Glacial tectonics at Hither Hills, eastern Long Island: evidence from Ground Penetrating Radar

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Introduction

Hither Hills State Park on the southern fork of Long Island contains a long (kilometer-scale) chain of subparallel E-W trending hills. It has been theorized that glacial tectonism related to the Wisconsinan advance is responsible for its formation via proglacial thrusting. Ground Penetrating Radar surveys have been undertaken in the area in an effort to search for evidence relevant to this theory.

Background

Overview of Glacial Tectonism

Glaciotectonism encompasses a wide range of types of deformation of pro- and subglacial sediments by the advancing glacier. Several different styles of proglacial deformation have been reported in front of glaciers around the world (*e.g., Boulton*, 1986; *Croot*, 1987), in some cases taking a form very similar to that of foreland fold-and-thrust belts. Studies of modern and Pleistocene glacial environments include many examples of folded and faulted sediments proximal to and in front of the snout of glaciers (*e.g., Boulton*, 1986; *Croot*, 1987; *Bennett*, 2001). These push moraines and related structures clearly record deformation that has shortened and thickened some combination of glacially-derived sediments, pre-glacial sediments, and bedrock.

Glaciotectonic composite ridge moraine systems grow through the excavation and elevation of proglacial materials during advance (seasonal or maximal) of glacial ice. The growth of these ridge systems relies on the large-scale displacement of proglacial materials due to stresses imposed by the glacier. A part of that stress is static - due simply to the weight of the overlying ice. This can be very important in the immediate proximity of the glacial front, causing weak sediments to extrude from beneath the ice. Farther from the glacial terminus, the elevated material has a corresponding excess potential energy and a stress field tending to reduce the height of the highest areas, while shoving distal material outward and, often, upward (Fig. 1). For such gravity spreading to work, the deforming medium must be able to flow under low, gravitational stresses, either by some sort of plastic creep or by low-stress frictional sliding, as in the presence of elevated pore fluid pressure. This condition can be facilitated by loose proglacial ablational till and vast amounts of outwash fluid.

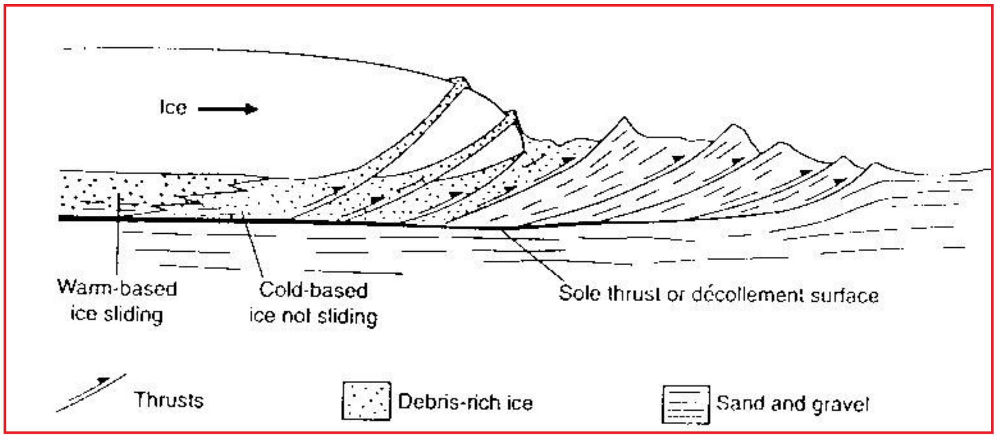


Fig. 1: *Cross-section illustrating the process of deformation in glacio-tectonic environments (after* Hambrey, 1994). *Folds overlying similar thrust sheets may represent folding in the Hither Hills area.*

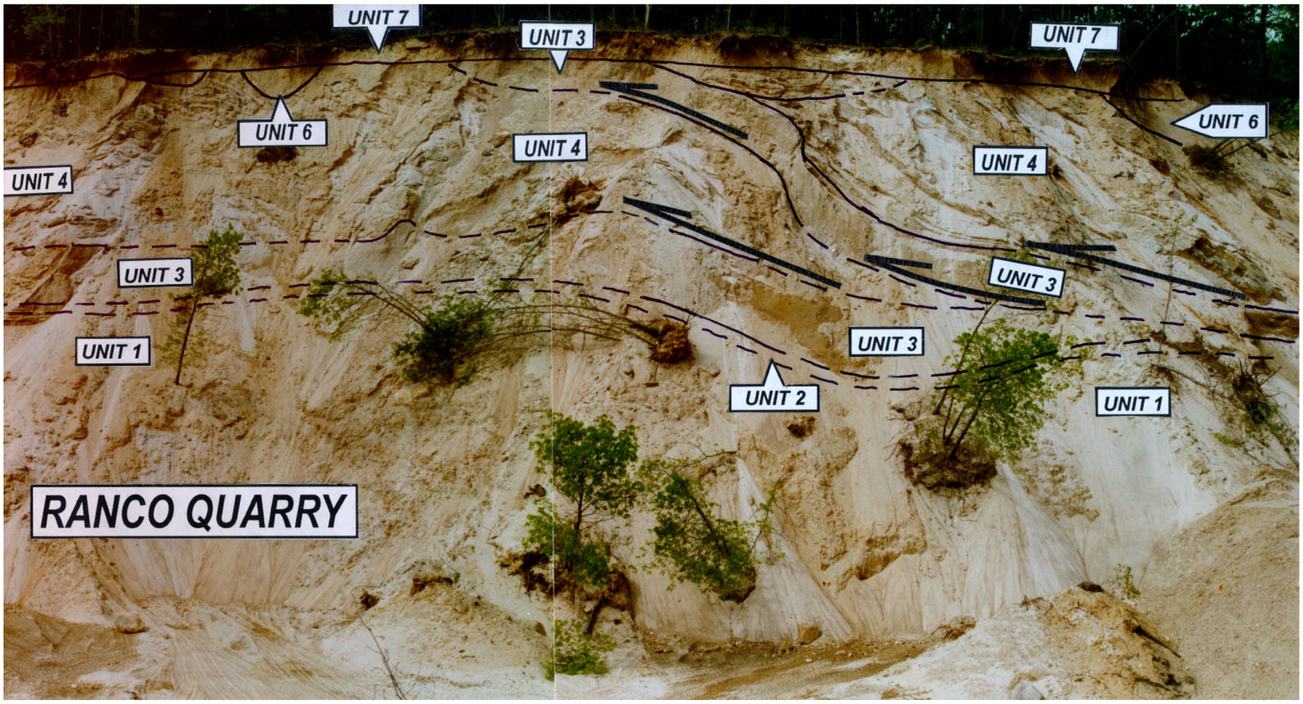


Fig. 2: *Interpreted photomosaic of glacially-thrusted strata in Ranco Quarry, southern Suffolk County (after* Meyers et al., *1998*)

Glacial Tectonism on Long Island

Glaciotectonics has been cited by numerous authors as the likely cause of folding and faulting in Long Island glacial sediments (*e.g.*, *Nieter et al.*, 1975; *Fullerton et al.*, 1992). Coherent glaciotectonically-thrust blocks (Fig. 2) have been mapped several tens of meters above and hundreds of meters or more laterally from their source, and along their gravel-rich thrust zones there is sedimentological and structural evidence for the sediment having been in a condition of permafrost (*e.g.*, *Meyers et al*., 1988). However, the subsurface geometry of these folds and faults, and therefore the mechanisms of their emplacement, generally remain unclear, as does the nature of the environment - both physical and climatic - that led to their formation.

Fig.3: *Map of Long Island showing location of Hither Hills on the south fork.*

Procedure

Location of Study Area

Hither Hills State Park is located on the south fork of Long Island, approximately 15km west of Montauk Point (Fig. 3). Within the park are chains of roughly E-W trending hills, all subparallel to one another. They vary in height and spacing, but topographic relief from crest to trough is typically on the order of 10-15m and distance from crest to crest varies from 80-200m. The possibly glacial genesis of the orderly alignment of these hills is the subject at hand. Glacial tectonism, creating a composite ridge moraine system, may have created this systematic orientation - discovering evidence supporting this notion is the intent of our study.

There are many possible explanations for the observed alignment. The hills may have been deposited as individual terminal (likely recessional) moraines, *i.e.*, they might mark interseasonal maxima where the Wisconsinan glacier annually deposited material as it withdrew during the respective summers. Alternatively, they could represent the result of topographic inversion: crevasses near the terminus of the glacier could have been filled with a combination of upthrust englacial and deposited runoff sediments, which form narrow ridges when deposited during glacial melting. Both of the former arguments would favor the deposition of poorly sorted, well rounded sediments with massive or chaotic bedding. However, in our working hypothesis, where glacial tectonism caused the formation of proglacial thrust sheets (Fig. 1), flat-lying sediments would already have been in place, with the ensuing tectonism creating a series of hills with continuous folded, well-sorted layers.

Subperpendicular to the trend of these hills is a major trail (more than 1km) off of Montauk Highway (Fig. 4), which is the former site of a series of poles carrying power lines across the southern fork. For this purpose a roughly 5m-wide trail, here referred to as the Power Line Cut (PLC), across the hilled region was cleared by the Long Island Power Authority for maintenance service. The presence of this path makes the area accessible, and several hiking paths branching off of it are fairly well suited to radar surveys.

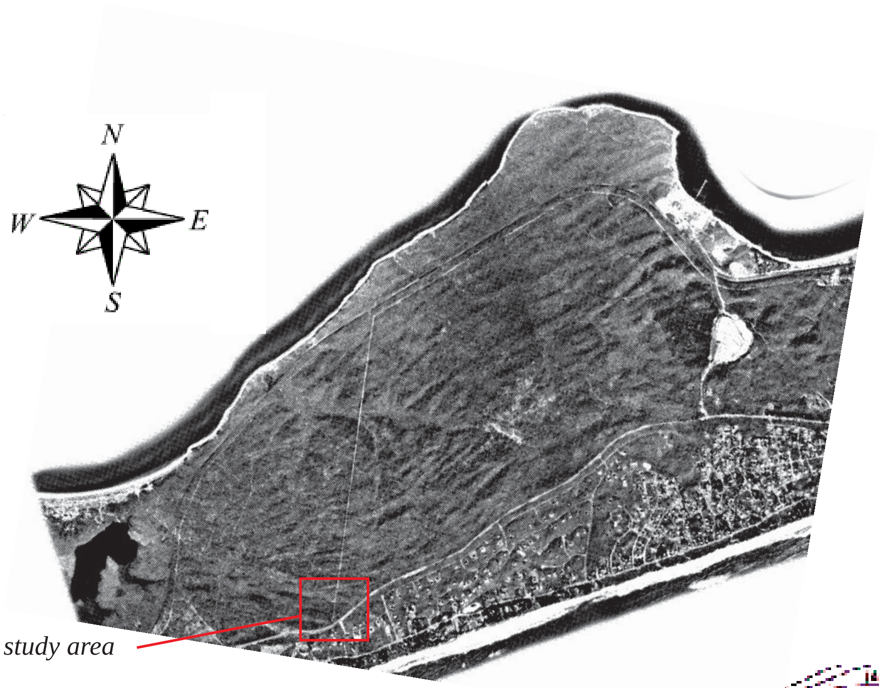
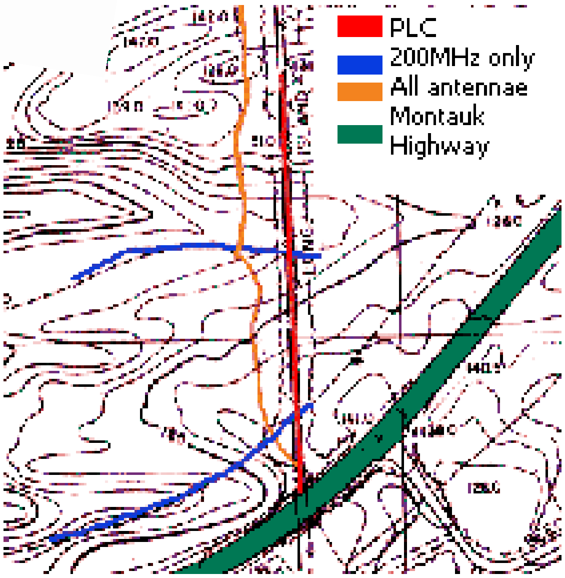


Fig. 4a): *(left) Aerial image of Hither Hills State Park. The WSW-ENE-trending chain of hills is easily visible in this photograph. Also visible is the NNE-trending Power Line Cut, a thin line extending from the highway to the North Shore.* ***4b):*** *(below) Topographic map of the PLC, with approximate locations of survey lines highlighted.*



Basic Principles of Ground Penetrating Radar

Ground Penetrating Radar (GPR) is a geophysical technique involving the emission of electromagnetic waves near the radio spectrum from an antenna (*transmitter*). The waves propagate downward and outward through the ground. When these waves encounter an object or layer with differing electromagnetic properties (*e.g.* wetter, denser, or different material), it causes a reflection which returns to the surface, and is detected by a second antenna (*receiver*) being moved in tandem with the transmitter (Fig. 5). Each wave reaching the receiver registers as a single time-dependent line called a *trace*, which records encountered objects as "wiggles" to the left or right. By moving the GPR system

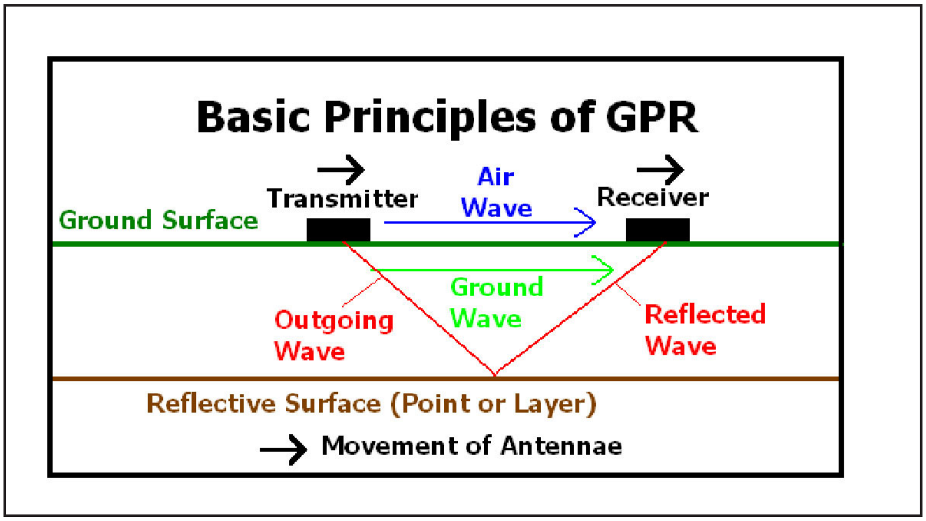


Fig. 5: *Main concepts of a GPR system: Data are received when electromagnetic waves originating from the transmitter reflect off an object and reach the receiver (After* Hubbard et al., *2002*).

along a line, many (hundreds to thousands) traces can be added to create a *radargram*, a 2-D (time vs. distance) analogy of the subsurface (Fig. 6; *Hubbard et al.*, 2002).

Site-specific details such as topography, accessibility, and electromagnetic properties of the subsurface medium often determine the course of action for a survey. For example, high-frequency (small-wavelength) antennae are capable of higher resolution, but are more easily scattered and attenuated, and thus cannot penetrate to depths so great as lower frequency antennae, especially in environments with many shallow reflectors. However, the physical size of low-frequency antennae can be restrictive. Also, lines perpendicular to the main line (cross lines) can be run to create a quasi-3-dimensional view of the subsurface, if terrain allows.

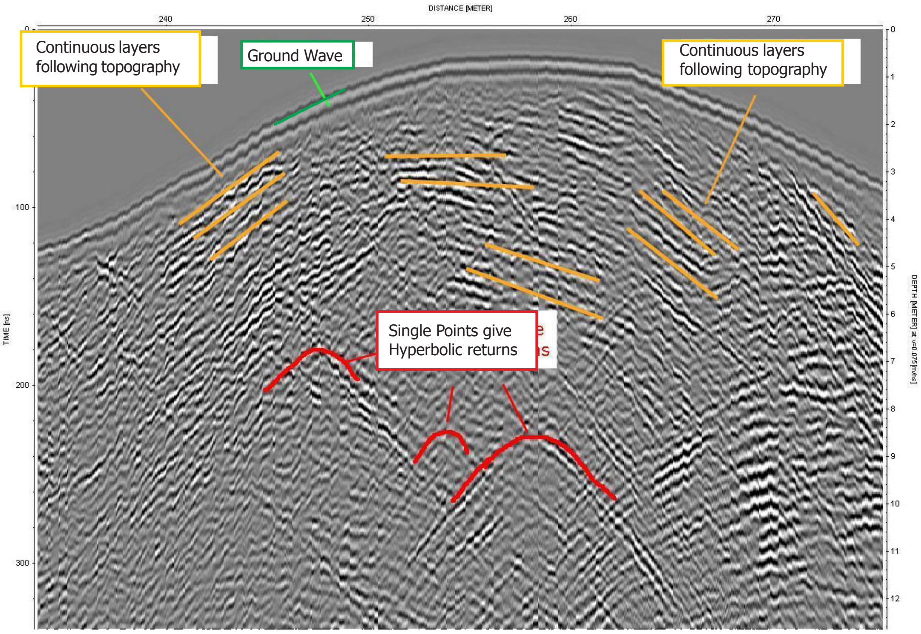


Fig. 6: *200 MHz radargram, representing a cross-section of a hill along the N-S trail parallel to the PLC. Vertical scale is equivalent to about 10m, horizontal scale is about 50m. The presence of dipping, reflecting stratigraphic layers amounts to strong evidence that originally flat layers have since been folded (see Fig. 1)*

Data Collection

Data were collected with 100 (low-frequency, low-resolution, deep penetration), 200 (intermediate), and 500 MHz (high-resolution, shallow) RAMAC antennae attached to a laptop running RAMAC GroundVision sample collection software. The 500 MHz monostatic (single-unit) antenna was attached to the base of a wheeled, buggy-like device and pushed along the length of the trail. The physically larger antennae (200 & 100) were attached to a flexible-polymer sledge and dragged along the trail by a second person. The sledge was run in front of and connected by fiber-optic cable to the buggy, which ran the control unit and laptop.

The main (N-S) hiking path, roughly parallel and several meters to the west of the PLC, was followed for approximately 340m, using all antennae during the course of several runs (Fig. 4b). The 200 MHz system was then used to map two cross lines: the first (E-W, 128m) followed a second hiking path (perpendicular to the first), began 4m to the east of the PLC, and intercepted the starting point (y=0m) of the N-S hiking path line 15m from its starting point; the second (W-E, 59m) followed another perpendicular hiking path that began to the west of the N-S line, crossed the N-S line at y=133m (29m from its starting point) and ended just past the PLC (Fig. 4b).

Preliminary Results

Preliminary analysis of radar data using Reflexw 2.5 processing software suggests that there is a series of coherent, dipping stratigraphic layers present beneath a significant portion of the surveyed area. Prior to the addition of topographical data, the radargram is displayed with a flat surface. However, once topography has been accounted for, it becomes clear that some of these curving waveforms are following topography, indicating folding of flat, stratigraphic layers, rather than hyperbolic reflectors which represent single points (Fig. 6). Cross lines also suggested the presence of folded layers.

Taking into account the tectonic location of Long Island (well within the continental margin and away from recent orogenies), and noting that the deformation appears to be taking place in a reflector-rich, glacial till, one conclusion, and our working hypothesis, is that the linear chain of hills was created by glacial tectonism. The force of the Wisconsinan glacier pushing on the unconsolidated proglacial, or perhaps subglacial, sediments could have caused folding on a kilometer scale, leaving the hills now visible (Figs. 1, 4a).

Conclusions/Future Work

Judging from preliminary analysis of data collected along the hiking trail, the theory that glacial tectonic forces created the chain of hills in Hither Hills State Park appears to be on solid ground. However, more data will need to be collected in support of this theory, and perhaps to understand more precisely the mechanisms which could have formed the hills in this manner. A high-resolution (500 to 800 MHz) survey in selected areas that appear to have a significant amount of folding could lend insight into the exact mechanisms taking place there and present even more accurate pictures of the structure. Also, additional 100 and 200 MHz main lines and cross-runs at other accessible hills might create a 3-D perspective of a larger portion of the N-S trail.

Further, a survey along the main PLC could allow us to test the continuity of the large-scale fold structure parallel to the N-S hiking path. However, the presence of a utility pipe beneath the PLC, as determined by several short cross runs along the path, complicates matters, as metal pipes make very good reflectors and would “wash out” the picture beneath them on a high frequency radar. As an alternative, a very-low frequency system (25-50 MHz), with its much larger wavelength, would be able to penetrate the subsurface without significant washout, and would still be able to investigate possible large-scale fold structures. In fact, the deep penetration achievable by such low-frequency antennae might create a more complete picture of the subsurface, perhaps by detecting a decóllement or similar structure.

References

Bennett, M. R., 2001, The morphology, structural evolution and significance of push moraines, *Earth-Science Reviews*, vol. 53, p. 197-236.

Boulton, G. S., 1986, Push-moraines and glacier-contact fans in marine and terrestrial environments. *Geomorphology*, vol. 33, p. 677-698.

Croot, D. G., 1987, Glacio-tectonic structures: a mesoscale model of thin-skinned thrust sheets?, *Journal of Structural Geology*, vol. 9 no. 7, p. 797-808.

Fullerton, D. S., and 9 others, 1992, Quaternary Map of the Hudson River 4° x 6° Quadrangle, United States and Canada, *Map I-1420*, U. S. Department of the Interior, U. S. G.. S.

Hambrey, M. J., Glacial Environments. UCL Press: London, 1994.

Hubbard, S. Grote, K., Rubin, Y., 2002, Mapping the subsurface volumetric water content of a California vineyard using high-frequency GPR ground wave data, *The Leading Edge,* vol. 22 no. 6, p. 552-559.

Meyers, W. J., Boguslavsky, S., Dunne, S., Keller, J., Lewitt, D., Lani, M., McVicker, A., Cascione, 1988, Matituck Cliffs and Ranco Quarry: Models for Origin of Roanoke Point and Ronkonkoma Moraines?, *Conference on Geology of Long Island and Metropolitan New York,* p. 83-90.

Nieter, W., Nemickas, B., Koszalka, E. J., and Newman, W. S., 1975, The Late Quaternary geology of the Montauk Peninsula, Montauk Point to Southampton, Long Island, New York, p. 129-153, in New York State Geological Association Guidebook, 47th Annual Meeting.