Drumlin-Bluff And Baymouth-Barrier Erosion Along the Southeastern Shore of Lake Ontario, New York

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Introduction

The coastline of Lake Ontario has a long, complicated history of rapid morphologic development. The purpose of the trip is to examine the principal landform elements of this lakeshore sector -- drumlin bluffs and baymouth barriers (Fig. 1) -- in order to understand the shoreline's primary evolutionary history. Our focus will be on the coastal geomorphic changes that have occurred since the beginning of this century. The specific goals are 1) to assess our proposed model of coastal bluff evolution, 2) to examine the sedimentological interconnections between bluffs and baymouth barriers, and 3) to appraise the long-term impact (50-100 years) of engineered shore-stabilization structures.

A Synopsis of the Pleistocene-Holocene History of Southeastern Lake Ontario

The present-day shoreline processes of Lake Ontario are best understood against the backdrop of 1) glaciation/deglaciation that occurred between 35,000 and 10,000 years ago and 2) the post-glacial events of the Holocene. The relevant geologic events of these two time periods are summarized below.

Late Pleistocene Events

Pleistocene glaciation which began about 2 million years ago has had a profound effect on the land morphology and surficial deposits of Upstate New York. Repeated advancements and retreats by thick continental ice sheets originating in Canada have carved the bedrock, laid down glacial tills, and produced a variety of glacial landforms. The most recent advancement of the Laurentide Ice Sheet reached its maximum southerly extent some 35,000 to 25,0000 years ago, at which time it covered virtually all of New York State. The topography immediately south of Lake Ontario is dominated by an extensive drumlin field, which reflects the former presence of thick continental ice sheets in central and northern New York. Drumlins are elongated hills of glacial till that in Upstate New York range in height between 15 and 50 m and that are oriented north-south parallel to the inferred regional flow direction of the the Ontario Lobe of the Laurentide Ice Sheet. The specific origin of these drumlins is controversial. Although the consensus among glacial geologists is that the drumlins were formed and sculpted by the flow of ice (Dremains and Goldthwaite, 1973), others have recently proposed that meltwater at the base of the ice sheet during deglaciation is an unappreciated agent of drumlin construction (Shaw, 1983; Shaw and Gilbert, 1990). Regardless of their exact genesis, drumlins eroded by waves serve as the foremost point sources of sediment currently supplying the southern Ontario lakeshore. The drumlins are closely spaced to one another, and the low areas between them along the coast appear as bays, wetland swamps, harbors, and agricultural fields.

Holocene Events

With the waning of the Pleistocene, the various ice lobes of the Laurentide Ice Sheet retreated and released copious quantities of meltwater that produced numerous small and a few large glacial lakes. Some of this meltwater filled in topographic depressions, and some of it was ponded against the southern terminus of the receding ice sheet. An example of the latter in Upstate New York is Glacial Lake Iroquois, which was created about 11,0000 years ago

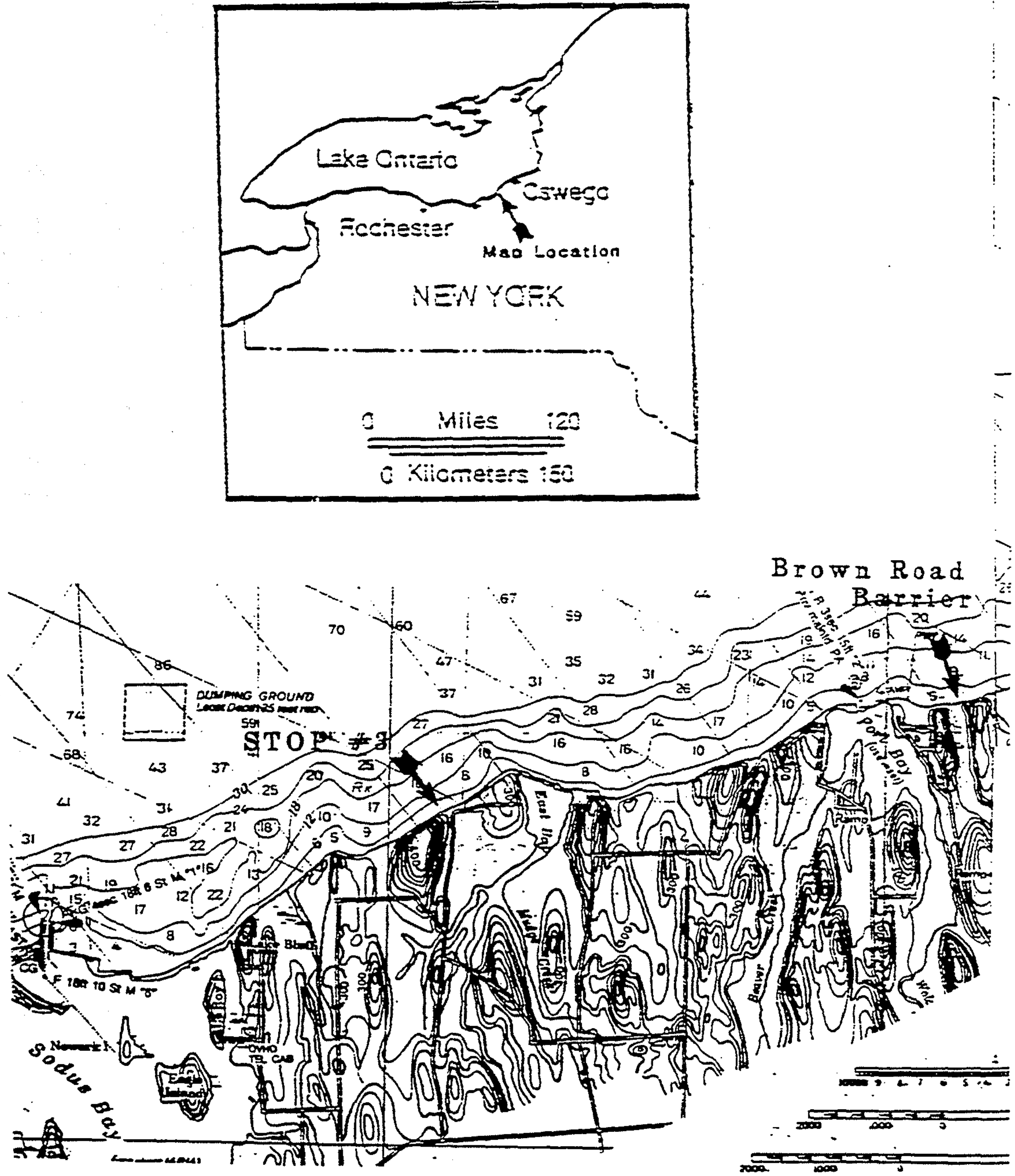
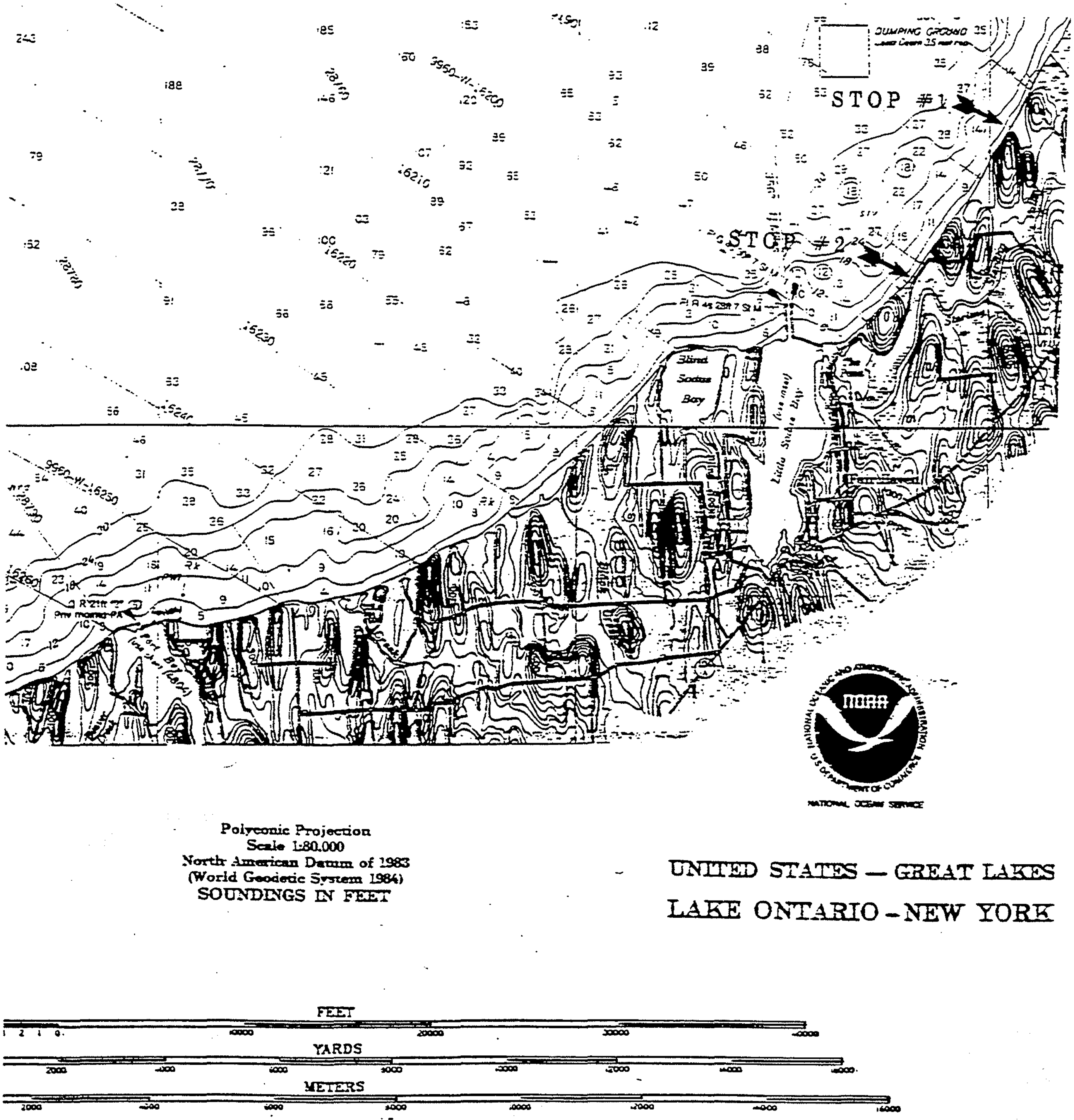


Figure 1. Coastal chart of a stretch of the southeastern shore of Lake Ontario that shows location of three main field stops.



Polyconic Projection
Scale 1:80,000
North American Datum of 1983
(World Geodetic System 1984)
SOUNDINGS IN FEET

UNITED STATES — GREAT LAKES
LAKE ONTARIO - NEW YORK

(Karrow and others, 1961; Calkin, 1970). Lake Ontario is a remnant of this much deeper and more extensive body of water. About 55 km of the Lake Iroquois shoreline between Rochester and Sodus Bay can be followed by tracing a series of truncated drumlins, downdrift baymouth barriers, wave-cut terraces, and flat lake plains on topographic maps (Muller and Cadwell, 1986; McKinney, 1997). Lake Iroquois was almost 50 m deeper than Lake Ontario is today, implying that present-day coastal drumlins were covered by water; this explains the truncation of and the presence of water-worked deposits on the crests of some of the taller drumlins, such as Chimney Bluffs. Field studies indicate that the main outlet of Lake Iroquois was to the east near Rome, New York with the lakewater discharging into the Mohawk Valley and Hudson River watershed. As the glacial ice dam to the north of Lake Iroquois melted, the lake's level dropped markedly as water discharge was established through the lowlands of the St. Lawrence River, as it remains today for Lake Ontario.

Once Lake Iroquois drained, a new strandline was established somewhere to the north (lakeward) of the current Lake Ontario shore. Drumlins that earlier had been submerged beneath Lake Iroquois water were subaerially exposed as the lake drained. The southern lakeshore then entered a stage of erosional transgression as the basin was tilted southward by differential isostatic uplift. Because the ice sheet was thicker and retreated later in Canada than in New York, glacial rebound was and continues to be greater along the northern than the southern margin of Lake Ontario. Drumlins in Upstate New York were systematically eroded away by breaking waves as the shoreline advanced southward to its current position. The former presence of offshore drumlins is indicated by boulder pavements that occupy about 40 % of the lake bottom to a distance of 4 km offshore (Fig. 2). Based on their distribution and shape, the boulder fields are interpreted as lag deposits of the largest materials (boulders and large cobbles) in the drumlin till that could not be carried away by wave activity and longshore currents (Mutch and McClennen, 1996).

At present, the southeastern shoreline of Lake Ontario consists of a series of alternating drumlin bluffs and baymouth barriers (Fig. 1). Wave notching, slumping, and gullying of the drumlin bluffs provide sediment to the nearshore and offshore zones. The mud component is suspended and fluxed offshore (Sutton and others, 1974; Thomas and others, 1972; McKnight and McClennen, 1997), whereas the coarse fraction -- sand and gravel -- is dispersed to the east by the prevailing longshore drift and is accreted to baymouth barriers that separate bays, ponds, and marshes from the lake proper (Brennan and Calkin, 1984; Christensen and others, 1990). Our studies suggest that the Ontario strandline can be subdivided into coastal compartments, each consisting of a drumlin bluff-baymouth barrier couplet (Fig. 3); the bluff serves as a point source of sand and gravel in the compartment which are fluxed eastward to a downdrift baymouth barrier (Pinet and others, 1992; Pinet and others, 1993). Although these compartments appear to be closed over the short term (years to decades), it is unclear whether or not they "leak" sediment into adjoining compartments over the long term. During the course of this trip, we will examine several of these coastal couplets, and offer an argument for their closure at least over the short term (~50 yrs).

Model of Bluff Evolution

A cursory examination of Lake Ontario bluffs reveals that their morphological character depends on the relative interplay of wave notching, slumping, and gullying. The extent of gullying is directly correlated to the height of the bluff (Fig. 4). The taller the bluff, the more deeply incised and larger the gullies tend to be. Bluffs that are no higher than about 15 m are ungullied and display steep, planar surfaces created by slumping activity (Covello and others, 1993; Pinet and others, 1997).

Our field studies indicate that the individual coastal bluffs of Ontario undergo distinct phases of morphological development, progressing systematically through young, mature, old, and terminal stages (Pinet and others, 1997). As the drumlin is eroded back by the transgressing lakeshore, its bluff height changes systematically, at first increasing until it attains a maximum height above the lake level that depends on the elevation of the drumlin's crest and thereafter decreasing until the last vestige of the drumlin is destroyed by wave erosion (Fig. 5). Below we describe the features and processes that characterize each of the four morphological bluff stages.

Young Bluff Stage

When lake waves first bite into the northern end of the drumlin, they create a low bluff. Wave notching directed at the bluff's base destabilizes the slope and causes slumping (Fig. 6). The slumped debris that collects at the foot of

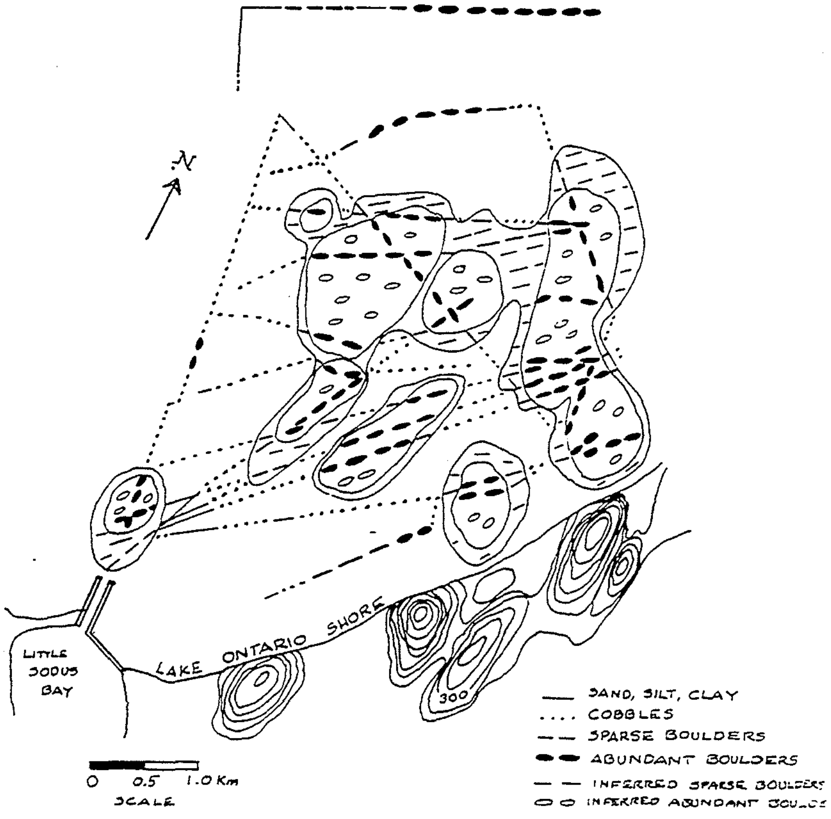


Figure 2. Interpretive map of side-scan data showing locations of boulder fields that are interpreted as lag deposits of formerly-existing drumlins.

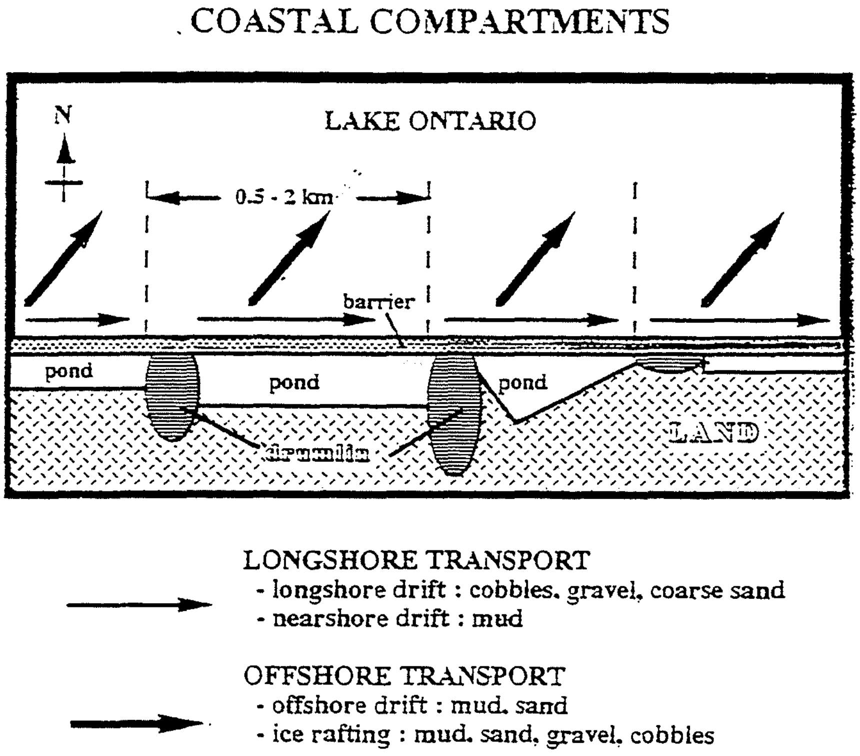


Figure 3. The southeastern Ontario lakeshore can be divided into coastal compartments, each consisting of a drumlin bluff - baymouth barrier couplet. The coastal compartments seem to function as closed systems over the short (< 50 yrs) term.

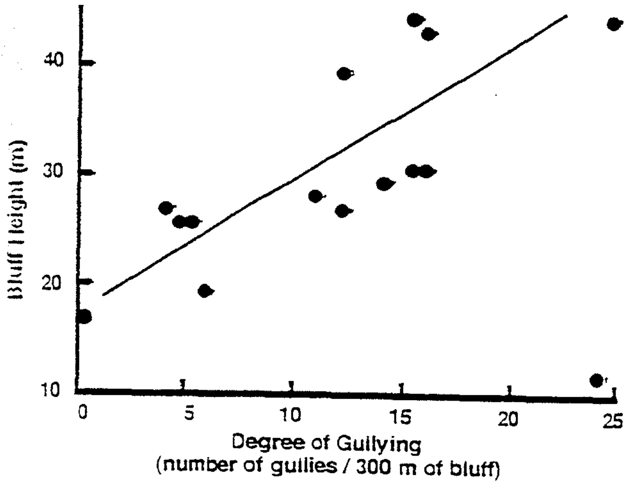


Figure 4. There is a strong correlation between the topographic height of a bluff and the degree of gullying.

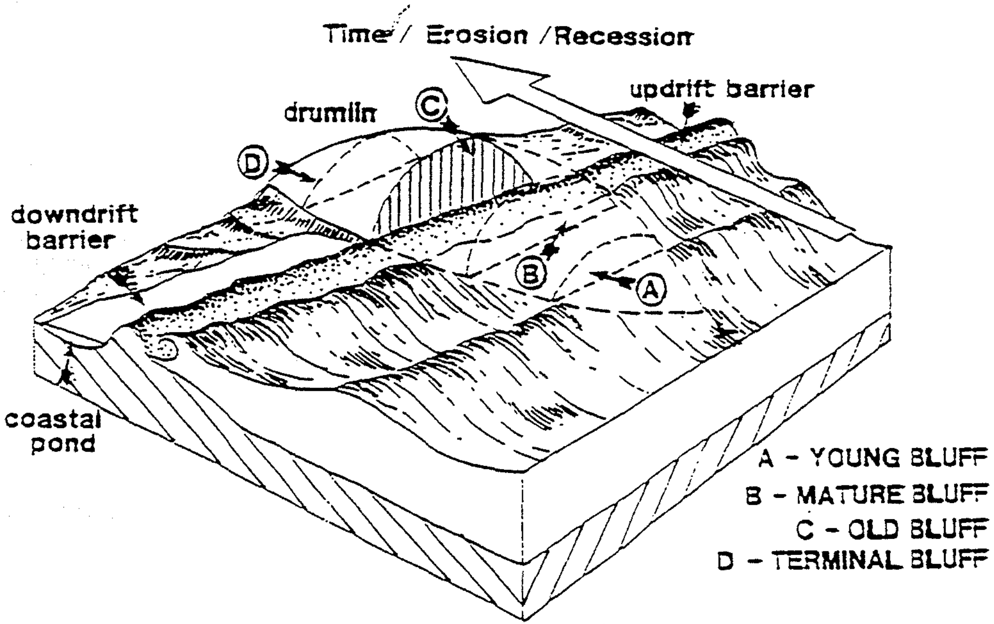


Figure 5. As a drumlin is eroded by a transgressing shoreline, the breadth and height of the resultant bluff change systematically. We have identified four distinct developmental stages -- young, mature, old, and terminal -- that are related to these morphologic changes.

the drumlin is sparse because of the low height of the bluff. In short order, breakers sort out the material in the slump masses that collects at the base, moving the suspended mud offshore and dispersing the sand and gravel to the east promoting the development of a downdrift baymouth barrier. As the drumlin is eroded back, the bluff increases in height due to the parabolic shape of the drumlin's longitudinal axis; this results in increasingly greater amounts of debris that is supplied to the adjoining beach, which as a result grows in height and width. Groundwater seepage and surface runoff (Fig. 7) carve rills and channels into the steep slump face. However, the channels do not evolve into large gullies because of the frequency of gravity slides that result from the persistent destabilization of the cliff by wave notching. This condition reflects the meager quantities of sediment that are supplied to the beach by the still relatively low-lying bluff. The domination of gravity sliding maintains a steep (> 45 degrees), planar bluff face, and the base and top of the bluff retreat landward at similar rates (Fig. 6).

Mature Bluff Stage

Recent field measurements (Montesi and Pinet, 1997) suggest that when bluffs attain a height of about 22 m above the lake level, the system crosses a geomorphic threshold and the dominant processes that denude the drumlin change dramatically. This changeover reflects the increasing quantities of sediment supplied to the beach by the collapsing bluff face which grows in height as more of the drumlin is excavated by the transgressing shoreline. Because the sediment input by gravity sliding to the beach exceeds the rate at which the debris effectively can be removed by waves and longshore currents, the base of the bluff becomes increasingly more protected from wave notching except under extreme storm conditions and/or under unusually high lake levels. This armoring effect reduces the frequency of slumping events because the bluff face is now rarely undercut and, hence, destabilized by wave attack.

The steep, stable face of a mature bluff is subjected to extensive groundwater seepage and surface runoff (Fig. 7) that in some cases are controlled by joint systems in the semi-indurated glacial till. As a consequence, channels become enlarged, as they are deepened by downcutting, and widened and lenghtened by lateral and headward erosion respectively. Eventually an extensive gully network is incised into the bluff face. The gullies when fully formed have a characteristic shape that includes a steep headwall that surrounds a bowl-shaped head region (this reflects control by groundwater stoping which promotes slumping), near vertical sidewalls that converge down gully into a narrow throat, moderate (< 45 degrees) longitudinal gradients to the gully bottom, and the presence of a colluvial fan composed of mud flow deposits that build outward onto the beach. Colluvial fans at adjoining gully mouths can coalesce to form an extensive colluvial terrace on the upper beach.

The sedimentological system of a mature bluff differs markedly from that of a young bluff. As described above, young bluffs are affected largely by lake conditions, whereby waves cut away at the bluff's base and induce frequent slumping. By contrast, mature bluff systems are controlled by the terrestrial environment, as groundwater seepage and surface runoff incise gullies into the bluff face. Headward erosion causes the gully system to lengthen and to cut deeply and irregularly into the drumlin (Fig. 6). Under heavy, persistent rain, slumped material that accumulates at the base of the gully's headwall is liquefied, producing mud flows that work there way downcanyon, eventually passing through the topographic constriction at the gully's throat and spilling onto the beach to form a colluvial fan. These fans effectively protect the bluff's base from direct wave attack which serves to stabilize the lower bluff. Hence, the top of a mature bluff erodes landward rapidly and is irregular in plan view, whereas the cliff's base is stabilized by the deposition of ample quantities of colluvium that spills out of the active gully mouths onto the beach deposits (Fig. 6). The colluvium protects the cliff base from direct wave attack, and reduces its recessional rate.

Old Bluff Stage

Groundwater and surface water drainage change appreciably with the onset of the old stage of bluff evolution. After about half of the drumlin is eroded, little groundwater and surface runoff drain lakeward; most of it flows landward away from the bluff face (Fig. 7). As such, the well developed network of gulleys becomes relatively dry and inactive. This reduces the supply of sediment to the beach, allowing waves to erode the beach back and eventually to undercut the bluff, causing slumping and reestablishment of a steep slump face that is superimposed on the gulley-floor profile (Fig. 6). As noted earlier, during the mature phase of bluff development, the top of the cliff retreats

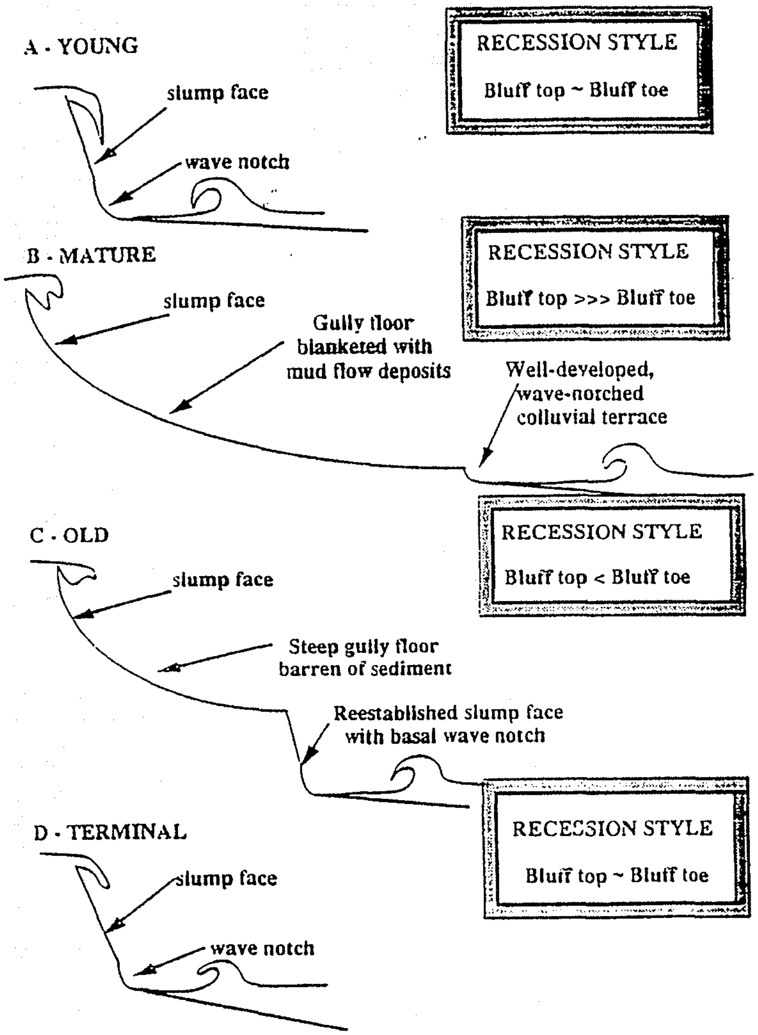


Figure 6. As described in the text, the height and morphological character of the bluff depends directly on its stage of development. Also, the recessional rate of both the top and base of the bluff vary widely depending on the bluff's evolutionary stage.

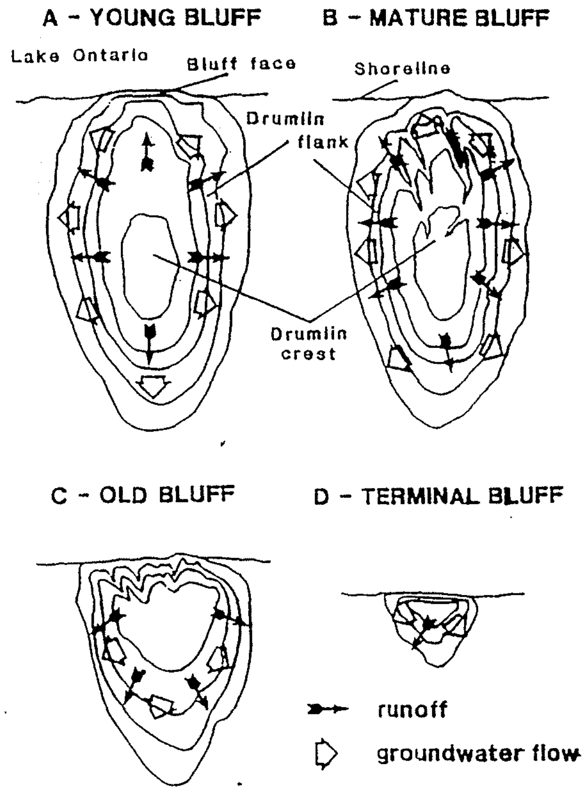


Figure 7. Young and mature bluffs are significantly affected by groundwater and surface water drainage. In contrast, old and terminal bluffs are not, drainage being directed landward away from the bluff face.

rapidly by headward erosion, whereas the cliff's toe remains more-or-less fixed because of the protection from wave activity afforded by an ample sediment supply to the beach. Once the mature bluff reaches the old stage of development, erosion of the cliff's base is reactivated and the cliff's top becomes relatively stable due to a reduction in the rate of headward erosion. With time, the steep slump face grows in height as it retreats, until the gully profile is eradicated entirely, at which point recession of the top and bottom of the cliff occurs at a uniform rate. As the drumlin is eroded further, the bluff height decreases causing a systematic diminution of the sediment supply to the cliff's base.

Terminal Bluff Stage

The final phase, the terminal stage, is a topographically low, steep bluff that results from the domination of wave notching and slump collapse of the cliff (Fig. 6). The bluff contributes increasingly less sediment to the beach as the last vestige of the drumlin is obliterated by the advancing shoreline. The only surviving evidence for the former existence of a drumlin is a boulder field (a lag deposit) in the nearshore zone that approximates the shape of the original drumlin (Fig. 2).

The Drumlin Bluff - Baymouth Barrier Couplet

Sand and gravel that are fractionated from the drumlin till and mud flow deposits of the colluvial fans are transported to the east by the prevailing longshore currents where they are shaped by waves into a baymouth barrier (Fig. 3). Clearly, any change in the rate of bluff erosion is going to affect the supply of sediment to the downdrift barrier. Rapid retreat of the bluff assures an ample longshore drift of sand and gravel, which results in a broad (> 20 m), high (~ 2 m) baymouth barrier. Conversely, the slow recession of a drumlin cliff depletes the sediment supply to the adjoining barrier which will then be low-lying and narrow. This sediment-starved barrier will be susceptible to wave overwash and, as such, will migrate landward by "rollover" processes, as sand and gravel on the lake side of the barrier are transported by overwah over the low crest to the backside of the barrier. This very process has occurred at the Brown Road barrier (Fig. 1) as waves associated with a severe storm overtopped the crest of the lowlying barrier causing it to shift landward by several meters (Fig. 8A). The same storm had no effect on the tall Juniper Pond barrier which lies downdrift of Sitts Bluff, the drumlin located to the west of McIntyres Bluff (Fig. 8B).

According to our model , the supply of sediment to the cliff base and by extrapolation to the downdrift barrier depends directly on the bluff's stage of development. The quantity of sediment that is fluxed to the downdrift barrier is greatest for the mature bluff stage when large colluvial fans at the mouth of the gulleys are growing onto the beach and even into the lake. Storm waves erode these deposits and longshore currents transport the material downdrift. Coversely, the amount of sediment eroded from the drumlin cliffs is least during the early young and late terminal bluff stages, times when the bluff height and hence sediment supply to the beach and baymouth barrier are low. In essence, the sustained and rapid erosion of a bluff results in a robust baymouth barrier, whereas a protected or stabilized bluff produces a narrow, landward-migrating baymouth barrier. As we shall see, protecting the base of drumlin cliffs with shore-stabilization structures accelerates the erosion and landward migration of the coastal compartment's downdrift barrier.

The Long-Term Impact of Shore Stabilization Measures at Little Sodus Bay

Little Sodus Bay (Figs. 1 and 9), located in Cayuga County about 25 km to the west of Oswego, New York, has been a center for trade and commerce dating back to the late 17th Century. Because of shifting shoals that interfered with shipping, jetties were constructed to stabilize the bay's inlet and to provide harbor protection. Construction on the west jetty began in 1854 and was completed by 1885; construction of the east jetty, initiated in 1872, was finished by 1906. Hence, the harbor mouth has been stabilized for about a century, offering an opportunity to assess the long-term consequences of these shore-protection structures.

Other artificial structures were built in the region in order to mitigate coastal erosion. For example, jetties stabilizing the inlet to The Pond (Fig. 9) are evident in aerial photos from 1938 to 1963, are not apparent in 1974 photos, but are visible on 1978 photos. Also, two groins were emplaced about 0.8 and 1.2 km to the east of Little Sodus Bay sometime before 1938; only the easternmost one survives today. Two additional groins (piers) were built

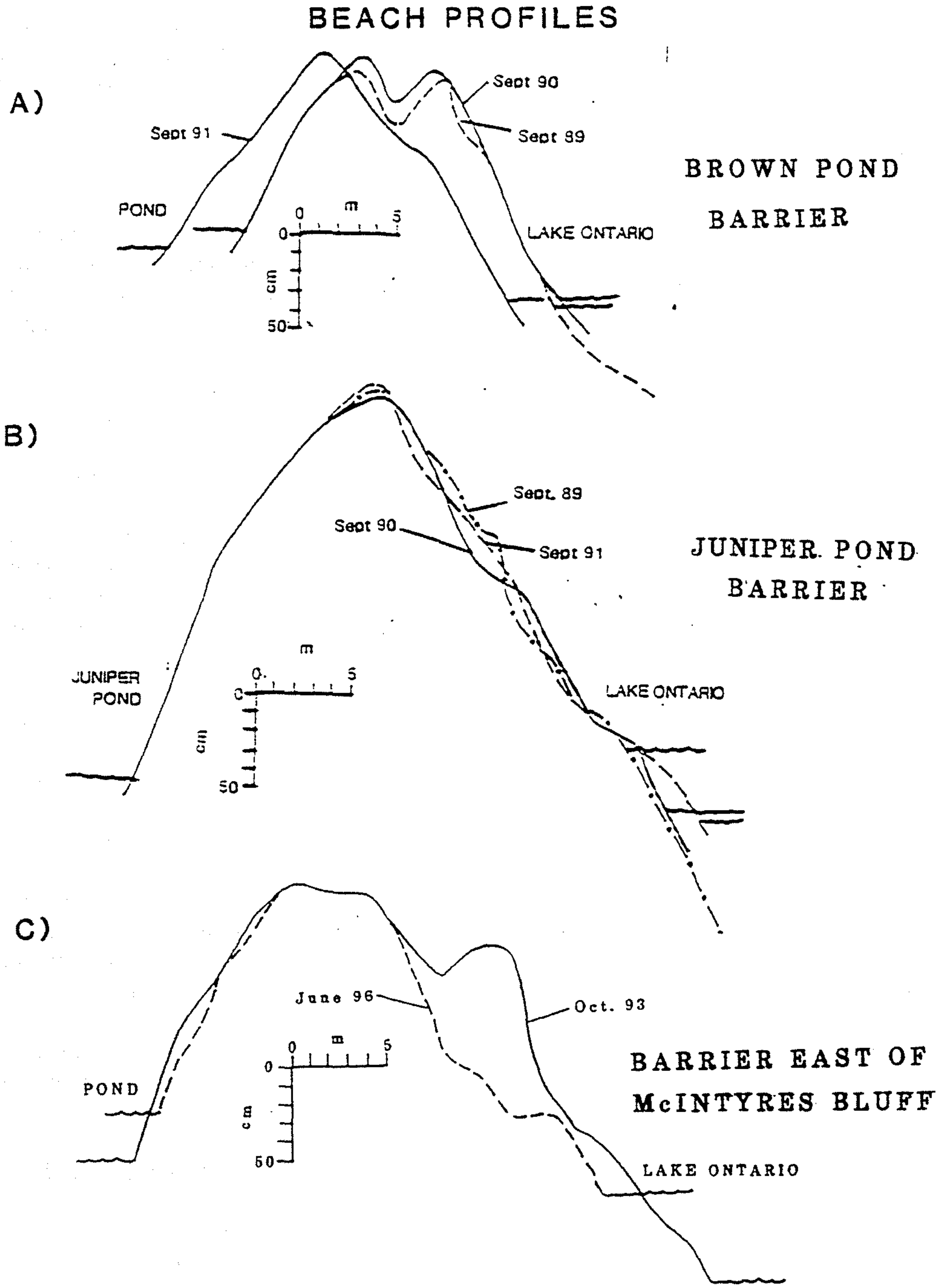


Figure 8. Beach profiles measured at selected shore sites. There exact locations are shown in Figures 1 and 12. All the profiles are drawn with a vertical exaggeration of 10X.

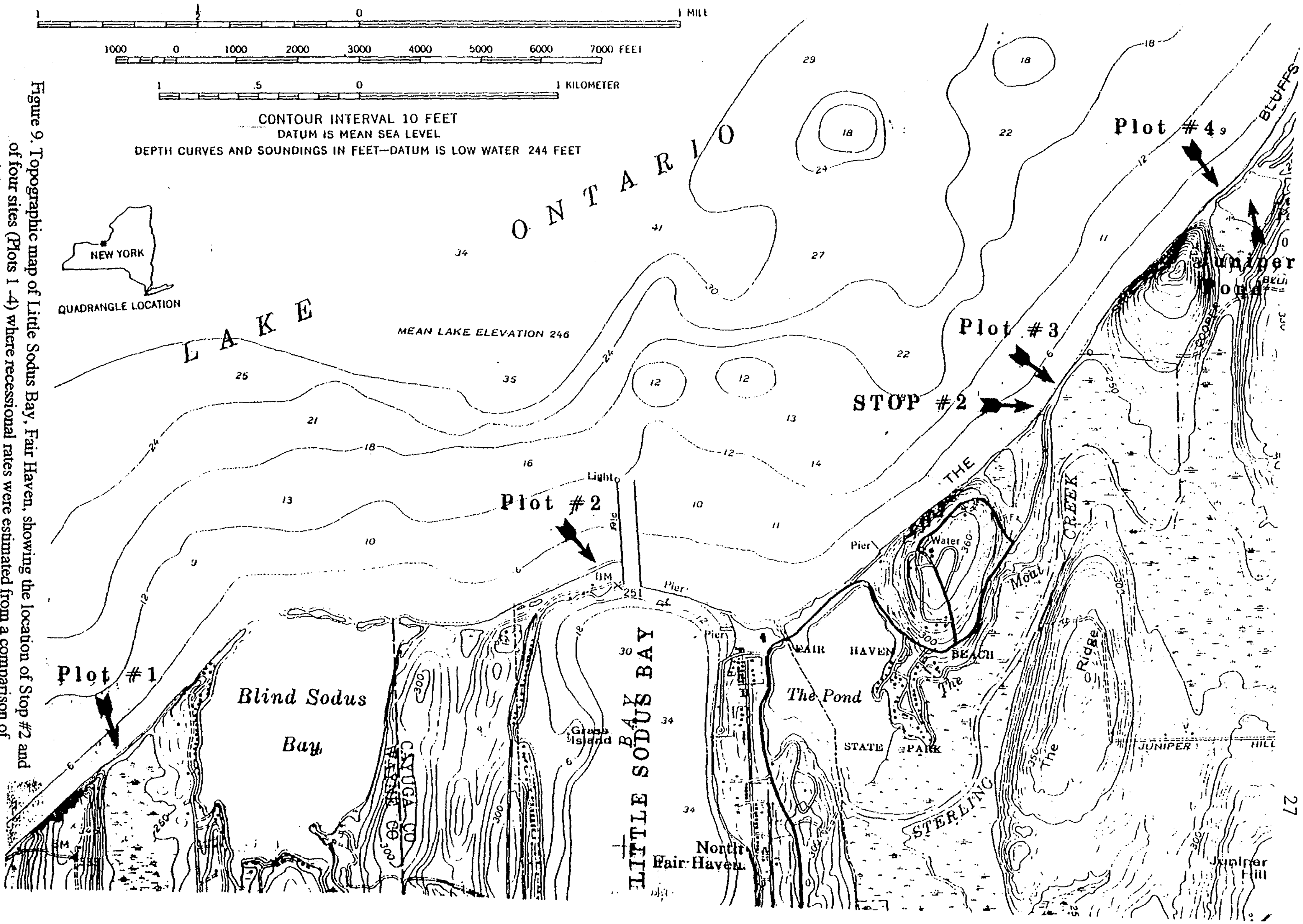


Figure 9. Topographic map of Little Sodus Bay, Fair Haven, showing the location of Stop #2 and of four sites (Plots 1-4) where recessional rates were estimated from a comparison of aerial photos; the latter are reproduced in Figure 10.

sometime between 1954 and 1960 about 2.2 and 2.4 km to the east of the harbor mouth. In addition, the entire shoreline extending from the east jetty of Little Sodus Bay to the the eastern edge of the drumlin bluff that is part of Fair Haven Beach State Park -- almost 2 km of lakeshore -- has been armored with an array of seawalls, revetments, and riprap.

A careful comparison of a series of aerial photos and in the case of the harbor mouth old survey charts reveals the 50- to 100-year long history of coastal change for four specific sites (Figs. 9 and 10). Our studies indicate that the net longshore drift is to the east, with short-term reversals of the prevailing drift during Nor'easters. We assume that the shore system consists of a series of coastal compartments consisting of a drumlin bluff-baymouth barrier couplet, the latter receiving the bulk of its sediment supply from erosion of the former. Our general conclusions are as follows:

1. The trend over time for the barrier located on the west side of Blind Sodus Bay has been net erosion, amounting to about 40 m of retreat since 1954; this translates to an average recessional rate of a bit more than 1m/yr. Note the marked shoreline progradation that occurred in the 1960s (Fig. 10). The limited amount of sediment supplied to the barrier presumably is derived from erosion of the drumlin bluff located updrift of the baymouth barrier (Fig. 9).

2. Since 1880, the beach adjacent to the west jetty of Little Sodus Bay has prograded by more than 140 m, due to entrapment of longshore drift (Fig. 10). This amounts to an average accretional rate of about 1.25 m/yr. However, note that the build-up was completed by the 1950s, and that there have been significant erosional periods during the 1970's. A dynamic "steady state" may have been reached since the 1950s. The lakeshore immediately downdrift of the east jetty has no sediment whatsoever (Fig. 9); an artificial breakwater separates the water of Little Sodus Bay from Lake Ontario.

3. The drumlin located immediately to the east of The Pond lies within the Fair Haven Beach State Park (Fig. 9); it is extensively armored with riprap and older sections of steel revetments. Also, the bluff is vegetated; this has stabilized its slope and reduced channeling and gullying of its face. These engineering measures have successfully reduced erosion of the bluff; however, this has interfered with the natural supply of sand and gravel to the small downdrift baymouth barrier of the compartment. This sediment-starved barrier is narrow and low, and has been and continues to be subjected to regular overwash which has resulted in rapid landward migration of the barrier into the backshore marsh. Our measurements indicate that the barrier has retreated landward by about 100 m since 1938, which amounts to a mean recessional rate of almost 2 m/yr (Fig. 10), a magnitude that is one of the highest that we have observed along the southeasten lakeshore of Ontario.

4. The Juniper Pond baymouth barrier (Fig. 9) appears to be in a quasi-equilibrium state since 1954, after having retreated by about 35 m between 1938 and 1954 (Fig. 10). Sitts Bluff, located updrift of the Juniper Pond barrier, is the supplier of sand and gravel for this coastal compartment. It is a mature bluff, judging from its morphology, and it is supplying sufficient sediment such that the barrier is relatively tall and broad, and, hence, stable (Fig. 8B).

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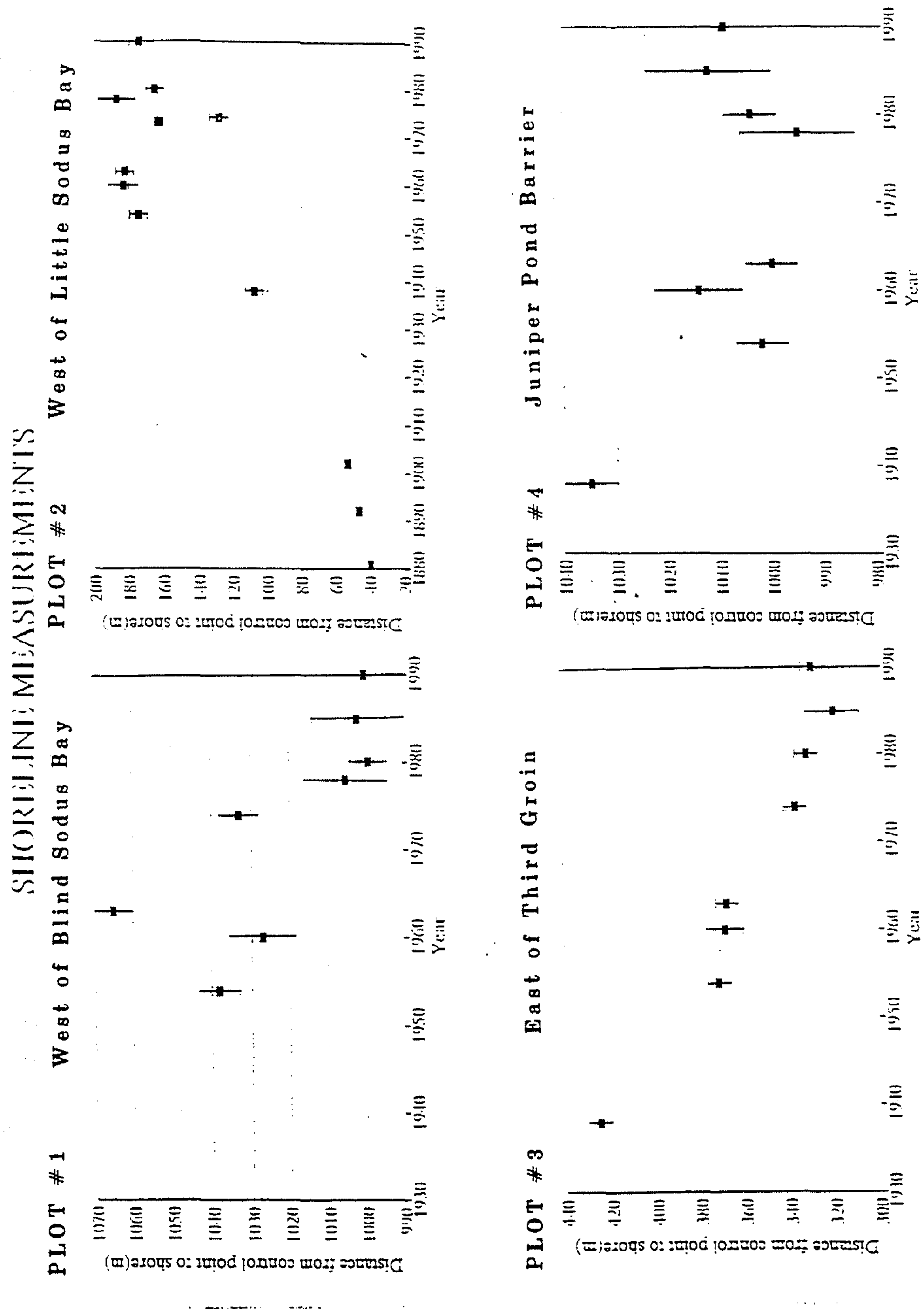

Figure 10. Each graph represents the position of the shore relative to a fixed, identifiable point on land as a function of time. The smaller the distance between the shore and the fixed control point on land, the greater the degree of erosion. The location of the plots are shown in Figure 9. Plot #1 and #3 show net erosion over time, plot #2 net deposition over time, and plot #4 little net change since 1954.

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Road Log

Cumulative Mileage	Miles From Last Point	Route Description
0	0	Start at Campus Road, Hamilton College, Clinton, NY. Head east on College Hill Road.
0.5	0.5	Turn left (north) onto Rt. 233 at bottom of hill. Drive past Rt. 5 crossing and through Westmoreland.
5.5	5.0	Turn right for Rt. 90.
5.7	0.2	Turn left to Rt. 90 tollgate and proceed onto 90 West.
38.7	33.0	Exit onto Rt. 481 North to Oswego. Interstate 481N becomes NY State 481N after about 6 miles.
63.2	24.5	Enter Fulton, staying on 481N.
64.3	1.1	Turn left onto Rt. 3 West (third traffic light at a Wendys). Continue through Hannibal on Rt. 3W.
75.8	11.5	At stop sign at the end of Rt. 3, turn right onto Rt. 104A North towards Oswego.
77.0	1.2	Just outside of Sterling Valley before a narow bridge, turn left (120 degree turn!) onto MacNeil Road.
77.1	0.1	Make a quick right (the first possible one) and continue on MacNeil Road.
77.7	0.6	Continue straight through stop sign.
78.2	0.5	Take the second right after last stop sign onto McIntyre Road (MacNeal curves to the left).
79.6	1.4	Continue onto unpaved extension ("seasonal use") of McIntyre Road.
79.7	0.1	Just before descending the hill to Lake Ontario, park between the trees on the right side of the road.

STOP #1. McIntyres Bluff and Environ

We will walk out to the edge of McIntyres Bluff in order to get an overview of this coastal compartment. BE VERY CAREFUL, BECAUSE THE EDGES OF THE BLUFF TOP ARE SUSCEPTIBLE TO COLLAPSE. Also, because the western end of McIntyres Bluff is private property with a home owner who values his privacy, we will confine our field inspection to the eastern half of the drumlin. Please comply with this request.

McIntyres Bluff is a north-south-trending drumlin. Note (Fig. 11) that the drumlin's axis lies oblique to the shoreline which east of Little Sodus Bay runs norhteast-southwest. Gravel and sand eroded from the drumlin till are transported by longshore currents to the northeast and nourish a low-lying baymouth barrier. Notice how narrow the gravel and cobble beach is at the base of the bluff. This is due to two factors: 1) the lake level this past spring has been unusually high which has resulted in more beach erosion than usual, and 2) the gullies are not supplying much debris to the beach, as indicated by the dearth of mud flows that typically fill the V-shaped gully floors as well as by the absence of colluvial fans at the gully mouths. Nine years ago when we began our field studies of the southeast Lake Ontario shore, a well-developed colluvial terrace occupied the upper beach which at that time was much broader than at present due to the availability of sediment.

Features that are important to note as we inspect the gully network include:
i. the bowl-shaped head region of the gully system and its control by jointing;
ii. wet spots on the headwall that identify zones of groundwater seepage;
iii. the ubiquity of fresh slump masses at the base of the headwall;
iv. the steep-flanked ridges and narrow throat of the gullies;
v. the presence of mud flow deposits in the stretch of gully below the headwall, and of cobble and boulder lag deposits in narrow channels that are cut into the gully fill;
vi. the angularity of the large clasts in the till and mud flow deposits and the subrounded to rounded shapes of cobbles and gravel on the beach proper;
vii. the presence of a wave notch at the bluff's base and the development of a slump scarp running the full extent of the bluff.

Given the above morphological characteristics, what stage of bluff development does McIntyres Bluff represent?

Now we will hike along the beach to the east, in order to examine the morphology and sediment character of the downdrift baymouth barrier (Fig. 11). Note that the surface of the beach that runs the length of McIntyres Bluff is dominated by boulders, cobbles, and gravel, despite the large quantities of sand in the glacial till of the drumlin. Clearly, these coarse sediments are lag and storm deposits, the sand having been eroded and transported offshore by high-energy waves. Unlike ocean beach systems, there is no long-period swell in Lake Ontario, and fair-weather waves are incapable of transporting the nearshore storm-deposited sands back onto the beach (McClennen and Pinet, 1993). As such, the beach deposits are out of equilibrium with the fair-weather conditions that prevail along the lakeshore.

Note the numerous trees that have been uprooted and fallen as a consequence of the rapidly transgressing shoreline. During the past four years, this baymouth barrier has been relatively stable as indicated by our profiling surveys (Fig. 8C). This past spring, the barrier has been overtopped by storm waves forming overwash deposits. The onset of overwash along this barrier seems related to the unsually high lake levels during the past spring, in conjunction with a significant reduction in tha amount of longshore drift due to the recent inactive nature of the gullies that are incised into McIntyres Bluff. Although McIntyres Bluff is in a mature morphological state, it is temporarily behaving as a bluff in old "age," because of the inactive nature of its gully system as indicated by 1) the lack of mud flow deposits and colluvial fans, and 2) the narrowness of the beach at the bluff's base. Presumably, the temporary reduction of sediment influx eroded from the bluff that supplies the coastal compartment is related to diminished groundwater seepage and surface runoff.

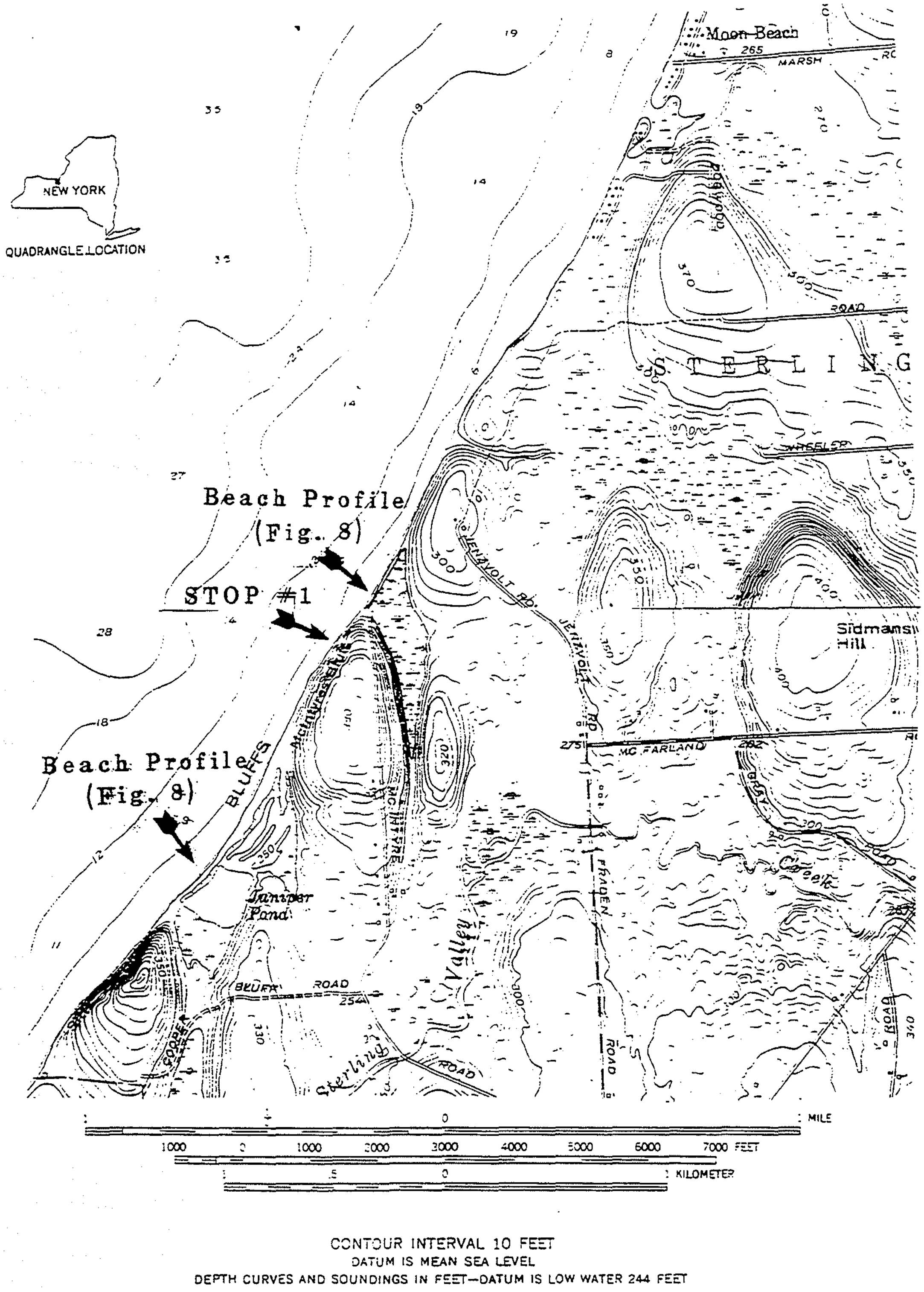

Figure 11. A topographic map of McIntyres Bluff and environs, the area to be visited at Stop #1. The beach profiles are reproduced in Figure 8.

About 0.5 km from the eastern edge of McIntyres Bluff (Fig. 11), we encounter a small bluff with a steep face and a wave notch. This small drumlin has just begun to be eroded by storm waves, and is a classic example of a bluff in a young stage of morphological development. Note the numerous fresh slumps at the bluff's base, the steep face (> 45 degrees), and the presence of rills and a few channels etched into the bluff's surface. Given that the crest of this small drumlin does not rise more than 20 m above the lake level, which is slightly below the geomorphic threshold that we believe separates young from mature bluffs (Montesi and Pinet, 1997), we expect that it will not undergo extensive gully development as the drumlin is cut back by the advancing shoreline; rather it will remain a young bluff and eventually pass directly (i.e., bypass the mature and old stages) into the final terminal stage of morphological development. However, if the gullies of McIntyres Bluff are reactivated and supply copious sediment to this downdrift barrier such that the beach widens substantially, then its possible that this small bluff will be protected from frequent wave attack, allowing the onset of gullying despite its small topographic stature.

Road Log (cont.)

Cumulative Mileage	Miles From Last Point	Route Description
79.7	0	Turn around and head away from lake Ontario.
81.2	1.5	Turn right (southwest) at yield sign onto Sterling Center Road.
81.9	0.7	Turn right (west) at stop sign onto Old State Road. You will be driving over a series of prominent drumlin hills.
84.2	2.3	Bear right onto 104A at yield sign, continuing west toward Fair Haven.
84.6	0.4	Just outside of Fair Haven, turn right onto road leading to Fair Haven Beach State Park.
85.9	1.3	At Park toll gate, continue straight on the road, proceeding past a series of parking lots and picnic grounds that are scattered along a barrier beach.
86.9	1.0	Bear right. Do not go left, uphill to a "Camping and Bluff Picnic Area."
87.3	0.4	Continue straight onto a gravel road and follow to the end.
87.7	0.4	Park by quarried limestone blocks right at the Lake Ontario shore.

STOP #2. Beach at Base of Drumlin Immediately to the West of Sitts Bluff

The lakeshore from this point westward to Little Sodus Bay (Fig. 9) has undergone extensive engineering in order to stabilize the shore of North Fair Haven and Fair Haven Beach State Park. The 1.5-km-long strand has been armored with jetties, seawalls, revetments, riprap, and groins. All of these structures are accessible by walking along the beach to the west. If we look to the northeast, we can see Sitts Bluff with its towering, unvegetated cliffs (Fig. 9). To the southwest, we can see a large drumlin that lies within the State Park. Note that it is vegetated and is stabilized by a revetment along the shore.

After examining a groin (pier) that has been reattached to the shore with riprap, we will proceed to the northeast in order to examine a baymouth barrier that is retreating at a rapid rate, at almost 2 m/yr (Figs. 9 and 10). This is not surprising, given that the net longshore drift is to the east and the barrier lies downdrift of jetties and groins, and that the base of the two bluffs between The Pond and the baymouth barrier are protected by seawalls, riprap, and revetments. This section of the lakeshore is sediment starved. Therefore, the baymouth barrier is retreating landward rapidly as storm waves overtop the beach ridge causing extensive overwash. Note the well-rounded character of the beach material.

One reason why we believe that at least segments of the southeastern Lake Ontario shoreline consist of discrete coastal comparments is that sediment starvation here is confined to the drumlin bluff-baymouth barrier couplet. Downdrift of us lies Sitts Bluff, an unprotected drumlin in a late mature stage of morphological development that is supplying coarse sediment to its dowdrift baymouth barrier. Our beach-profiling studies (Fig. 8) indicate clearly that the barrier to the east of Sitts Bluuff has been in a quasi-equilibrium state since 1950, and has not retreated appreciably in contrast to the barrier that we are currently examining. In other words, the past 50 years of severe sediment starvation that characterizes the segment of the lakeshore that we are now examining has not affected the adjoining downdrift compartment, suggesting that bluff-barrier couplets are self-contained entities to a large degree.

Road Log (cont.)

Cumulative Mileage	Miles From Last Point	Route Description
87.7	0	Depart Stop 2 parking area and head out of park the same way you entered it.
89.5	1.8	Pass through Park toll gate.
90.8	1.3	Turn right (west) at stop sign onto Rt. 104A ("Seaway Trail") and proceed through Fair Haven.
96.4	5.6	Rt. 104A turns to the right in the town of Red Creek; continue on Rt. 104A.
97.6	1.2	Rt. 104A ends at traffic light; turn right (west) onto Rt. 104 West.
100.2	2.6	Turn right (north) onto Ridge Road, following the "Seaway Trail" to Wolcott and to "Rt. 89" and passing through Wolcott Falls.
101.8	1.6	In Wolcott, turn right onto Main Street, still following the "Seaway Trail."
102.8	1.0	After State Police Station, turn right onto Loomisville Road.
106.8	3.8	Turn right onto East Bay Road (Caution - the road sign reads E Bay Road).
108.7	2.1	Turn right (north), continuing on East Bay Road just after wetlands and stream.
109.6	0.9	Park in the lots at the end of East Bay Road at the Ontario lakeshore.

STOP #3. Chimney Bluffs

Chimney Bluffs (Fig. 12), an undeveloped State Park, is located about 22 km to the west of Stop #2 (Fig. 1), and about 3 km to the east of Sodus Bay. This excursion adds a considerable amount of time (1-2 hrs) to the trip. Chimney Bluffs is a high, broad drumlin with enormous, deeply-incised gullies that are unusually long for the Ontario lakeshore. According to our classification, it looks to be in a very late mature stage of morphological development, as judged from its appearnace on topo maps (almost half of the drumlin has been eroded) and clear signs of old "age" in the field. As we walk along the beach to the west, note how the steep, planar, low sides of the bluff which are controlled by gravity slides are replaced by small and then large gullies as the bluff height increases toward the drumlin's center. Also, note that the gully floors are devoid of thick accumulations of mud flow deposits. However, there are remnants of colluvial fans at the gully mouths that have been eroded back by waves to the bluff face; observe how difficult it is to distinguish glacial till from mud flow deposits which grade into one another at the gully mouths. Wave notching and a slump scarp at the bluff's base are clear evidence of a lack of sediment supply to the adjoining beach. If our interpretation that Chimney Bluffs is in the old stage of morphological evolution is correct, we expect that the rate of retreat of the top surface of the bluff will diminish with time, whereas recession of the base of the bluff will likely accelerate as the sediment supply to the beach is reduced, allowing storm waves to undermine the bluff and cause increasingly more slumping with time.

As we approach the west flank of the drumlin, we will encounter varved lake sediments deposited in glacial Lake Iroquois. Typically the varves are millimeters thick, and alternate between clay-rich and silty sand-rich laminations, the former representing low energy winter conditions when the lake surface was frozen, the latter higher-energy conditions associated with spring melting. Ice-rafted dropstones are common. Some of the varve sequences are distorted, crumpled into tight folds, that represent either soft-sediment deformation, iceberg keel groundings, or minor glacial ice readvancements during the retreat of the Ontario Lobe of the Laurentide Ice Sheet.

We can return to our vehicles by climbing up the bluff along a crestal trail which provides a superb panorama of the gullies, embayments, fans, and beach and nearshore features. BEWARE OF TREACHEROUS FOOTING AND UNSTABLE CLIFF EDGES. If you prefer, you may return to our starting point by retracing your steps along the beach. For those of us hiking the ridge line, note the appearance of the gullies from above and the nature of the shoulders of adjoining gullies. Also, the map view of Chimney Bluffs shows a flat top to the drumlin, a feature that is attibuted to wave planation when the drumlin was immersed beneath Lake Iroquois. Support for this interpretation is provided by irregular lag deposits of gravel that are visible at the very top of some of the gully headwalls. Presumably, the glacial gravel was sorted and the pebbles were rounded by shallow-water wave activity

Figure 12. A topographic map of Stop #3, Chimney Bluff.

on this former shoal which at that time was located several kilometers offshore of the southern Lake Iroquois shore.

Road Log (Return to Clinton)

Cumulative Mileage	Miles From Last Point	Route Description
109.6	0	Head south from parking lot along East Bay Road.
110.5	0.9	At stop sign, turn left and continue on East bay Road.
112.6	2.1	Turn left at stop sign onto Loomisville Road.
116.4	3.8	Turn left (east) at stop sign onto West Main Street, heading into Wolcott.
117.4	1.0	In Wolcott, bear left after traffic light onto Oswego Street which becomes Ridge Road. Follow signs "to 104 East."
120.1	2.7	Continue across Rt. 104, staying on Ridge Road.
122.2	2.1	Bear right onto Rt. 370, and pass through Victory, Cato, Meridian, and Baldwinsville.
143.5	21.3	In Baldwinsville, turn left onto Rt. 690 South.
148.9	5.4	Take exit for Thruway Rt. 90 East.
195.4	46.5	Take Exit 32 for Westmoreland-Rome and Rt. 233.
195.6	0.2	Turn left heading south on Rt. 233.
200.6	5.0	Turn right onto College Hill Road at blinker.
201.1	0.5	Turn right onto Campus Road of Hamilton College.