Anatomy of Glaciotectonic Folding and Thrusting Imaged Using GPR in the Ashley Schiff Preserve, Stony Brook, NY

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Introduction

The geology of Long Island is dominated by the Harbor Hill Moraine and the Ronkonkoma Moraine, the various parts of which exhibit a range of similar glaciotectonic structures and landforms, but at the same time differ in many significant ways. The Stony Brook area, located on the Harbor Hill Moraine, exhibits a less regular topography than found at Hither Hills on the south fork. The lack of such a trend, as well as evidence for a late diamict, suggest that this part of the moraine is the result of a complex series of depositional, faulting, and folding processes that may well have occurred subglacially.

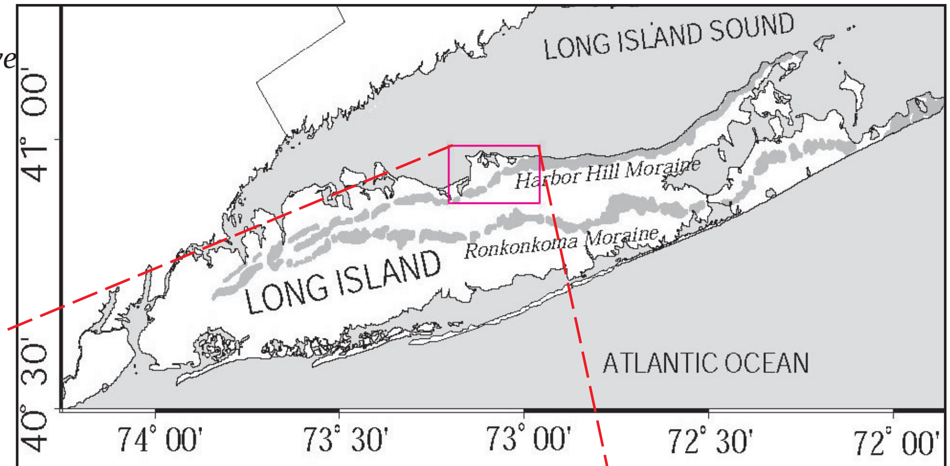
A site that serves as a relatively undisturbed place to study the complex interplay of various glacial processes is the Ashley Schiff Preserve at Stony Brook University. The hills of this 27-acre preserve are well-defined and clearly exhibit characteristics that are expected in relation to glaciotectonic topography. In order to understand better the structural patterns and trends and to further analyze the glaciotectonic processes that formed the Ashley Schiff Preserve's surface, we must examine the subsurface. Ground-penetrating radar (GPR) provides us with the ability to examine the structural trends to sufficient depth to allow us to examine more closely the processes that occurred to produce the topography of this part of the moraine. The results of the GPR imaging of sediments in the Ashley Schiff Preserve suggest a complex combination of glacial push structures along with subglacial deposition and removal of material and only a small amount of post-glacial erosion of the tops of hills and deposition in low areas.

Background

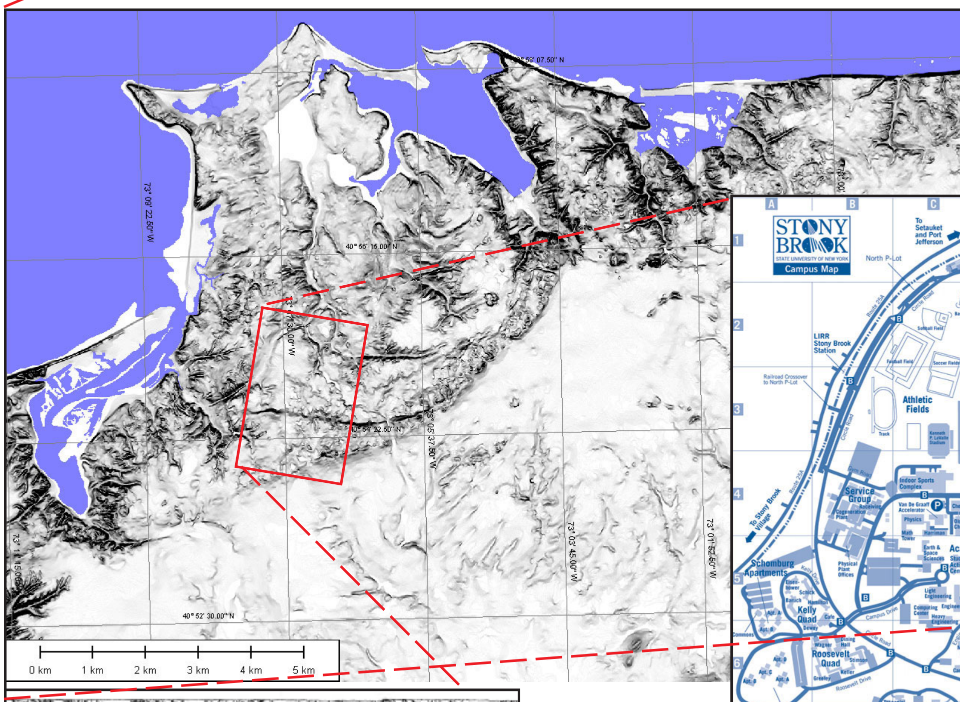
The geology of Long Island, NY includes examples of a wide range of glacial processes. The island is dominated by two push moraines, running in a general west-east direction: the Harbor Hill Moraine and the Ronkonkoma Moraine (Figure 1a). Both of these moraines show evidence of glaciotectonic structures and landforms, but the nature of that glaciotectonism varies greatly across the island. For example, Hither Hills, located on the southern fork of Long Island, lies at the eastern end of the Ronkonkoma Moraine. Klein and Davis (1999) noted that the hills forming the dominant topography of the region are well organized and generally uniformly spaced. The series of hills tend to follow a northeast-southwest direction, consistent with the local trend of the moraine. Some other parts of that same moraine show evidence of long-distance lateral transport of relatively intact sediment thrust slices (e.g., Meyers et al,. 1998)

Figure 2) *GPR study area in the Ashley Schiff Preserve*

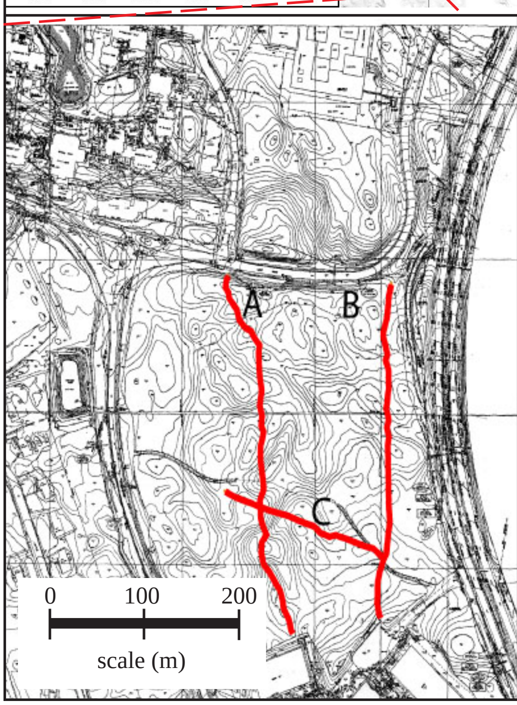
a) *(at right) Generalized map of Long Island. The red rectangle indicates the area of (b)*



b) *(below) DEM of Stony Brook area, showing the effects of glaciotectonic and fluvial processes on local landforms. The rectangle is the area in (c)*



c) *(above) map of Stony Brook University campus, showing the location of the Ashley Schiff Preserve and (d).*



d) *(at left) map of the ashley Schiff Preserve, showing the two main GPR lines ('A' and 'B') and the cross-line ('C'). Lines 'A' and 'B', which run roughly parallel to the direction of glacier motion, show considerable evidence of glaciotectonic folding, but 'C' does not.*

The Stony Brook area (Figure 1b), located on the Harbor Hill Moraine, exhibits a less regular topography than that found at Hither Hills. In the Ashley Schiff Preserve (Figure 1c), a north-south transect shows a series of hills of similar heights, the spacing and height of the hills and other glaciotectonic structures is less consistent. This study was directed toward investigating what the lack of such a trend in terms of the depositional, faulting, and folding processes that created what we now see in the Ashley Schiff Preserve.

Most of the mechanisms used to explain the formation of folded moraines depend upon a lateral push by the glacier. A simple version of such a model calls on the advancing glacier to act as a bulldozer, forcing sediments in front of and under it into the rolling hills evident on much of the moraines of Long Island. Alternatively, a glacier may gradually melt away and stop its forward progress, dumping sediments in a moraine without significant push. Topographic relief within a glacial moraine may also be formed by glaciofluvial processes. As the glacier advances and melts, water may become trapped under or in front of the glacier, and become subjected to intense pressure as it has no way of escaping the glacier. The pressurized water pushes itself through the surface under the glacier, and forms stream-like structures as a result. Figures 1b shows clear examples of such processes in and around Stony Brook, and many of the major roads in the area tend to follow these same stream-like structures.

A site that serves as a relatively undisturbed place to study the complex interplay of these processes is the Ashley Schiff Preserve at Stony Brook University. The hills of this 27-acre preserve are well-defined, and the composition of sediments at the surface suggests glacial deposition as the glacier advanced through the area. However, to what extent are the hills formed by glacial processes such as pushing and dumping, and how much of a role do faulting and folding processes play?

Presumably, the Ashley Schiff Preserve was originally wooded, and any deforestation after European settlement has been reversed and it has stood for some time as a developed forest. The preserve has been left generally untouched, and attempts are now being made to legally protect it, due to its historical, biological, and geological significance.

Method

In order to understand the structural patterns and trends and to further analyze the glaciotectonic processes that formed the Ashley Schiff Preserve's surface, we must look into two aspects of the preserve: the topography of the area, and the geological characteristics of the subsurface. Topographic maps of the Ashley Schiff preserve, dated 1970, clearly outline the significant hills expected in such a moraine. However, we doubted that the data shown on the map were accurate enough for it to be useful in landform analysis. Therefore, an important preliminary step in this study was to determine the accuracy of the topographic data. Three lines, later used for the GPR survey, were plotted through the preserve, two ~400m lines running roughly parallel in a north-south direction, and a third line, generally perpendicular to the other two, ~260m from the northern extrema of the lines (Figure 1d). Data were collected at 3m-4m intervals (closer where there was more irregular topography) using a surveying transit and level system, a compass, and tape measures. We found a surprisingly good correspondence between our measurements and the 1970 topographic maps (the data correlated with an R^2 value of 0.9489 for line A, 0.9758 for line B, and 0.9882 for line C), and mismatches were generally about 1m or less, indicating that the maps are sufficiently accurate to permit their use in evaluating broad trends in land forms.

A greater understanding of the geological processes that had occurred can be obtained by taking a closer look at the patterns in the sediments below the surface. In order to do this, it is necessary that we have an imaging technique that allows us to obtain at least a two-dimensional cross-section of the surface layers. Ground-penetrating radar (GPR), a technology that has come into relatively common use in geological surveys only over the past decade or so, provides us with the ability to examine the structural trends at a considerable depth and discern more closely the processes that occurred to produce the topography of the region.

A GPR system uses a pair of antennas; one designated a transmitter, the other a receiver. An electromagnetic wave is emitted into the ground, and the reflections from the subsurface are collected and recorded. When the wave encounters a surface where the dielectric constant of the material changes, the wave energy will be reflected. In addition, the wave is constantly being attenuated and scattered, two processes that reduce the amount of energy available for transmission and reflection. The reflected waves are recorded as distance vs. time data, along with polarity and relative magnitude of the returning wave. The time is recorded as the total time elapsed from initial transmission to reception. Each returning wave is defined a separate *trace* in the data collection process, and each trace consists of a series of polarities and amplitudes for a certain x-coordinate as a function of the depth, digitally recorded as a series of *samples* in a time sequence.

When using the GPR system to image layering under the surface, a layer will appear as a layer in the data. An object embedded in the surface (for example, a boulder) will produce a hyperbolic (diffraction) signal, as the two-way trip of the wave from transmitter to object and back to receiver covers a longer time span while the radar unit is farther away from the object, and the shortest time span as the radar system is directly over the object. Using data from these hyperbolic events, one can determine the velocity of the transmitted and reflected wave, and then determine the depth of a layer or object and the general composition and density of the layering under the surface.

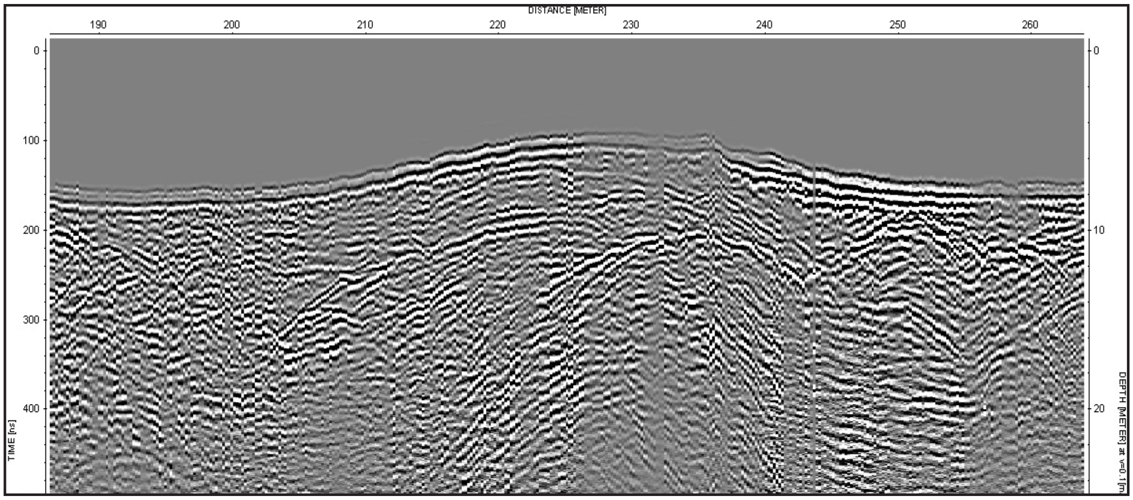
The frequencies of the Stony Brook Geoscience Department GPR antennas range from 25 MHz to 800 MHz. The lower frequency antennas suffer less attenuation and allow for greater penetrating power, making them ideal for examining major layering patterns deep into the surface. When used in dry sandy material, antennas transmitting at 25 MHz can commonly distinguish layers at depths of as far as 40m, but provide very low resolution, which is limited by wavelength. For a typical velocity of 10 cm/ns, the wavelength of the signal emitted by a 25 MHz antenna is ~4m, and its resolution is ~1m (van der Kruk, et. al., 1997). Frequencies of 500 MHz and above are more suited for analyzing layer composition closer to the surface. The short wavelength of a high-frequency antenna yields a resolution 20 times better than the 25 MHz antennas, but because of its greater attenuation, its penetrating power is far less. The resolution of the higher-frequency antennas makes it possible to distinguish small boulders and cobbles in clast-rich sedimentary layers. An ideal GPR survey incorporates a wide range of radar frequencies and looks for consistencies between the various radargrams.

Realistically, it would have been impractical to run a survey on the narrow paths of this densely wooded survey area using antennas with a frequency of lower than 100MHz, due to the very large size of the lower frequency antennas. The 100 MHz and 200 MHz antennas connect to a control unit and a laptop computer strapped to one operator, while another places the antennas at specified increments along the survey line. For this method, 100m measuring tapes were laid out along the paths of the preserve and made to correspond with the points used for the topographic data. The 500 MHz antennas, due to their smaller size, are contained in a single unit, and can be easily transported along the line with a push cart. The raw data collected by the control unit requires a series of processing steps before it can be used for geological analysis. We processed the radar data using Reflexw, a commercially-available program designed to interpret seismic and GPR data. The program contains a wide variety of customizable processing filters and functions necessary to obtain fully processed data.

Analysis

The rolling hills that are evident in lines A and B (the two north-south lines, both ~400m long) seem to be lacking in east-west line C (the perpendicular line, ~200m long). Although there is one steep hill in the middle of line C, it is not comparable to the many rolling hills that run perpendicular to the moraine. Along with the lack of obviously transected structural features, this supports the idea that these hills were formed by glacial processes, due to a glacier advancing from the north and with the east-west direction parallel to strike.

The hlls within the Ashley Schiff Preserve are generally revealed by the GPR to be anticlines. Stratigraphic layers are often difficult to discern in these glacial sediments, but in general, they are closer to the surface at the tops of hills than in the valleys - as one would expect for folding and opposite to what one would find if the topography were the result of erosion. An interesting example of such a fold is found about 220m south of the northern end of line A (Figure 1d). At meter mark 228m (Figure 2a), one of the many hills of the preserve reaches a peak, and there is significant evidence of folding activity under the surface. Towards the base of the hill, however, there seems to be a break in the continuity of the layers, suggestive of a fault associated with the folding (Figure 2b). A possible explanation would be a fault-bend fold mechanism (Figure 2), similar to those found in foreland fold-and-thrust belts. As a sediment layer advances, there comes a point where any further compression is impossible due to the composition of the impeding layer. The sediments then must bend and ramp towards the surface, riding over the dipping thrust fault. This bend is the first of four fold axes associated with a fault-bend fold (FBF). The others correspond to when the advancing layer reaches the top of the footwall, where the fault levels off at a new stratigraphic level, and where sediments again ride laterally across the upper fault surface (Suppe, 1983).



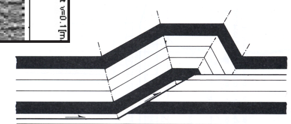
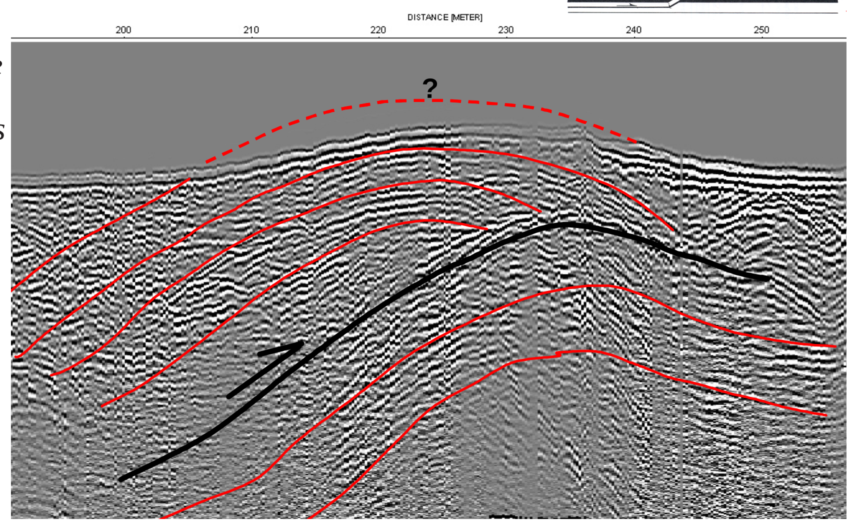


Figure 2) *Apparent fault-bend folding in the Ashley Schiff Preserve*



a) *(above) 100 MHz radargram of part of line 'A' (Figure 1d). Note the distinct reflective layers beneath the hill. There are also some hyperbolas ('frowns') corresponding to buried boulders.*
b) *(at right) Interpretation of the radargram in (a). Red lines correspond to sediment layers and the black line is the interpreted position of a thrust ramp on which displacement has occurred. Note (above right) a schematic fault-bend fold (after Suppe, 1983)*

If the entire preserve were built upon such structures, it might appear that the glaciotectonics in this area was in the form of relatively straightforward pro-glacial thrusting. Other areas, however, show clear evidence of dipping layers that follow the topography for distances of up to several tens of meters and then approach the surface and disappear (e.g., Figure 3). A logical explanation would be a certain shearing process that truncated these layers at the surface. Although most of the truncating material (ice) has melted away, a "dirty" (sediment-rich) ice sheet might have been advancing over the current surface, and sheared off the upward extension of the imaged layer. This implies that there was another zone of localized shear (a fault) above the FBF. Whereas near 220m (by the FBF), this upper fault was high enough to cut mostly dirty ice, a bit to north (e.g., Figure 3), it apparently cut through and truncated the sediments of the fold.

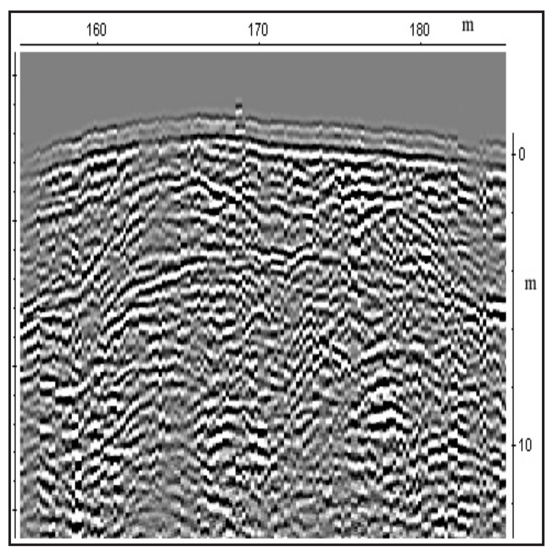


Figure 3) *Some complex near-surface reflectors vary greatly in thickness or disappear entirely - perhaps an indication of sub-glacial truncation.*

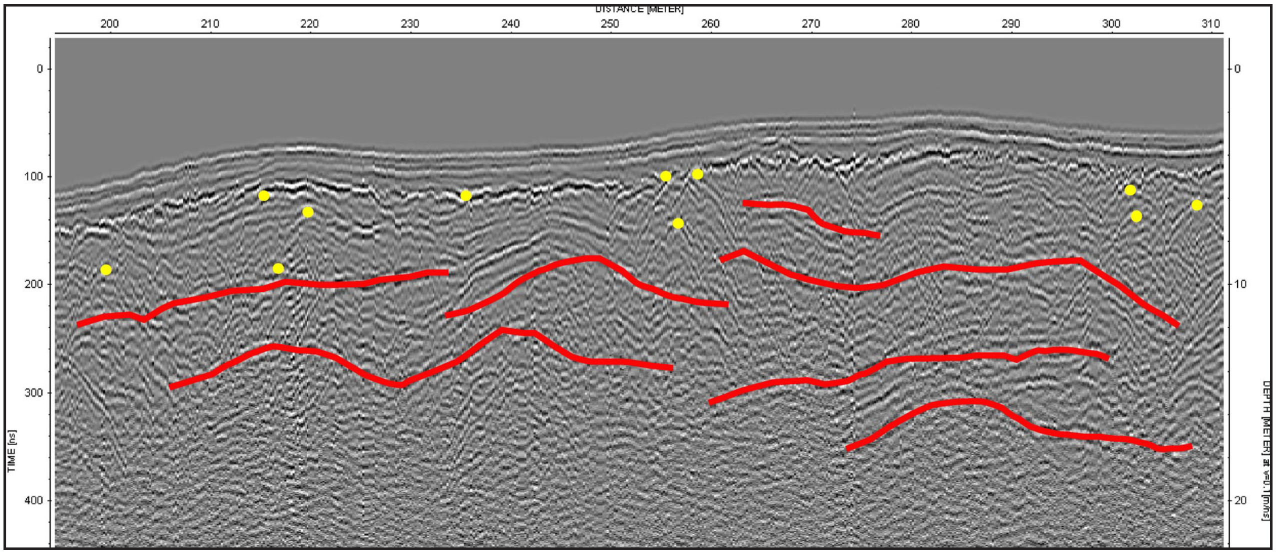


__Figure 4)__ (above) Radargram from part of line 'A', showing complexly folded sediments (annotated by red lines) and shallow boulders and cobbles (identified by hyperbolic 'frowns', and annotated by yellow dots). The truncation of beds at the surface and the presence of a capping diamict are both consistent with subglacial tectonism.

In other areas (e.g., Figure 4) there is clear evidence of layering that roughly follows the topography at the surface. The topmost layer is rich in cobbles (shown by the hyperbolas), suggesting that it is similar to cobble-rich diamict (poorly-sorted sediment) that has been excavated nearby. The mild folding in these layers was most likely caused by the pushing of an advancing glacier, but the presence of such a late-stage diamict suggests that the ice was above (and not merely to the north of) the preserve (Figure 5).

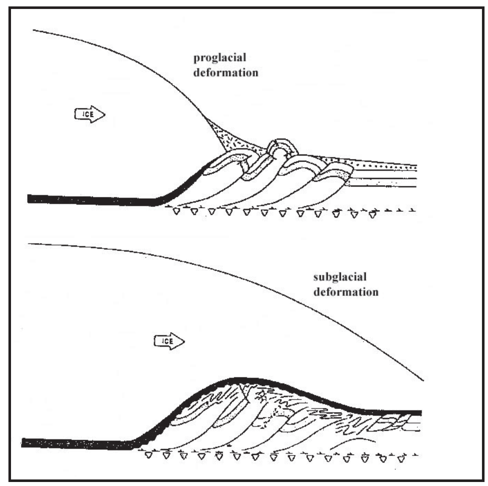
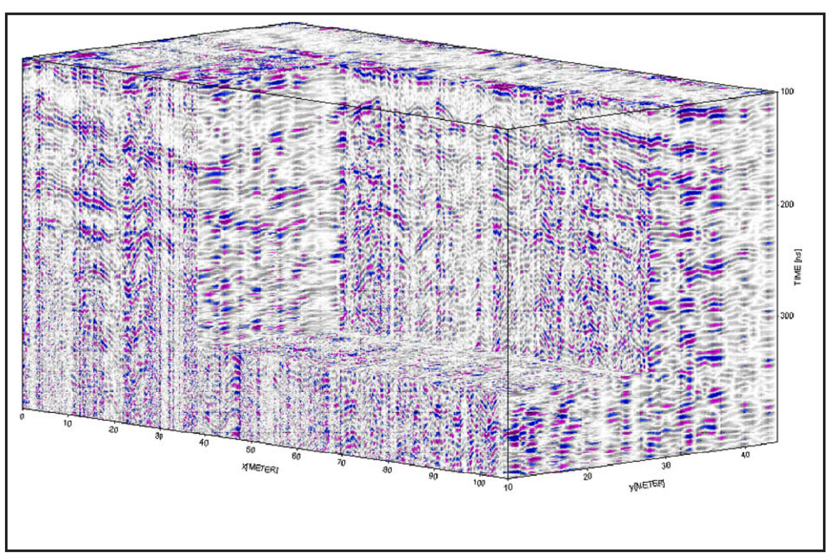


__Figure 5)__ (above) Schematic illustration of the difference between proglacial and subclacial glaciotectonism (after Aber, 1982).

*__Figure 6)__ (at right)
3-dimensional cut cube representation of a series of 41 parallel 100 MHz GPR lines run a short distance in front of the moraine, about 1 km southwest of the Ashley Schiff Preserve. Note the gently undulating, but otherwise nearly 'layer-cake' character of the reflectors from this site which, unlike our primary survey area. is nearly flat and lacks evidence of any significant glaciotectonism.*



Unlike the two parallel lines, A and B, radargrams on the east-west line C show no repeating series of hills. Rather, there is only one major slope and slightly undulating topography to the east. This is consistent with the idea that this west-east line is parallel to the prevailing structural strike, unlike north-south lines A and B, which clearly show shortening structure.

In a related GPR study, we surveyed a field just in front of the moraine, near the South P-Lot at SUNY Stony Brook, within 1km of the Ashley Schiff Preserve. Figure 6 is a 3-dimensional composite of a series of radargrams at that site. Note the nearly 'layer-cake- geometry of the site's subsurface, with only slight undulations attributable to the chaotic deposition of sediments from the immediately adjacent moraine and water rapidly expelled from the glacier itself. The radargram also shows a great number of hyperbolic events both at the shallower layers, towards the surface, and at greater depths. The boulders and cobbles that were imaged at the greater depths were most likely deposited by an earlier advance of the ice, while the those found at the surface were certainly from the advance of the glacier that formed the moraine.

While the Hither Hills site exhibits uniform, rolling hills, certainly formed by a glacial push method alone, the Ashley Schiff Preserve contains a complex combination of glacial push structures along with subglacial deposition and removal of material and only a small amount of post-glacial erosion of the tops of hills and deposition in low areas.

References

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