SEDIMENTATION-EROSION PATTERNS ALONG THE SOUTHEASTERN SHORELINE OF LAKE ONTARIO

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Introduction

The southeastern shoreline of Lake Ontario (Fig. 1) is dynamic and evolving rapidly in response to wave conditions, rainfall patterns, groundwater seepage, and short- and long-term variations in lake levels. We have been studying these changes in a systematic way for three years, trying to document the nature of these processess as they interact to produce depositional-erosional effects. The field trip is designed to acquaint you with the results of our work and to show those of you who are in academia the potential this area has for field instruction about glacial and coastal deposits and processes. Furthermore, we hope that some of you may opt to direct your research efforts to some of the many unsolved problems that we will be discussing during the trip.

Relevant Background Geology

The Oswego Sandstone, an Upper Ordovician (440-445 MYBP) unit, is the dominant bedrock of the southeastern shore of Lake Ontario. This red-to-grey-colored unit is composed of clastic sediment that accumulated in fluvial, deltaic, and shallow marine environments. As you would expect, there are extensive outcrops around the coastal town of Oswego. The erosion rate of coastal sections underlain by outcrops of the Oswego Sandstone is lower than for regions that are not, because of the resistant character of the rock. The two field sites that we will visit do not have outcrops of the Oswego Sandstone, although the glacial till of the areas contains many clasts of the unit.

The stratigraphic units that are most relevant to the modern-day coastal processes are a variety of unconsolidated to semi-consolidated glacial deposits of Late Wisconsin age that are about 12,000 to 20,000 years old. Multiple cycles of ice advance and retreat scoured the Ontario Basin and laid down an uneven cover of glacial material, which along the southern edge of Lake Ontario consists of extensive drumlin fields, kame deposits, ground moraines, and proglacial lake-bed sediments (Kaiser, 1962). Reconstructions of ice-flow patterns and deglaciation events in and around the Lake Ontario region are presented by Shaw and Gilbert (1990), Ridky and Bindschadler (1990), Hicock and Dreimanis (1989), Mullins and Hinchey (1989), and Gadd (1980). The latest readvancement of the ice sheet shaped a variety of morainal deposits into streamlined drumlins that trend south-southeast (Dreimanis and Goldthwaite, 1973); many of these have been truncated at the shoreline by wave erosion, exposing their interiors for inspection. The bedded kame deposits formed in ponds, lakes, and around the margin of the retreating ice sheet by the reworking of glacial sediments by meltwater (Solomon, 1976).

About 12,000 yrs BP, glacial Lake Iroquois formed south of the retreating ice sheet with an outlet to the east near Rome, N. Y. (Muller and Prest, 1985). The complex drainage history of this lake, including a reconstruction of water-level variations, has been inferred from a study of sediment cores and shoreline outcrops of Lake Iroquois deposits (Anderson and Lewis, 1985; Anderson and Lewis, 1982; Sutton and others, 1972; Karrow and others, 1961). Some 10,000 to 11, 000 yrs BP, a eustatic rise of sea level flooded the isostatically-depressed crust of northern New York, resulting in a marine incursion, the Champlain Sea, into the St.Lawrence Valley lowlands and its environs. Studies of bottom sediments from Lake Ontario have not yet provided compelling evidence for the incursion of seawater into the Ontario Basin (Muller and Prest, 1985; Clark and Karrow, 1984; Schroeder and Bada, 1978). In any event, the present rate of crustal rebound on the northern side of the lake exceeds that on the south, causing a lake transgression of the southern shore (Clark and Personage, 1970). This differential isostatic rebound which is tilting the Ontario Basin to the south has important implications for present-day erosional processes of the southeastern shoreline (Drexhage and Calkin, 1981).

A few thousand years ago, Lake Ontario attained its present water level. In the process, the shoreline, including the landscape and its deposits, was transformed . For example, the refraction of waves focused energy on drumlins which were coastal promontories; these glacial hills were eroded and truncated, forming numerous coastal bluffs that continue to dominate much of the landscape of the southeastern shoreline (Fig. 2). The wave-driven longshore drift of gravel and sand, derived from erosion of the bluffs, formed barrier spits and baymouth bars, which separate the inlets, bays, creeks, and wetlands from Lake Ontario. Thus, a very irregular shoreline is being straightened by the erosion of headlands and by the infilling of coastal indentations and lowlands. The Lake Ontario bottom received and continues to receive an influx of fine sediment, largely mud that is winnowed out of of the glacial till deposits (Kemp and Thomas, 1976; Sutton and others, 1974; Thomas and others, 1972).

Previous work has documented the prevalence of coastal erosion by mass wasting and wave activity along the southeastern shore of Lake Ontario (Brennan and Calkin, 1984). See Martin (1901) for an interesting turn-of-the-century perspective on the nature of coastal changes in this region. Also, Kemp and Harper (1976) and McAndrews and Power (1973) provide important insights into the nature of Lake Ontario sedimentation.

Field-Site Visits

We are going to make two stops during the course of this trip. The first will be McIntyres Bluff located in the township of Sterling in Cayuga County; the site is about 4 km to the northeast of Fair Haven State Park (Fig.2). Here we will walk about one kilometer of the shoreline, examining in detail the gullies that are carved into McIntyres Bluff, the cobble beach fronting the bluff, and a baymouth barrier in front of Juniper Pond. The second stop will be near the jetties constructed at the mouth of Little Sodus Bay in the town of North Fair Haven (Fig.2). Here we will study the impact of shoreline-stabilization projects on erosional-depositional patterns of the adjoining shorelines.

Bluff Erosion

Much of the shoreline physiography is dominated by tall bluffs separated by bays, ponds, or wetland marshes that are fronted by barriers (Christensen and others, 1990; McClennen and Pinet, 1990). The bluffs, which have moderate to steep slopes and heights ranging between 10 and 50 m above lake level, are backed up by north-south-trending drumlins that have been truncated by a combination of wave erosion and mass-wasting processes. The drumlin bluffs, which are composed of unconsolidated to semi-consolidated Pleistocene till, are eroding at rapid rates (0.5 to >1.0 m/yr) and provide the main input of sediment to the nearshore zone and barrier island-bay complexes of the area.

Surveys (Drexhage and Calkin, 1981) indicate that the rapid retreat of the bluffs along the lakeshore of Ontario is attributable to a number of factors. These include:

i) bluff height: tall bluffs tend to recede at a faster rate than short bluffs;
ii) bluff steepness: the steeper the slope, the faster the rate of erosion;
iii) bluff orientation: bluffs that face northwest erode significantly faster than bluffs with other orientations because of exposure to waves generated by the dominant northwesterly winds;
iv) till composition: bluffs composed of mud-rich till tend to be unvegetated and erode more rapidly than the vegetated bluffs composed of sand-rich till;
v) beach width: the wider the beach at the base of the bluff, the slower is the rate of erosion;
vi) beach composition: bluffs fronted by gravel and cobble beaches retreat more rapidly than those fronted by sand beaches, because the former tend to be high wave-energy zones;
vii) slope of the beach and nearshore bottom: beach and bottom declivities control the amount of wave energy that is expended against the toe of the bluff;
viii) lake levels: bluffs are most susceptible to undermining by wave attack during high stands of the lake level.

We would add several other factors to the list based on our own work. Groundwater seepage may exert considerable control on the durability of the bluff to withstand erosion, particularly if there are sand-rich and clay-rich horizons in the till of the bluff. Sites where groundwater seepage occurs are revealed by near-horizontal bands of moist till that appear dark in color relative to the drier and lighter-colored zones (O'Neill, 1985). Seepage lubricates surfaces that may act as potential glide planes for slumps. Also, if the outflow of water from a seepage point is substantial, rills and gullies with deep relief are carved into the cliff's surface. Bluff surfaces that are smooth and planar undergo a slower rate of inland retreat than those that are deeply incised by an network of drainage gullies. The reason for this, one of our primary reasearch goals, is discussed at length below and will be one of the main focuses of the visit to our field sites.

Because so many natural factors directly and indirectly control the rate of bluff recession along the Lake Ontario shoreline, it is difficult to isolate the primary causative factors for any specific bluff, or for that matter for any stretch of shoreline. Furthermore, human activity -- developing property near bluffs and constructing of shore-protective structures -- has influenced, sometime profoundly, the nature, degree, and rate of coastal erosion. However, it is possible to say that in principle, a high, steep, gullied bluff, oriented to the northwest and composed of mud-rich till, and fronted by a narrow cobble beach that slopes steeply into the nearshore zone, likely will be eroding at an alarming rate, well in excess of one meter per year.

Based on our frequent trips to the lake shore under all types of weather conditions, we have observed a variety of erosional processes that are denudating the drumlin cliffs (Table 1). Our work has been directed at studying deeply gullied bluffs; we have not yet examined denudational processses of smooth, planar bluffs, which undoubtedly have a different style of cliff recession. Not surprisingly, gullied bluffs are most active during periods of heavy rainfall that lasts for several days. At such times, surface runoff becomes channelized into the rills and gullies that are incised into the cliff. Mud, sand, and gravel are flushed down the thalweg of the gullies and are deposited near the base of the cliff as small alluvial fans that radiate out from the mouth of the gully onto the upper beach. If the rain persists so that infiltration into the ground occurs, the till loses its cohesiveness. This leads to the generation of mud flows. These viscous slurries, a mixture of water and mud, have enough cohesive strength that they prevent the settlement of even large particles (> 50 cm) out of suspension. The mud flows are not restricted to the gullies, but occur everywhere on the bluff slope, wherever the ground is saturated with water and particularly where the gradients are moderate (about 20 to 60 degrees). These mud flows collectively transport a large quantity of unsorted sediment to the gullies and eventually to the upper beach where they accumulate at the base of the cliff as a wedge-shaped deposit of unstratified, poorly-sorted sediment with particle sizes ranging from clays to boulders. In effect, they resemble a glacial till, and are, in fact, difficult to distinguish from glacial debris on the basis of textural characteristics.

The mud-flow fill in the gullies is reworked by water supplied by groundwater seepage and/or surface runoff, and by rainshowers. This flowing water cuts small channels into the gully fill as it winnows out mud and entrains sand. The stream also cuts a channel through the wedge-shaped mud-flow deposits that collect at the base of the bluff. All this eroded material accumulates on the upper beach in the form of small, thin alluvial fans. These small fan deposits are quite temporary features, as waves quickly erode them when they break on the upper beach.

Slumping occurs on different scales, as masses of till, owing to shear failure, become separated from the face of the bluff and slide downward along glide planes. Fresh slump scars are a common sighting during most visits to the field sites. Large and small masses of till covered with topsoil and vegetation, including grasses, bushes and trees, occur in the middle and lower reaches of many of the gullies, and represent material that slumped off the very top of the bluff. The slumping process is enhanced substantially by periodic wave notching of the cliff base, a process which undermines the lower sections of the bluff and causes their collapse.

Under dry conditions, the bluff face is quite stable and, hence, inactive. Occasionally a boulder or pebble is dislodged and falls downslope. Wind deflation winnows and scours out clay, silt, and sand. Also, minor gravity slides have been observed where a section of the bluff has become oversteepened and collapsed, dislodging material downslope. During the winter season when storms are frequent and intense, the bluff face is remarkably stable, because of the extensive build-up of ice, as thick as a few meters, on the beach that fronts the cliff. This mass of ice serves as a natural protective revetment, and the storm waves expend their energy breaking on the ice rather than eroding the base of the cliff. Also, the bluff is frozen and covered with snow, both of which tend to insulate the cliff face from erosion. During winter or early spring thaws, mud flows transport large quantities of sediment onto the ice surface; these deposits remain perched high above the lake level until the ice melts later in the spring, and waves degrade them.

Field Measurements and Observations of Bluff Erosion

In an effort to surmise the nature, rate, and regularity of bluff retreat along southeastern Lake Ontario, we installed an array of nine steel rods on small planar sections of McIntyres Bluff (Fig.2) and a bluff near Brown Road in Wolcott, Wayne County (located about 10 km west of the jetties at the mouth of Little Sodus Bay, our second field stop). These rods were emplaced perpendicular to the slope along the bluffs' upper, middle, and lower sections, in order to establish whether the degree of erosion varies with elevation at a specific site. We attempted to select a region of each bluff that was not extensively gullied. The degree of cliff denudation was estimated by visiting the sites regularly and measuring the height of the exposed porion of the rods.

Our results are tabulated in Figure 3. Note that most of our rods (13 out of 18 installed) currently have been eroded out of the cliff or have been buried under sediment. Also, all but one of the rods emplaced near the base of the bluffs disappeared within two months of their installation as a result of burial beneath a pile of sediment debris that accumulated in this zone. However, we have sufficient data for the upper and middle regions of the bluffs to make some reasonable statements about temporal and spatial variations in the rate of cliff erosion at these two sites.

The most obvious features of our data are the changes that occur in a stepwise fashion over time (Fig.3). The bluff faces are reasonably stable during most of the year; little measurable change was noted for the seven-month stretch extending from May to November during the two-year monitoring period. Erosion seems to occur mainly during the winter or early spring These data suggest that snowmelt, thawing of ground frost, and spring precipitation, which induced seepage, surface runoff, slumping, and mud flows, were the principal factors that caused cliff recession during the measurement period. Waves, which attack the cliff at its base, cutting a notch and undermining the bluff from below, did not seem to have been a factor during this time. Bluffs are most susceptible to wave attack when lake levels are high which occurs during the early and middle summer in Lake Ontario, a time when the bluffs, based on our erosion-rod data, were inactive and stable. Another way to state this is that bluff erosion tended to occur when lake levels were low to moderately high, a time when cliff-base erosion by waves is less likely to occur. However, we know from previous observations that wave notching of the cliffs periodically contributes significantly to gravity slides and slumping. What happened fortuitously is that significant wave cutting of the bluff base did not occur at the two field sites during the monitoring period. Therefore, the erosion that we measured reflects the effects of precipitation, runoff, and seepage. Because the data are limited to two small areas at two bluff sites and to two years, these conclusions are necessarily limited and tentative. But they are a beginning at understanding details of short-term events in the long history of bluff recession.

In an attempt to identify and possibly quantify erosional and depositional processes in major gullies that are carved into the bluff face, we initiated a five-month-long profiling study of Sitts Bluff located in Cayuga County, about 2 km northeast of The Pond at Fair Haven National Park (Frederick and others, 1991). Five large gullies were profiled at three-to-four-week intervals, and a series of erosional rods were emplaced in the gullies proper and in the side slopes of the adjoining ridges. Grain-size analyses of the till indicated that it is a sand-rich deposit, comprised in terms of weight percent dominantly of sand (30 - 50 %), comparable amounts of silt and gravel (each 20 - 35 %), and a minor admixture of clay (1 - 5 %).

A summary compilation of some of our profiling data for two gullies are presented in Figure 4. They show clearly that the thalweg of both gullies periodically was lowered (erosion) and raised (deposition) as a function of time. Although this has yet to be confirmed, we suspect, based on field observations, that aggradation in the gully occurred during very wet periods when mud flows off the gullies' side slopes supplied large quantities of sediment to the gully. Subsequently, during periods of normal rainfall, channelized runoff cut into these deposits, scouring mainly mud and sand, and lowering the floor of the gully. Scouring by channelized water flow is indicated by boulder-lag deposits in the thalweg of the gully.

During the short observation period, the gullies served mainly as chutes for the dispersal of sediment shed from adjoining ridge slopes and drainage rills. Sometimes the floors of the gullies were filled with sediment, at other times they were emptied of sediment. Note that over the five-month survey there was no net change in the level of the floor in gully 1 and a net aggradation of about 60 to 80 cm in gully 2. What is perplexing, however, is that phases of erosion and deposition are not synchronous in these two gullies even though they adjoin one another (Fig.4)! The only obvious difference between the two sites is their size and orientation. Gully 2 drains directly north and is protected from the prevailing northwesterly winds by a 75-m-high ridge; gully 1 drains northwest and receives inflow from a larger tributary network carved into the bluff face than gully 2. Whether these factors somehow are responsible for the out-of-phase relationship remains problematical.

Baymouth Barrier and Beach Processes

Material eroded from and deposited at the base of the drumlin bluffs eventually is reworked by wave activity. The waves fractionate the sediment into various size fractions; the gravel and sand components are transported to the east by longshore drift across the embayed areas between drumlin bluffs where they become incorporated into the deposits of baymouth barriers and spits. This section examines the coastal processes and their resultant deposits that characterize segments of two barriers that we chose for profiling studies.

The northwest-facing baymouth barrier that encloses Juniper Pond and the surrounding wetlands to the west of McIntyres Bluff (Fig.2) is about 25-m across and relatively high, rising more than two meters above the September lake level. In profile, it resembles a broad-based triangle with a slightly steeper pondside than lakeside (Fig.5). Its crest is heavily vegetated with brush and trees and the beach is composed of medium to fine sand with a significant admixture of gravel, pebbles and cobbles..

During our three-year surveying period, the barrier remained remarkably stable despite its exposure to the prevailing winds and waves, and inclement weather. This is revealed by superimposing three topographic profiles of the same barrier site, each measured a year apart (Fig. 5). There are no substantial changes in the overall shape of the barrier, suggesting that this landform has attained a stable, steady-state configuration, at least in the short term, for the inputs and outputs of sediment, and wave-energy conditions.

Seasonal patterns of erosion and deposition are evident on the beach side of the barrier (Fig.6). The summer beach profiles are characterized best as rolling or "lumpy", and reflect minor aggradation and shifting of sand under low-to-moderate wave energy conditions. During the fall season, two to three distinct berms tend to accrete to the beach face, each typically having a slightly oblique orientation with respect to the lake's waterline. The uppermost berm represents deposition under storm conditions, a time when wave approach is from the north or northeast, rather than the more typical west or northwest quadrants. The lowest berm is the more active of the set, as it is reworked regularly by the prevailing fair-weather waves. By winter, ice builds up on the beach and the nearshore zone from swash and surf spray. The ice cover attains a maximum thickness in excess of two meters, and extends almost to the crestline of the barrier. As is the case for the bluffs, the ice which is grounded solidly to the barrier acts as an effective bulwark and protects the beach from the damaging effects of winter storms. Large storm breakers collapse against the wall of ice and fling pebbles and even cobbles up onto the ice's surface; these large particles often become covered by ice with the subsequent freezing of spray. The exposed sand at the crestline is immobilized as well by freezing spray which temporarily cements the grains into a resistant "sandstone" and "conglomerate". The lower trunks of trees and their overhanging branches get coated with ice also; some become top heavy because of the ice load and fall over, uprooting sediment. By spring, ice break up, which we have not witnessed, but has been reported by others, can scrape and bulldoze the beach, and drop pebbles and cobbles onto the sand as the beach ice melts. At this time, a reasonably prominent berm tends to form on the lower beach, which gets smeared out across the beach face by summer, creating the aforementioned lumpy microtopography. This cyclical response of the beach to the weather, we assume, is representative of tall barriers along the southeastern shore of Lake Ontario.

By contrast, low-lying barriers respond quite differantly to wave conditions, particularly those associated with storms or strong winds. A case in point is our other profiling site on a short baymouth barrier that closes off a creek and wetland area that drain the lowlying area between two prominent drumlins to the west of Brown Road (Fig.2). This barrier is narrow, about 16-m across, and rises no higher than 1.25 m above the September lake level. A comparison of three profiles taken a year apart from this site reveals its susceptibility to washover processes (Fig.7). No significant changes occurred to the barrier between September 1989 and September 1990, except for the deposition of about 10 cm of sand on the crest and upper beach face. However, a year later the entire barrier shifted its position landward by almost three meters, as a consequence of washover processes, whereby sediment on the lakeside of the barrier was transferred to its backside. The migration of the barrier shoreward was not gradual, but occurred over a very short period of time, likely during the course of a single storm event. This is suggested by a comparison of the the April and May 1991 profiles (Fig.8). Note that the "rollover" process, the transfer of sand and gravel from the front to the backside of the barrier, was completed by early May. We surmise that a combination of factors is responsible for the sudden landward displacement of the barrier. Late spring is the time of year when the lake level is rising in response to rainfall and runoff, and high river discharge. The effect of these factors is clearly evident in our May profile of the barrier which shows unusually high lake and pond levels at this time, such that merely six meters of the barrier remained emergent, rising near our profiling site no higher than 75 cm above the lake level. A storm surge created by strong onshore winds could easily have raised the water level by that much, such that storm waves would have broached the barrier, carrying sand and gravel to the backside of the barrier. The storm event responsible for overwashing the barrier probably had little rainfall associated with it. This inference is based on the fact that the metal rods set into McIntyres bluff show no sign of erosion during April 1991 (Fig.3) which they would have if there had been substantial amounts of rainfall.

During the same month-long interval (April to May, 1991), the tall barrier near McIntyres bluff showed the greatest lakeward progradation of the surveying period (Fig.8). A broad storm berm was accreted to the middle part of the beach face, widening it by four meters. If what we measured at our survey site is representative of the system, a tremendous volume of sand was plastered against the barrier at this time. Because the amount of accretion during this month-long interval is so anomalous when compared to all of our other measurements during the three-year monitering period, we assume that the storm responsible for the landward migration of the Brown Road barrier caused this depositional event as well. However, unlike the rollover effect at the Brown Road barrier,which resulted in the permanent shift of that barrier, the widening of the beach near McIntyres Bluff was temporary and did not represent a net gain of sand to the barrier system. By mid-August, McIntyres barrier had regained its former triangular profile that seems to be the stable configuration for the system (Fig.5). We should note, however, that a small washover fan occurred recently (spring 1992) on the McIntyres Bluff barrier, about 15 m to the east of our profiling transect.

Our data, which are limited, indicate that low-lying barriers are susceptible to washover processes and landward drift at times when a storm coincides with high lake levels. These conditions are more likely to occur in the spring or early summer, because lake levels are naturally higher at this time than during the remainder of the year. Moreover, it appears that washovers are uncommon during the winter season despite the high frequency of storms, because of the wide expanse of ice build-up against the shore. This ice mass absorbs the impact of waves and minimizes sediment entrainment despite the high-energy conditons. If washovers do occur during the winter, it is likely that little sediment is transported to the backside of the barrier because of the ice cover and the frozen nature of the exposed beach sand. The tentative results of our survey to date suggest that low-lying barriers along the southeastern shore of Lake Ontario are undergoing active landward migration by washover effects. This process is episodic and requires special hydrologic (high lake levels) and storm conditions. The barrier we studied off Brown Road shifted pondward by almost three meters probably during the course of a single storm. This is the only significant landward retreat of a barrier that we noted during our three year survey.

Coastal Sediment Fractionation Model

Based on our observvartions and measurements over a three-year period, we have constructed a qualitative model that purports to describe the fractionation of sediment along the southeastern coastline of Lake Ontario. Our model applies to the shoreline zone extending to the west and east of Fair Haven State Park. This coastal sector is dominated by coastal bluffs (70-80 %) separated by lowlands and wetlands, most of which are fronted with a baymouth barrier or spit (Christensen and others, 1990). Few natural inlets are evident along this shoreline segment. Hence, our model does not incorporate the complicating sedimentological effects associated with water and current discharge through an inlet. Occasionally an inlet is cut through a barrier, but it typically is short-lived because of the longshore drift of sand and gravel across the opening. Given these general physiographic conditions, we believe that the shoreline can be divided into a system of reasonably discrete coastal compartments, each consisting of three principal elements: a sediment source, a sediment dispersal network, and sediment sinks (Fig.9). Each element is described separately below.

Sediment source: For the vast majority of the shoreline under study, the active sedimentary cover is derived from a drumlin which serves as a point source for the compartment. Much of the shoreline is dotted with cliffs which represent drumlins that have been truncated by erosion. The till in these drumlins is the source of virtually all of the sediment currently being reworked by waves and coastal currents. The drumlin till is unsorted and is comprised of a heterogeneous mixture of clay, silt, sand, gravel, cobbles and boulders. This glacial material, once released from the drumlin, is what is eventually dispersed downcurrent by longshore and offshore currents.

Sediment dispersal: The network for sediment dispersal is complicated and involves two distinct pathways: one out of the source area (the drumlin bluff) to the nearshore zone, the other parallel to the shore. The dispersal mechanisms are distinct at each site of the compartment, with gravitationally-induced transport dominant in the source area and wave-generated transport prevailing in the nearshore zone. The removal of till from the drumlin bluff is accomplished by mass slumping and by water-induced transport -- surface runoff and mud flows -- down rills and gullies. In both cases, till is removed from the drumlin proper and placed at the toe of the cliff where it is eventually reworked by waves. Slumping leads to the sliding of cohesive packages of till to the cliff base. The confined flow of sediment through gullies, in contrast, leads to the formation of unsorted mud-flow deposits and stratified alluvial fans at the mouths of the gullies; if the gully system carved into the bluff is extensive, the mud-flow sediments coalesce into a wedge-shaped deposit on the upper beach. Waves then begin eating away at these deposits, eroding the fan sediment and notching the cliff or slump masses, and, by so doing, undermine the slope and induce additional gravitational sliding of till.

Waves then fractionate the sediment into various size classes, each of which has different flow paths through the coastal compartment (Fig. 9). Particles coarser than gravel tend to collect as a lag deposit on the beach that fronts the bluff. Apparently, the bluff-backed shore is a high-energy zone, likely due to wave refraction over a bathymetric swell caused by the incompletely eroded base of the drumlins and the deeper embayed areas of the lowlands to either side of the drumlins. The domimant longshore currents carry material to the east, creating a barrier or less commonly a barrier spit. The updrift end of the barrier near the bluff is composed of angular coarse gravel and pebbles; the sediment of the barrier grades into finer gravel and sand, and becomes better sorted and rounded with distance away from the bluff source. The mud fraction is put in suspension just offshore of the gravel/cobble beach that fronts the drumlin cliff, and is dispersed to the east alongshore as a discolored band of turbid water in the nearshore zone.

Sediment sinks: The boulder- and-cobble-sized particles tend to collect at the base of the drumlin bluffs. These large particles typically become well rounded and are commonly imbricated.

As the bluff face retreats in response to erosion, the boulder and cobble deposits are drowned by the advancing shoreline, and with time probably are covereded by finer sediment as water deepens. The gravel and sand fraction that is fluxed along the spit by longshore drift is molded to the beach face and nearshore zone (Fig. 9). If the barrier or spit is low-lying, then some fraction is transported across the island by washover processes where it is deposited either on the backside of the barrier or in the pond or bay proper. If the barrier is topographically high so that washovers are less likely, then the sand must be dispersed offshore in some manner that is not yet documented or is fluxed into the next compartment that begins at the base of the adjoining drumlin cliff. The suspended mud in the nearshore band is dispersed lakeward where it settles to the lake bottom.

Human Impact on the Shoreline

Many changes in depositional-erosional patterns along the present-day shoreline are the direct result of human intervention. A case in point is the construction of jetties at the entrance to Little Sodus Bay to the north of Fair Haven (Fig. 10). These structures have influenced profoundly the disposition of sediment on both the updrift and downdrift sides of the inlet. We will stop at a public beach located to the west of the inlet and walk the entire length of the barrier, trying to surmise what exact changes have been brought about to this coastal system as a result of stabilization and dredging of the bay inlet. Also, looking eastward from the western jetty, we will get a superb view of three prominent drumlin bluffs (Fig. 2), the farthest being McIntyres Bluff, our first stop of the trip. Note that the nearest bluff is vegetated, and that the other two are not. Any speculations why this is the case?

Rather than detailing the post-construction history of the shoreline adjoining the jetties, we thought it would be more valuable to make observations and attempt as a group to reconstruct what effects stabilization of the jetty has had on this coastal system. Following the discussion, we will provide each of you with a handout summarizing the sedimentation history of Little Sodus Bay and its environs. We will include information about the time of construction and the physical nature of the jetties and breakwater, the configuration of the shoreline and nearshore lake bottom prior to jetty construction, and the sedimentation-erosional patterns after jetty construction.

References Cited

Anderson, T. W. and Lewis, C. F. M., 1982, The Mid-Holocene Nipissing Flood into Lake Ontario: *American Quaternary Assoc. Program and Abstracts* , Seventh Biennial Conference, Seattle, Washington, p. 60.

Anderson, T. W. and Lewis, C. F. M., 1985, Postglacial water-level history of the Lake Ontario Basin: *Geol. Soc. Canada Special Paper* 30, 231-253.

Brennan, S. F. and Calkin, P. E., 1984, Analysis of bluff erosion along the southern coastline of Lake Ontario, New York: Dept. Geol. Sciences, SUNY Buffalo, New York Sea Grant Institute, Albany N. Y., 74 p.

Christensen, S., McClennen, C. E., and Pinet, P. R., 1990, Coastal erosion: southeastern Lake Ontario shore: *Geol. Soc. America Abstracts* 22, 7.

Clark, P. U. and Karrow, P. F., 1984, Late Pleistocene water bodies in the St. Lawrence Lowland, New York, and regional correlations: *Geol. Soc. America Bull.* 95, 805-813.

Clark, R. H. and Personage, N. P., 1970, Some implications of crustal movement in engineering planning: *Canadian Jour. Earth Sciences* 7 (no. 2, part 2), 628-633.

Dreimanis, A. and Goldthwaite, R, P., 1973, Wisconsin glaciation in the Huron, Erie, and Ontario lobes: *Geological Soc. Amer. Memoir* 136, 71-106.

Drexhage, T. and Calkin, P E., 1981, Historic Bluff Recession along the Lake Ontario Coast, New York. Dept. of Geological Sciences, SUNY Buffalo, New York Sea Grant Institute, Albany, N. Y., 123 p.

Frederick, B. C., McClennen, C. E., and Pinet, P. R., 1991, Qunatification of differential erosion patterns on a drumlin bluff along the coast of southeastern Lake Ontario:*Colgate Jour. Science* 23, 65-77.

Gadd, N. R., 1980, Late glacial regional ice-flow patterns in eastern Ontario: *Canadian Jour. Earth Sciences* 17, 1435-1453.

Hicock, S. R. and Dreimanis, A., 1989, Sunnybrook drift indicates a grounded early Wisconsin glacier in the Lake Ontario basin: *Geology* 17, 169-172.

Kaiser, R. F., 1962, Composition and origin of glacial till, Mexico and Kasoag Quadrangles, New York: *Jour. Sedimentary Petrology* 32, 502=513.

Karrow, P. F., Clark, J. R., and Terasmae, J., 1961, The age of Lake Iroquois, Lake Ontario: *Jour. Geology* 69, 659-667.

Kemp, A. L. W. and Harper, N. S., 1976, Sedimentation rates and sediment budget for Lake Ontario: *Jour. Great Lakes Research* 2, 324-339.

Kemp, A. L. W. and Thomas, R. L., 1976, Cultural impact on the geochemistry of sediments of Lake Ontario, Erie, and Huron: *Geoscience Canada* 3, 191-207.

Martin, J. O., 1901, The Ontario coast between Fair Haven and Sodus Bay, New York: *American Geologist* 27, 331-334.

McAndrews, J. H. and Power, D. M., 1973, Palynology of the Great Lakes: the surface sediments of Lake Ontario: *Canadian Jour. Earth Sciences* 10, 777-792.

McClennen, C. E. and Pinet, P. R. 1990, Southeastern Lake Ontario: a most informative field site for teaching coastal geology: *Geol. Soc.of America Abstracts* 22, 54.

Muller, E. H. and Prest, V. K., 1985, Glacial lakes in the Ontario Basin: *Geol. Soc. Canada Special Paper* 30, 213-230.

Mullins, H. T. and Hinchey, E. J. 1989, Erosion and infill of new York Finger Lakes: implications for Laurentide ice sheet deglaciation: *Geology* 17, 622-625.

O'Neill, Jr., C. R., 1985, A guide to coastal erosion processes: Information Bulletin 199, Cornell Cooperative Extension Publication, Ithica, N. Y., 15 p.

Ridky, R. W. and Bindschadler, R. A., 1990, Reconstruction and dynamics of the Late Wisconsin "Ontario" ice dome on the Finger lakes region, New York: *Geological Soc. Amer. Bull.* 102, 1055-1064.

Schroeder, R. A. and Bada, J. L., 1978, Aspartic acid racemization on Late Wisconsin Lake Ontarion sediments: *Quaternary Research* 9, 193-204.

Shaw, J. and Gilbert, R., 1990, Evidence for large-scale subglacial meltwater flood events in southern Ontario and northern New York state: *Geology* 18, 1169-1172.

Solomon, N. L., 1976, Stratigraphy of Glacial Deposits along the South Shore of Lake Ontario, M. A. thesis, Dept. Geol. Sciences, SUNY, Syracuse, N. Y.

Sutton, R. G., Lewis, T. L., and Woodrow, D. L., 1972, Post Iroquois lake stages and shoreline sedimentation in eastern Ontario Basin: *Jour. Geology* 80, 346-356.

Sutton, R. G., Lewis, T. L., and Woodrow, D. L., 1974, Sand dispersal in eastern and southern Lake Ontario:*Jour. Sedimentary Petrology* 44, 705-715.

Thomas, R. L., Kemp, A. L. W., and Lewis, C. F. M., 1972, Distribution, composition, and characteristics of the surficial sediments of Lake Ontario: *Jour. Sedimentary Petrology* 42, 66-84.

Table 1 Erosional Processes along Coastal Lake Ontario

Bluffs:

- winnowing and scouring by rain, sheetwash, and surface runoff
- groundwater percolation and seepage
- mud flows
- slumping
- gravity slides
- rock falls
- wave notching
- wind deflation
- freeze-thaw creep
- animal and human activity

Barriers:

- wave sorting, winnowing, and suspension
- longshore currents
- scour at stream outlets
- stream scour along the backside of the barrier
- storm washover
- inlet formation
- creep induced by vehicular traffic
- human construction and maintenace dredging

Beach Face:

- wave sorting, winnowing, and suspension
- scouring and rafting of sediment by beach ice
- longshore currents
- creep induced by vehicular traffic
- enhanced scour from backwash unable to penetrate frozen beach face

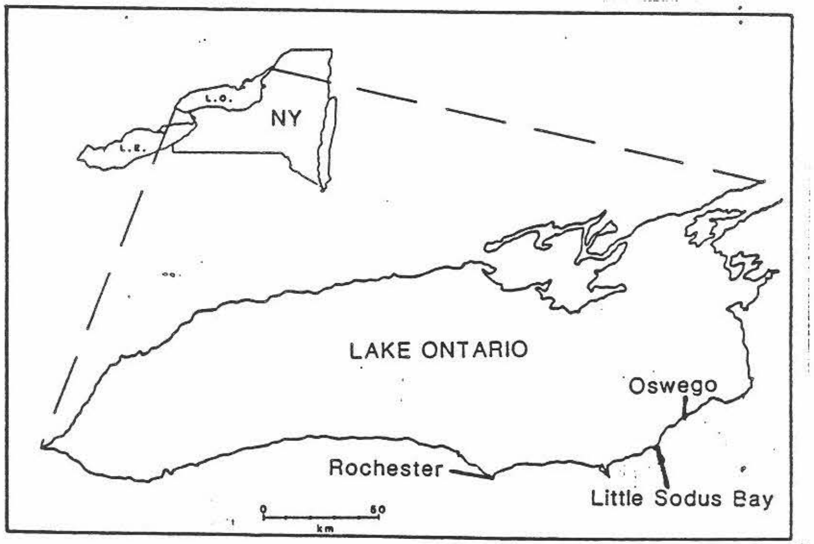

Figure 1. General location map.

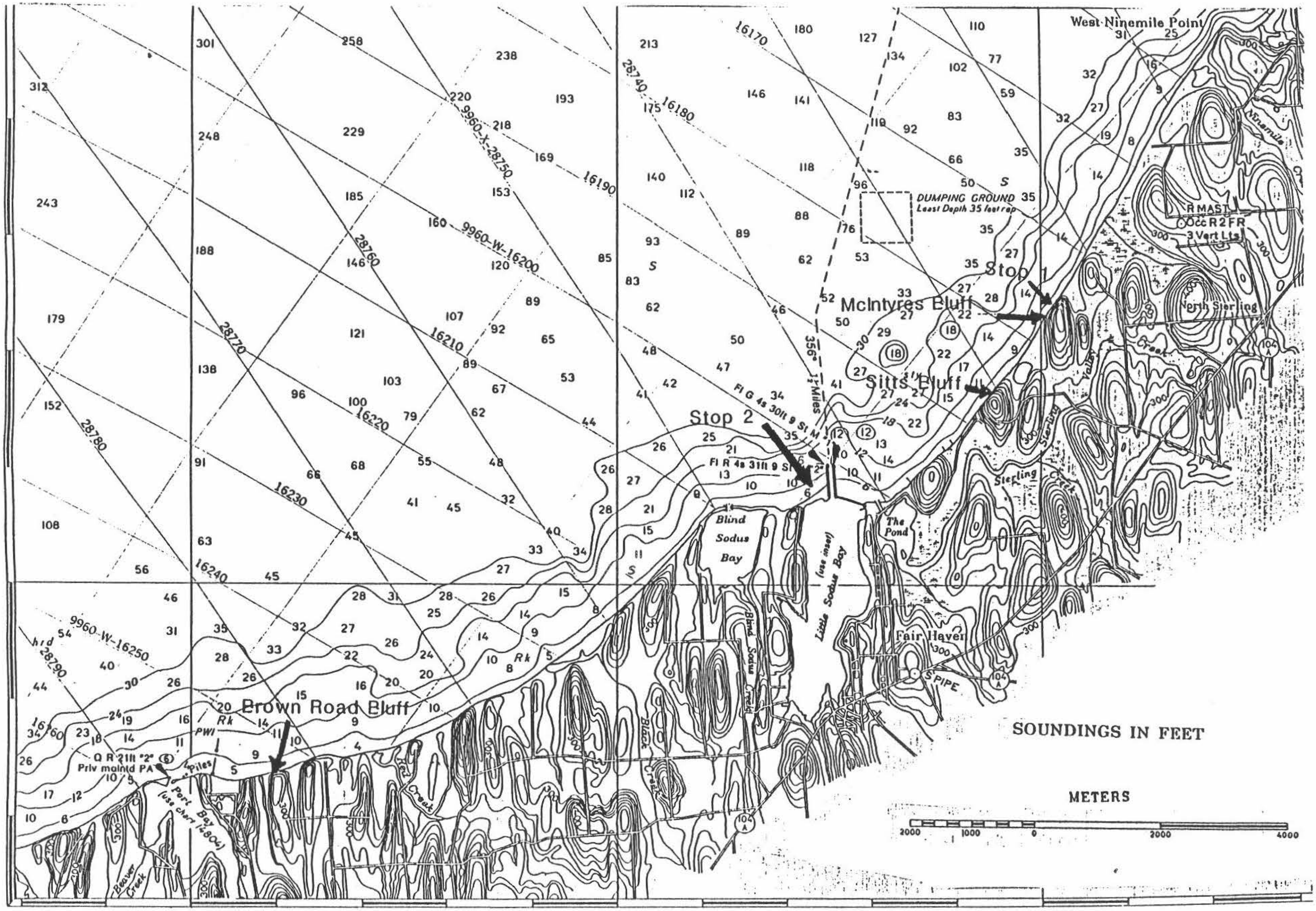

Figure 2. Southeastern shoreline of Lake Ontario showing location of the two field-trip stops.

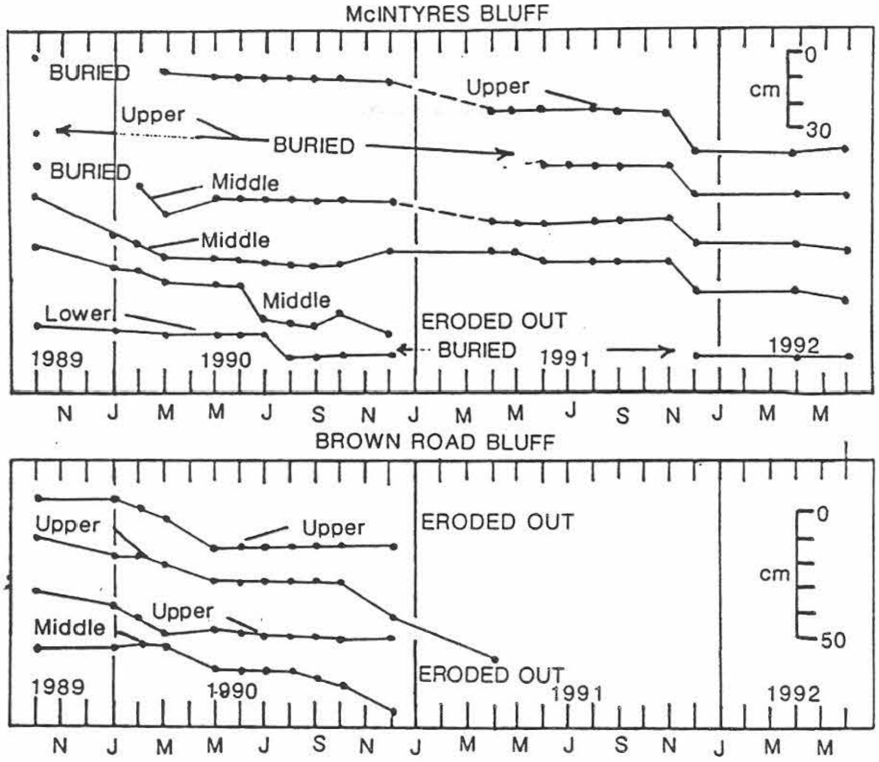

Figure 3. A plot of cumulative erosion around steel rods that were driven into the face of two bluffs.

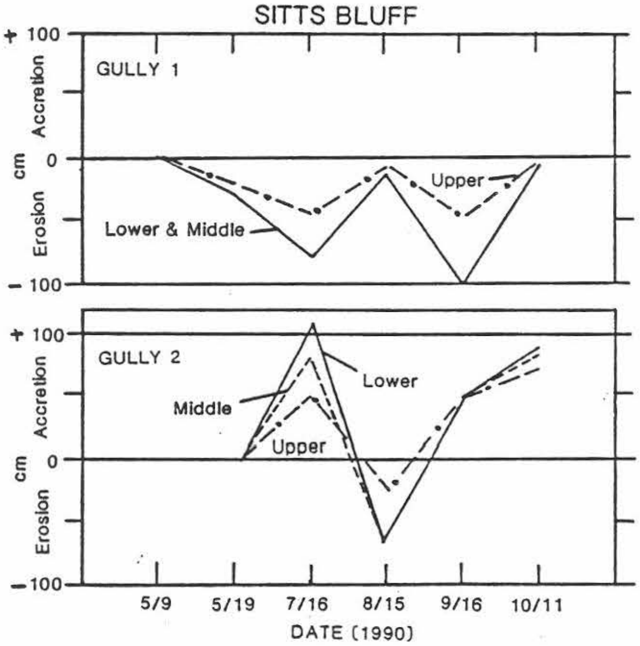

Figure 4. A time plot of variations in the floor depth of two gullies of Sitts Bluff. Gully 1 showed no net change, gully 2 a net accretion of 60 to 80 cm.

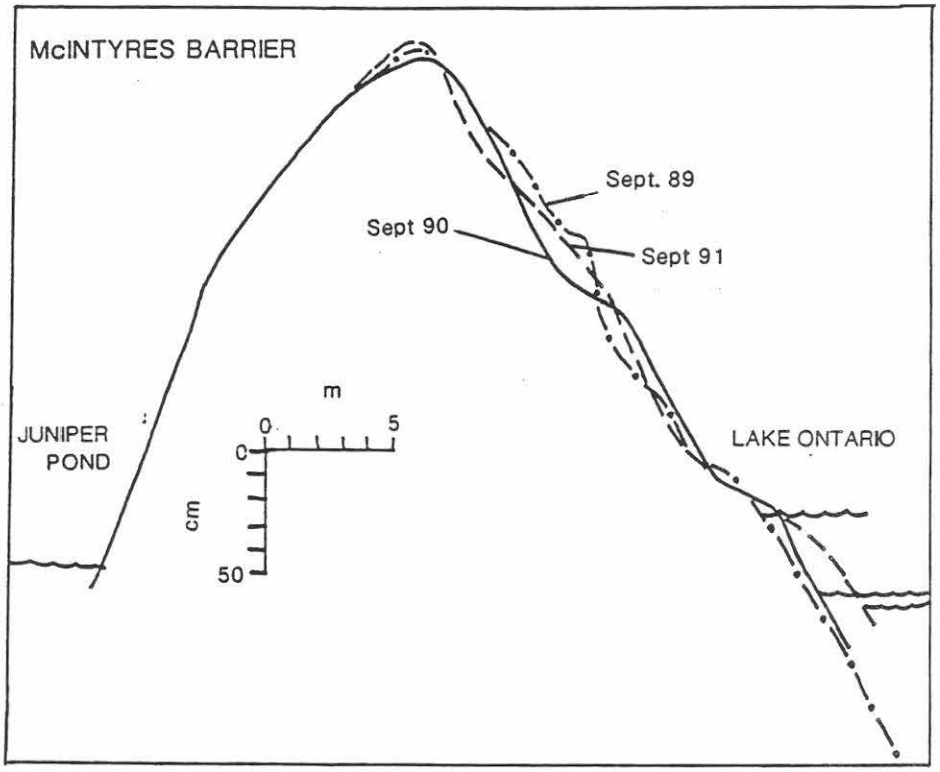

Figure 5. Beach profiles (vertical exaggeration = 10x) of McIntyres barrier.

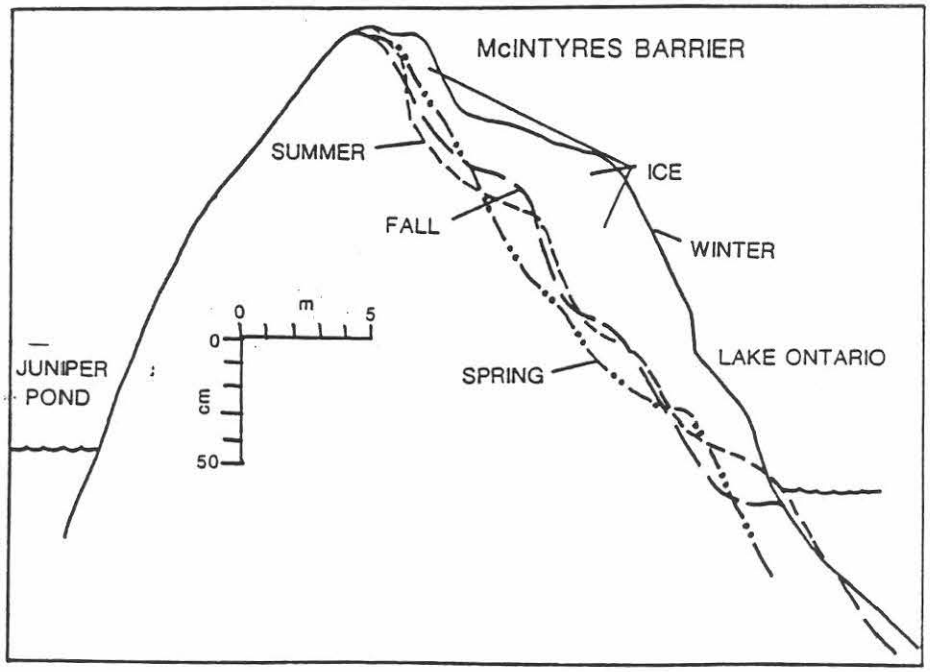

Figure 6. Seasonal variations in the beach profiles (vertical exaggeration = 10x) of McIntyres barrier.

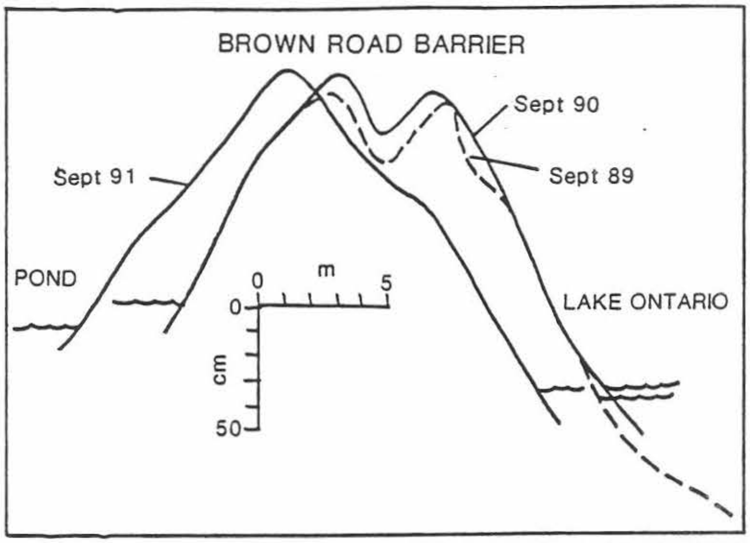

Figure 7. Beach profiles (vertical exaggeration = 10x) of Brown Road barrier.

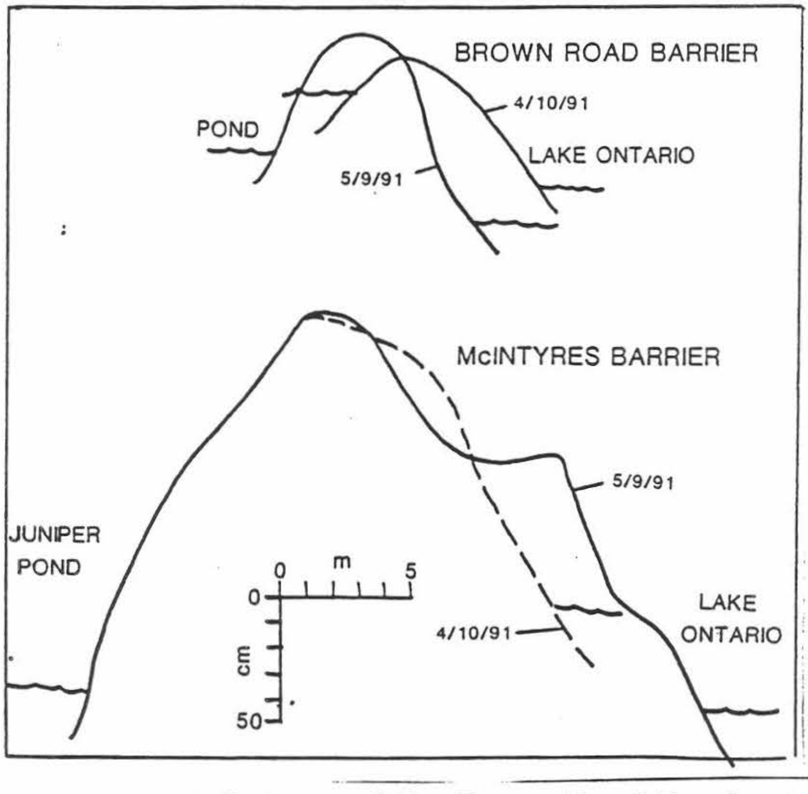

Figure 8. The storm event that caused the Brown Road Barrier to shift landward resulted in the accretion of a four-meter-wide berm to the beach of McIntyres Barrier.

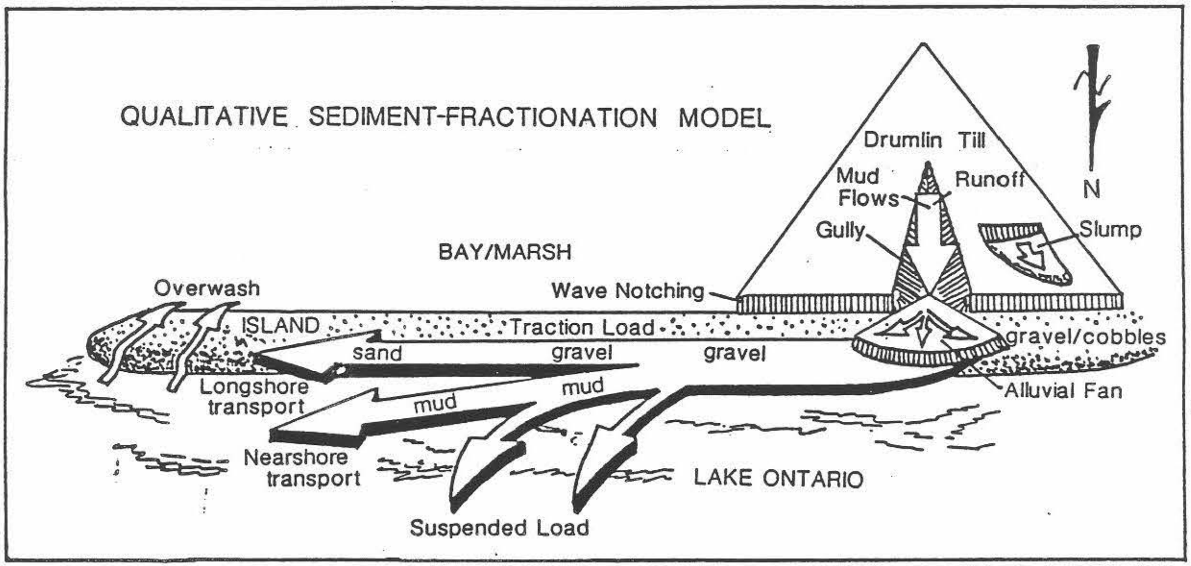

Figure 9. A model of a coastal compartment along the southeastern shoreline of Lake Ontario.

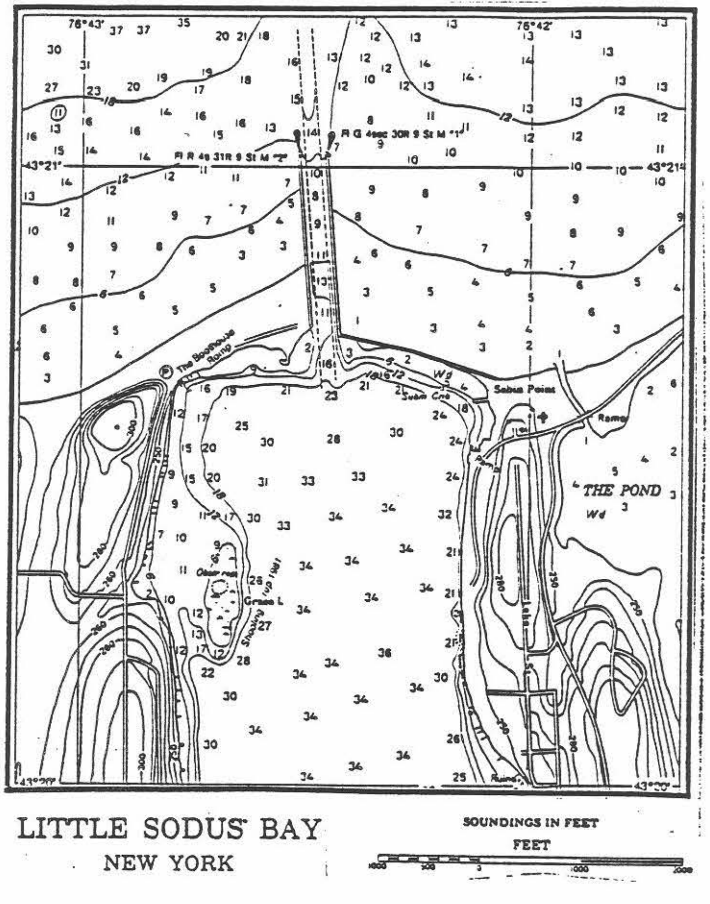

Figure 10. Chart of the jettied inlet to Little Sodus Bay.