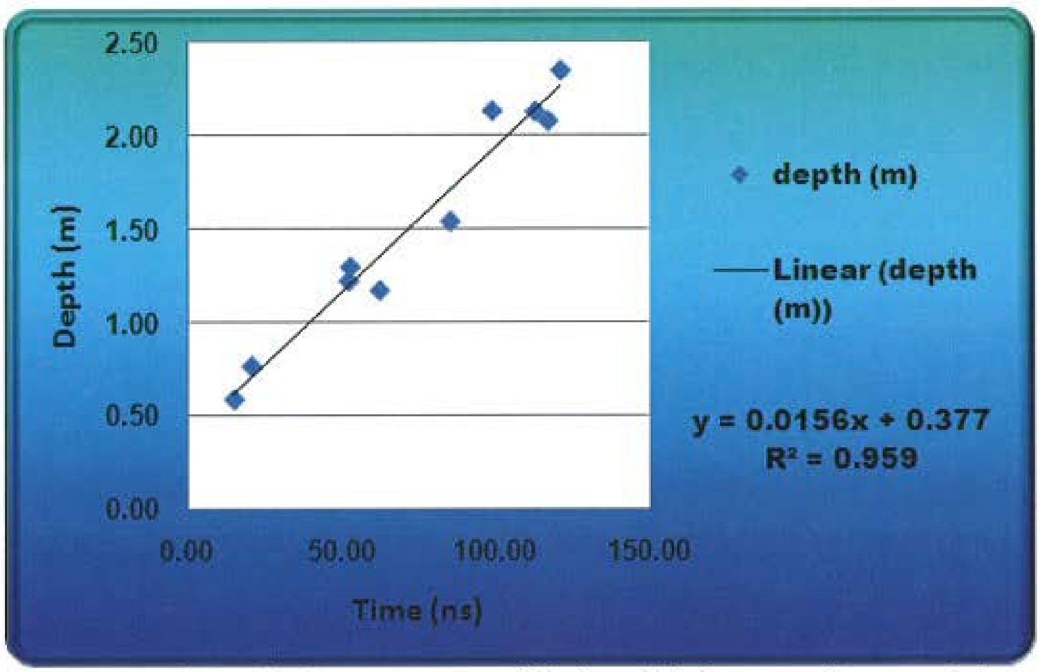


*Figure 2. Relationship between measured depths to lake bottom-sediments and the two-way pulse travel time of the GPR.*

Table 1 examines the relationship between the two-way pulse travel time and the measured depths to bottom sediments at the 10 calibration points. Using equation [3], the estimated depths to bottom sediments are listed in column 3 of this table. The average difference between measured and estimated depths to bottom sediments (column 4) is 10 cm, with a range or 3 to 21 cm.

Table 1. Measured two-way pulse travel time and depths to bottom sediments, and the estimated depths from equation [3].

| Time (ns) | Depth (m) | Estimated Depth | Difference |
|---|---|---|---|
| 15.06 | 0.58 | 0.61 | 0.03 |
| 20.71 | 0.76 | 0.70 | -0.06 |
| 52.24 | 1.22 | 1.19 | -0.03 |
| 52.79 | 1.30 | 1.20 | -0.09 |
| 62.35 | 1.17 | 1.35 | 0.18 |
| 85.29 | 1.54 | 1.71 | 0.17 |
| 98.92 | 2.13 | 1.92 | -0.21 |
| 112.94 | 2.13 | 2.14 | 0.01 |
| 117.06 | 2.08 | 2.20 | 0.12 |
| 121.18 | 2.35 | 2.27 | -0.08 |

**Study Sites:**

The focus of this study is the eastern portion of Missisquoi Bay in Franklin County, Vermont (Figure 3). Big Marsh Slough, Goose Bay and Gander Bay form the southern boundary, while the International Boundary forms the northern boundary of the Missisquoi Bay survey area. The southern portion of Missisquoi Bay had been surveyed in 2011. Figure 3 is a Google Earth image of the eastern portion of Missisquoi Bay showing the locations of the radar traverse lines and the color-coded, interpreted depth to bottom sediments along each line. During the present investigation, the northern portion of Maquam Bay was also surveyed Figure 4). Maquam Bay is situated about 5.5 km southwest of Missisquoi Bay. Figure 4 is a *Google Earth* image of Maquam Bay showing the locations of the radar traverse lines and the color-coded, interpreted depth to bottom sediments along each line.

**Results:**

Figures 3 and 4 are *Goggle Earth* images of the areas that were surveyed with GPR. In each image, the locations of the GPR traverse lines are shown. Each traverse line is colored-coded based on the interpreted depth to the water/bottom-sediment interface. The estimated depths that are shown in these figures are based on an average $v$ of 0.046 m/ns and an $Er$ of 42.5 (not the estimated and *preferred* depths derived from equation [3]).

Using the Equation [3], the thickness of the ice-water column was estimated based on the scanning time to the water/bottom sediment interface shown on the radar records. Figures 5 and 6 represent two-dimensional contour plots of the bathymetry of Missisquoi Bay and Maquam Bay, respectively. Using Equation [3], based on 787,133 radar picks (compiled in 2011 and 2012), the surveyed portion of Missisquoi Bay has an average depth of 2.51 m with a range of 0 to 4.74 m. Using Equation 3, based on 136,087 radar picks, the surveyed portion of Maquam Bay has an average depth of 2.41 m with a range of 0 to 7.11 m.


*Figure 3. This Google Earth image shows the locations of GPR traverses and the interpreted water depths for the portion of Missisquoi Bay that were surveyed with GPR in 2011 and 2012. (Imagery courtesy of Brian Jones, GSSI, Salem, NH).*

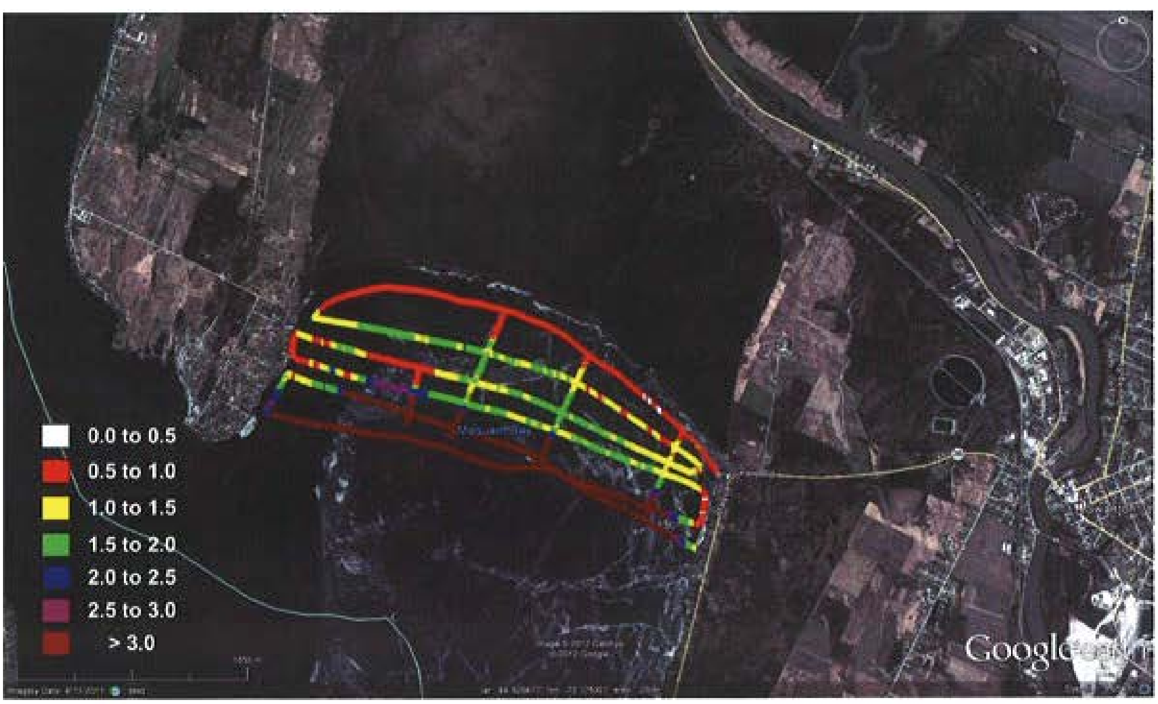


*Figure 4. This Google Earth image shows the locations of GPR traverses and the interpreted water depths for the portion of Maquam Bay that were surveyed with GPR in 2012. (Imagery courtesy of Brian Jones, GSSI, Salem, NH).*

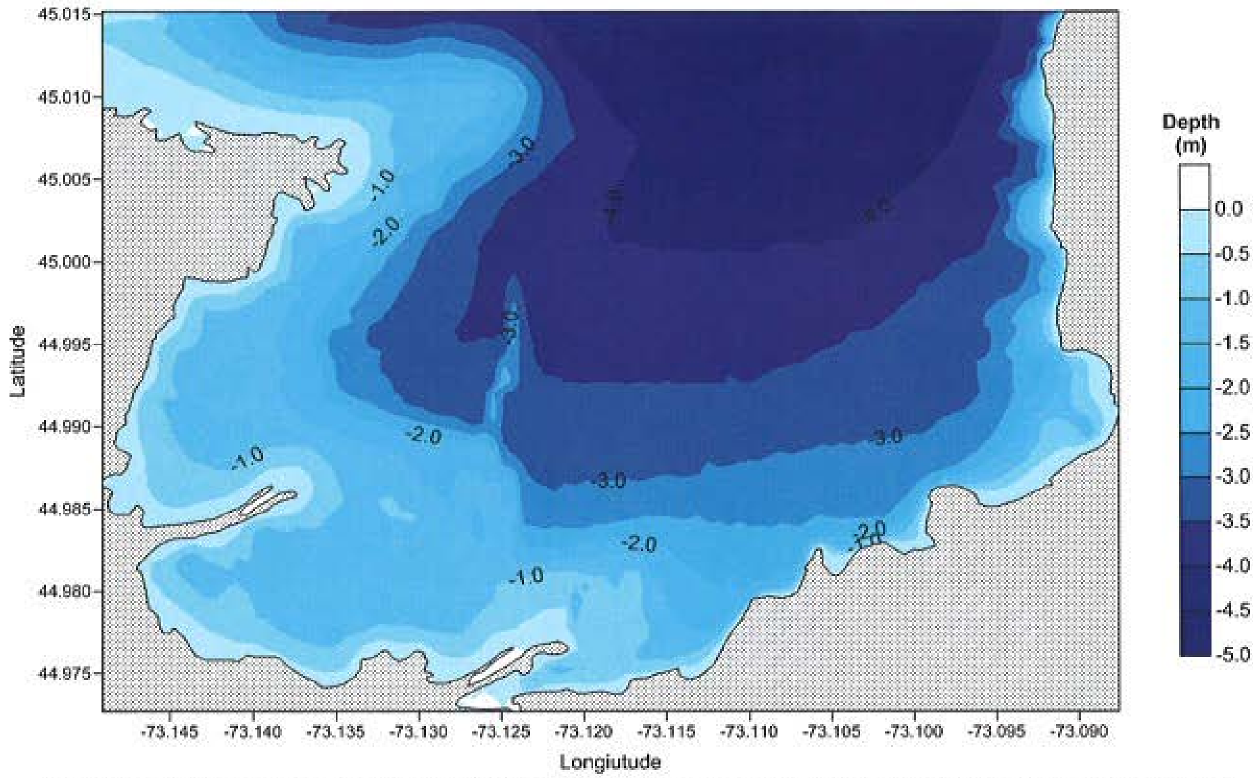


*Figure 5. This two-dimensional plot shows the interpreted water depths for the portion of Missisquoi Bay that have been surveyed with GPR.*

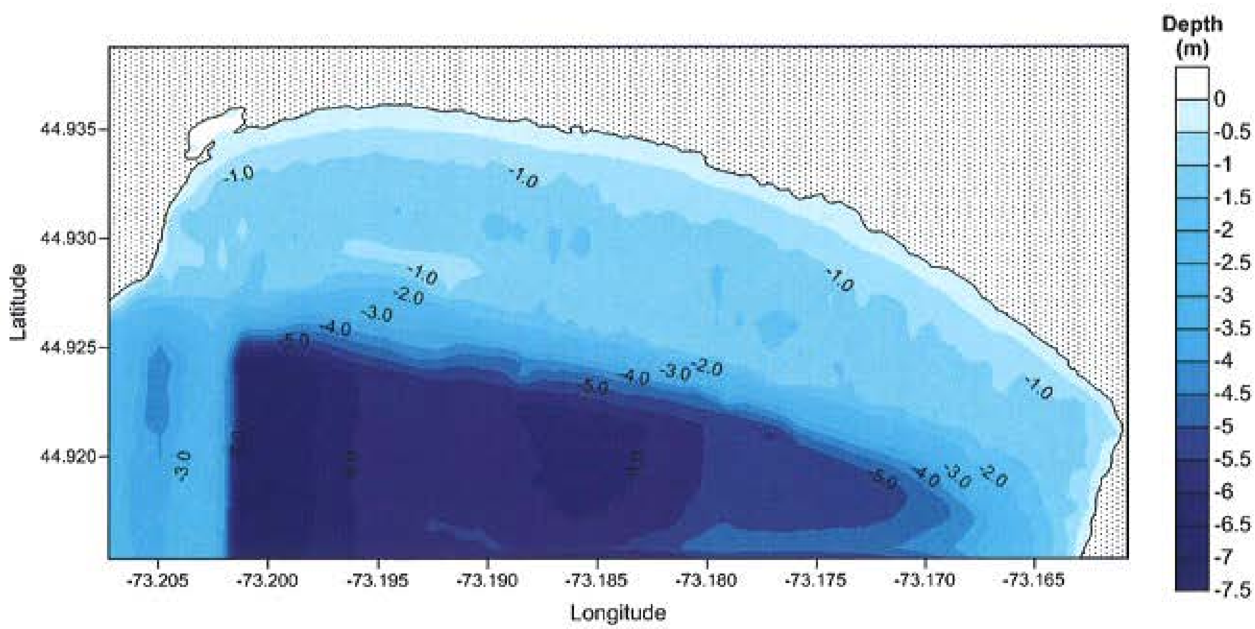


*Figure 6. This two-dimensional plot shows the interpreted water depths for the portion of Maquam Bay that have been surveyed with GPR.*

**Radar Facies:**

The bottom sediments of Missisquoi and Maquam Bays can be differentiated on the basis of radar facies analysis. A *radar facies* is a mappable 3D unit composed of GPR reflections whose parameters (internal reflection patterns and characteristics) differ from adjoining units. Based on distinctive reflection patterns three major facies were identified across the surveyed portions of Missisquoi and Maquam Bays: lacustrine silts, bedrock, and stratified deposits. Radar records of these facies are shown below:

Undulating Lacustrine Silts:

Figure 7 is an example of lacustrine silt deposits from Maquam Bay. Depth of penetration is limited by layers having relatively high silt and clay contents. In general there is an absence of subbottom reflectors do to high signal attenuation rates.

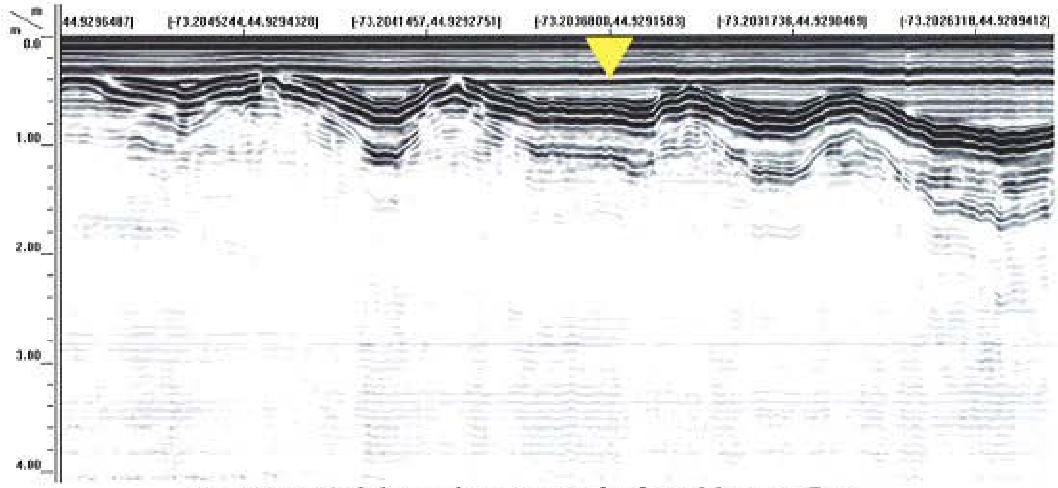


*Figure 7. Undulating lacustrine silts from Maquam Bay.*

Stratified Deposits:

These relatively coarse textured deposits have noticeable planar reflectors. Because of the lower clay and silt contents, attenuation is less rapid and deeper subbottom depths can be obtained in stratified deposits. Figures 8 and 9 are representative of the stratified deposit facies. In Maquam Bay, bottom relief was more variable over short distances than in Missisquoi Bay. As a consequence, an "undulating" phase is recognized.

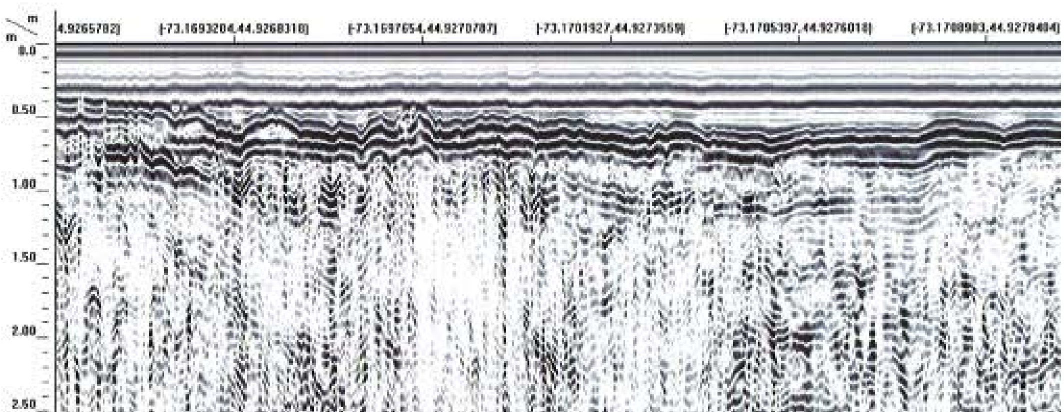


*Figure 8. Stratified deposits from Maquam Bay.*

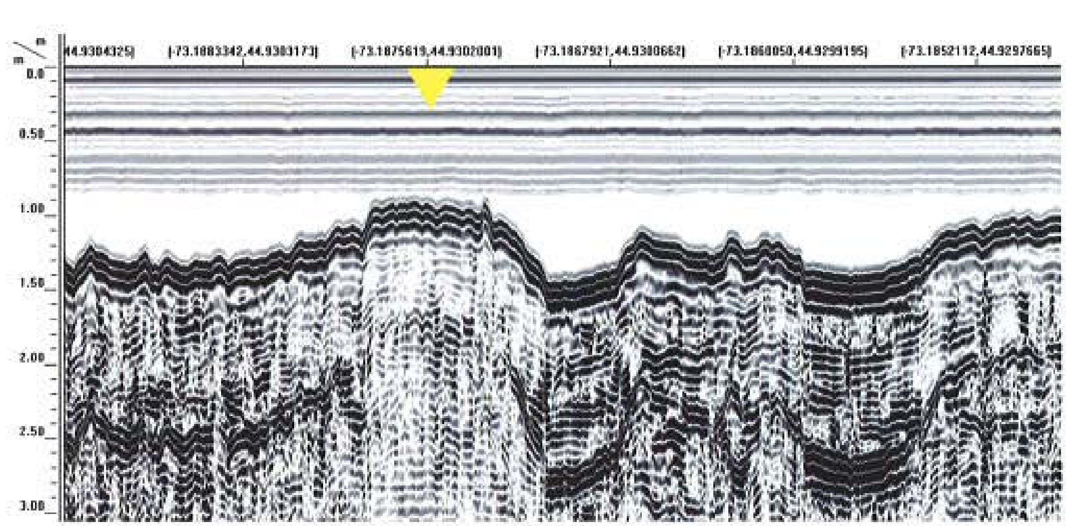


*Figure 9. Undulating stratified deposits in Maquam Bay.*

Rock Outcrop:
Figure 10 is a representative profile of a rock outcrop at the bottom of Missisquoi Bay. The rock projects from the bottom sediments and divides Missisquoi Bay into two parts. It is locally referred to as the "ledge".

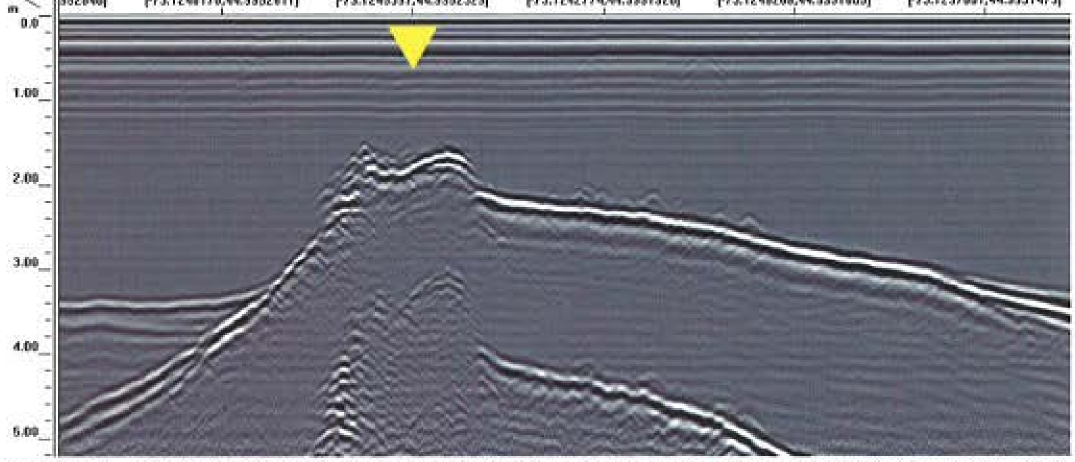


*Figure 10. Bedrock projects through the bottom sediment in this portion of Missisquoi Bay.*

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