First Steps at the Ground Penetrating Radar Mapping of the Shallow Subsurface Geology, Hither Hills, Eastern Long Island

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In order to improve our understanding of Long Island's regional geomorphology and near-surface hydrology it is important to establish glaciotectonic models and interpret glacigenic structures. Previous work at Hither Hills State Park (about 14 km west of Montauk Point) relied primarily on structural and stratigraphic data in interpreting the origin of the glacigenic sediments and glaciotectonic structures found there. Field data, topographic analyses, and seismic surveys have led to the tentative conclusion that a 'push moraine' model [Boulten, 1986; Aber et al., 1989] is the most viable explanation for the development of the sedimentary facies and the glaciotectonic features observed at Hither Hills. In general, Long Island glacigenic sediments and glaciotectonic structures are poorly exposed and are often difficult to evaluate with more traditional geophysical techniques such as seismic reflection surveying. We use ground penetrating radar (GPR), a geophysical instrument capable of mapping up to 10’s of meters of shallow subsurface deposits, and related geological features, at high resolution using electromagnetic radiation of radar wavelengths (tens to hundreds of MHz). Radar data are processed and analyzed in a manner similar to seismic reflection data allowing for establishment of radar facies, which describe distinct structural and stratigraphic changes in a depositional sequence.

Components of a typical GPR system include a transmitting (source) and receiving antenna, a central processing unit (CPU), and a laptop computer. During the survey the signal of the transmitted radar wave is partially reflected by buried features (e.g. sedimentary layers, boulders, groundwater table) back to the receiving antenna. After the transmitting antenna pulses a radar wave, the receiving antenna detects the returning signal trace and allows the CPU to process and send that trace to the laptop computer. Each radar wave is generally reflected off various buried surfaces and is seen as a wiggle-like trace on the laptop computer monitor. For our GPR surveys a fixed distance separated the antenna pairs; 2 m with the 50 MHz, 1 m with the 100 MHz, and 60 cm with both the 200 and 400 MHz antenna sets. Higher frequency GPR signals penetrate shallow surfaces (~10 m) with high resolution, resolving features as small as 10 cm. Lower frequency GPR signals penetrate more deeply below the surface (40 to 50 m) but with less resolution, resolving features as small as 100 cm. Individual pulses can be stacked at the same position increasing the signal-to-noise ratio. Such stacked traces acquired at each of hundreds of closely spaced sampling points along a line define a typical GPR profile. When all the traces of a GPR profile are displayed this is called a radargram.

Since radar is an electromagnetic wave, it travels at the speed of light (which is ~300 mm/ns in a vacuum). Radar velocities in the typically porous geologic sediments on Long Island travel at roughly one third this speed (~100 mm/ns). Radar velocities for salt water (e.g. seawater) are very slow (~33 mm/ns) and the wave energy completely attenuates [Reynolds, 1997]. In glacial diamict (e.g. tills) radar waves diffract in contact with boulders (point reflectors), and appear in an unprocessed radargram (plotted with horizontal distance on the x-axis and radar travel time on the vertical axis), as hyperbolas. It is possible to use the shapes of those hyperbolas to evaluate the size and location of each boulder, as well as to establish a radar velocity structure as a function of radar travel time down to the apex of each of these hyperbolas. The radar velocity structure is a record of inferred radar velocity down to the maximum depth from which the radar returns significant signal. Those velocities can then be used for migrating the unprocessed GPR data in order to restore geometrical relationships of the point reflector by collapsing the diffracting hyperbolas to their point of origin. Migration, a standard seismic technique now applied to radar, is also used to place a given radar event in its correct geometrical position on the radar travel time section. Migration along with topographic correction allows the production of reliable depth sections and radar facies of the subsurface.

Stratigraphic, structural, and seismic fieldwork at Hither Hills revealed evidence of syntectonic deposition, folded strata, cm-scale faulting, and lateral variation of sedimentary layers in the stratigraphy. We conducted two GPR surveys at Hither Hills during November 1999. The first GPR survey was on the top of two neighboring hills separated by less than 100 m, which are exposed as 3.5 to 12.5 m high sea cliffs at Rocky Point along the northeastern coastline of the park. On the first hill, two 130 m GPR profiles with trace spacing intervals of 10 cm were conducted along a line from south to north then bending northwest using the 200 and 400 MHz antennas. On the second hill, two 112 m GPR profiles with trace spacing intervals of 10 cm were conducted along a line from south-east to north-west then bending west using the 200 and 400 MHz antennas. For these GPR profiles, we find a radar velocity structure ranging from about 100 mm/ns to roughly 90 mm/ns at maximum depth. These radar velocities are typical of glacial diamict. Three stratigraphic columns [Klein and Davis, 1999] of those sea cliffs at Rocky Point serve as ground truth for a thorough evaluation of the radar velocities and radar facies as they relate to the sedimentary facies and structural features imaged by GPR. The migrated radargrams from the Rocky Point hills document the location of the groundwater table there as well as image the subsurface structure beneath those GPR profiles.

The second GPR survey includes GPR profiles taken along a line from south to north along 250 m of the LIPA power line cut in the southern part of Hither Hills State Park. We used GPR to survey directly over 100 m of previously conducted seismic reflection surveys performed in 1997 [Bernard, 1998]. Seismic data indicate the presence of complexly folded glacigenic strata of wavelength and amplitude similar to those seen in the sea cliffs exposed along the north coast of the park. The LIPA power line cut radargrams obtained with the 50, 100, and 200 MHz antennas provide complementary and far more complex images of the folded strata previously detected by the seismic reflection survey. The radargrams provide higher resolution to a greater penetration depth (as deep as 45 m) than accomplished with the seismic reflection survey. The LIPA power line cut radargrams imaged many folded strata having an appearance resembling a stacked imbricate thrust system [Boyer and Elliott, 1982]. Some of these imbricate thrusts exhibit an over-printed geometry consistent with a 'push moraine' glaciotectonic mechanism responsible for forming the hills found at Hither Hills.

Combining radar facies with previously recorded stratigraphic columns, seismic reflection studies, water table maps, topographic maps, and new field data improves our ability to assess a primary glaciotectonic model responsible for glacigenic hill formation in Hither Hills. Radar facies generated from these and future shallow subsurface GPR studies at Hither Hills State Park and elsewhere on Long Island, may prove to be useful for future Long Island groundwater model applications.

References

Aber, J. S., Croot, David S., and Fenton, Mark M., 1989, Glaciotectonic Landforms and Structures: Dordrecht, Kluwer Academic Publishers.

Bernard, M., 1998, Shallow Seismic Studies in Glaciotectonic Hither Hills, Long Island [M.S. thesis]: State University of New York at Stony Brook, 81 p.

Boulten, G. S., 1986, Push-moraines and Glacier-contact Fans in Marine and Terrestrial Environments: Sedimentology, v. 33, p. 677-698.

Boyer, S. F., and Elliott, D., 1982, Thrust Systems: Am. Assoc. Petrol. Geol. Bull., v. 66, p. 1196-1230.

Klein, E. C., and Davis, Dan M., 1999, Glaciotectonic Process and Glacigenic Sediments on Eastern Long Island, in Geology of Long Island and Metropolitan New York, SUNY Stony Brook, p. 36-43.

Reynolds, J. M., 1997, An Introduction to Applied and Environmental Geophysics: Chichester, John Wiley & Sons.