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QUATERNARY STRATIGRAPHY AND BLUFF EROSION
WESTERN LAKE ONTARIO, NEW YORK

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INTRODUCTION

Wave-steepened bluffs along the south coast of Lake Ontario display the most continuous and some of the most interesting exposures of glacial drift in New York. Study of these bluffs provides detail of local and regional Pleistocene history, as well as insight into mechanisms of glaciolacustrine sedimentation. In addition, knowledge of the composition, structure and correlation of bluff materials is fundamental to interpretation of rates and modes of coastal recession and sediment contribution to the lake basin. Wave and subaerial erosion of these bluffs has been particularly severe because bedrock comprises a very small part of the bluff sections.

Record, or near-record high lake levels between 1972 and 1978 greatly accelerated bluff recession and provided the stimulus for a Sea Grant study at SUNY Buffalo of more than 400 km (250 mi) of Lake Ontario coast in New York (Drexhage and Calkin, 1981).

In this guide book we focus on 1) the geologic setting, composition and stratigraphy of the bluffs west of Rochester (Fig. 1); 2) the historic rates and distribution of bluff recession and sediment loading to the lake along this same reach of coast; and 3) some of the factors that influence local differences in recession rates.

Much of the data on bluff recession in this report is from the comprehensive study of historic recession along the whole coast in New York (Drexhage and Calkin, 1981), as well as more local studies (Fortune and Calkin, 1981; Brennan and Calkin, in press). A comprehensive account of the Lake Ontario bluff stratigraphy in New York will be published elsewhere (P.E.Calkin and E.H.Muller, in prep.), but preliminary accounts have been presented by Calkin and Brennan (1976) and Calkin and others (1978).

Basic field measurements and sampling for the stratigraphic study were undertaken during the summers of 1974 and 1975 when Lake Ontario levels were, at times, as much as 1.5 ft (0.45 m) above the 100-year monthly averages which range from 245 to 246.6 ft (74.68 to 74.86 m), respectively. Bluff sections were measured at least every kilometer. Attempts were made to trace stratigraphic units continuously along the coast. In this guide, the same station numbers are used for location on Figures 5 through 25 and are referred to in the text without figure numbers and usually within parentheses.

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* Field trip leaders

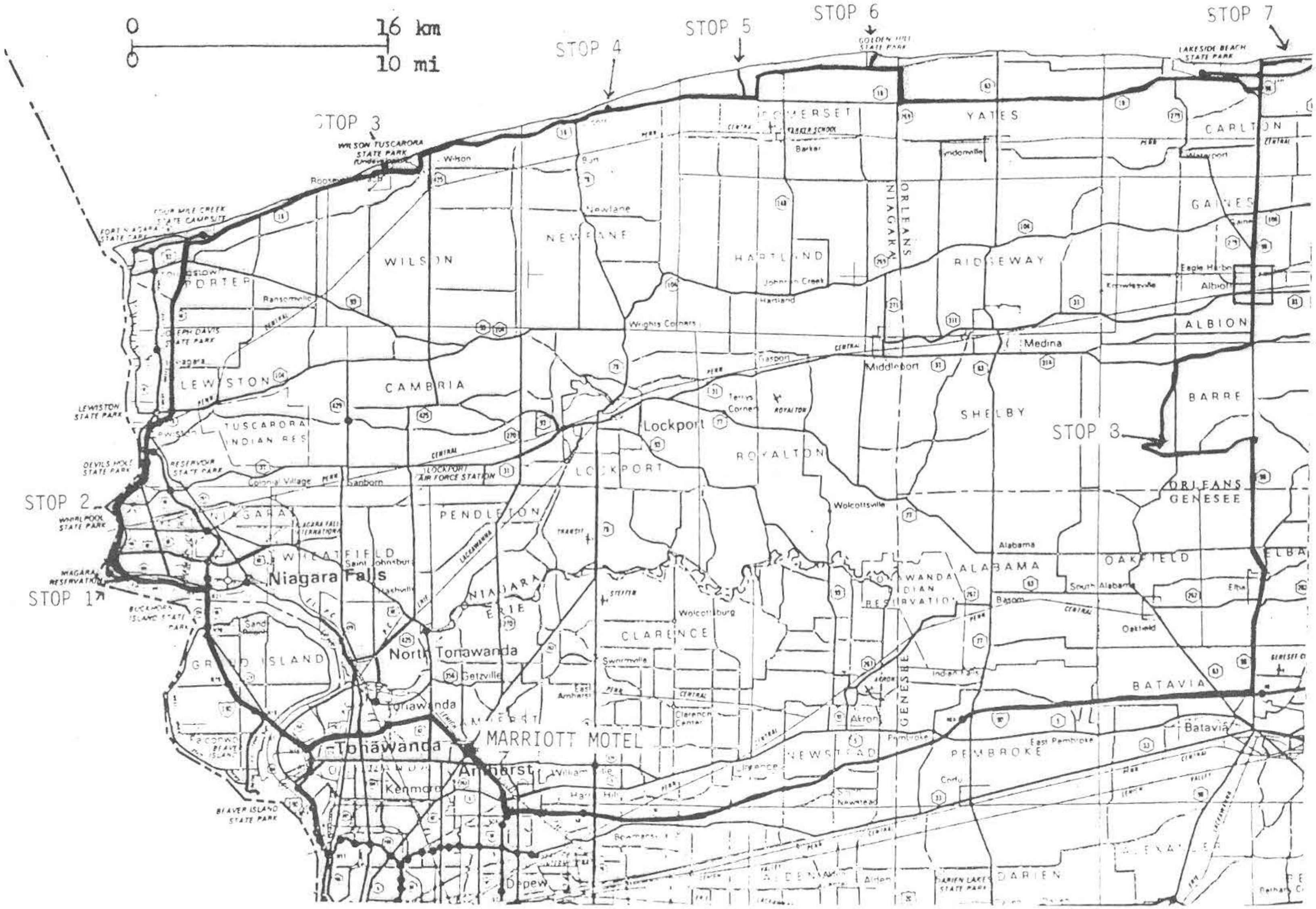

Figure 1A. Field trip route and stops for Lake Ontario shore bluffs field trip. Figures 1A and 1B are the same scale; e.g. Golden Hill State Park (Fig. 1B is at Thirty Mile Point (Fig. 1A).

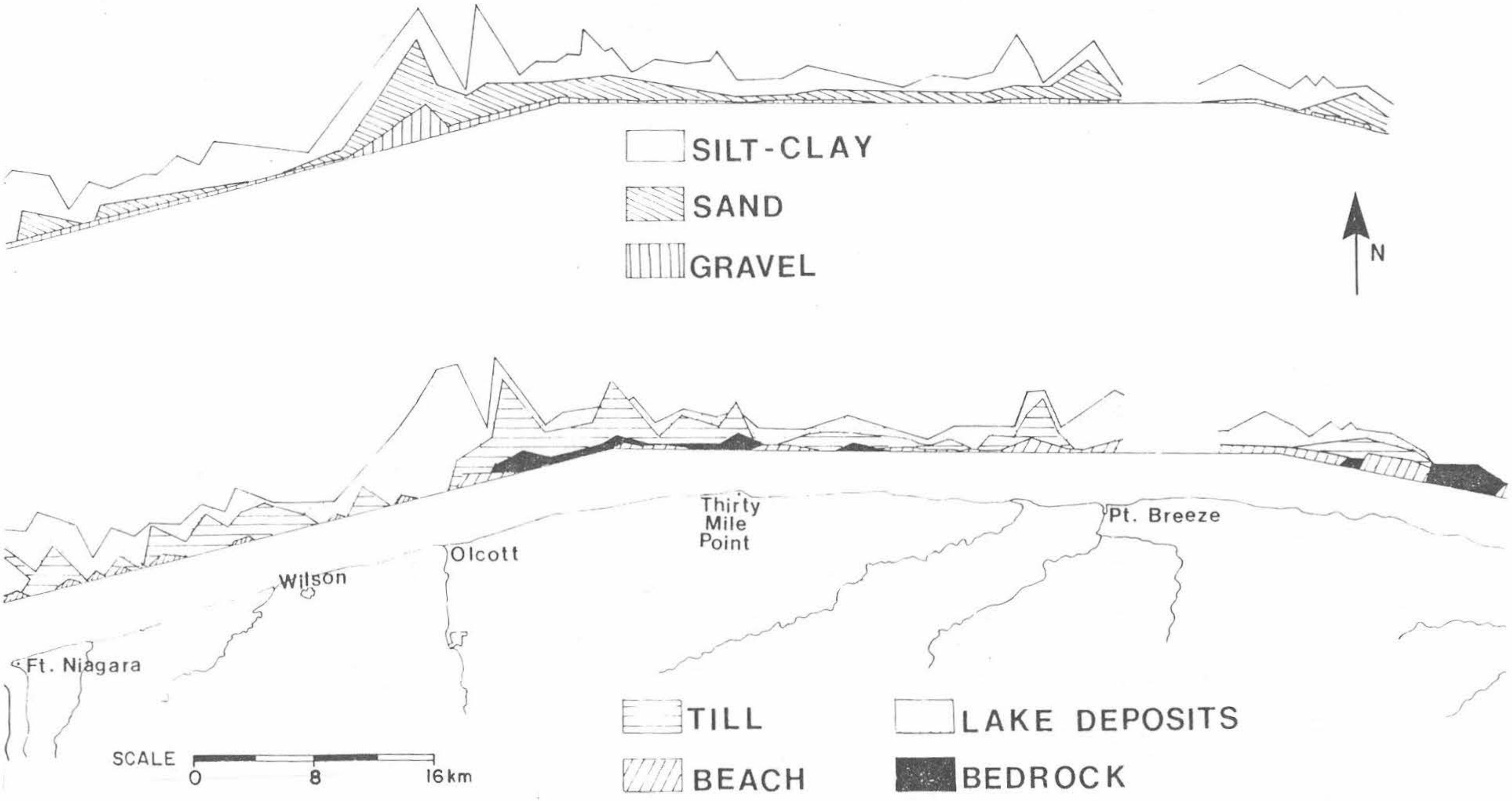

Figure 12. Areal distribution of sediments in bluff exposures along the south shore of Lake Ontario, by textures (above) and genesis (below) (Brennan and Calkin, in press).

The glacial geology of the south coast of Lake Ontario has been studied by many workers, particularly between 1880 and 1930 (Muller, 1965). The most pertinent works are those of Kindle and Taylor (1913), Dames and Moore (1974), Salomon (1976) and Muller (1977a, 1977b). Adjacent portions of the Niagara Peninsula in Ontario have been mapped by Feenstra (1972a, 1972b, 1975, 1981).

LATE QUATERNARY HISTORY

Glacial deposits in western and central New York originated during at least one pre-Wisconsin glaciation and five successively less extensive Wisconsin stadials (Calkin, 1982; Calkin and Wilkinson, 1982; Calkin et al., 1982). During the last, or Port Huron Stadial, starting about 13,000 yr BP (Dreimanis and Goldthwait, 1973), ice advanced through the Ontario Basin to the margins of the Allegheny Plateau. Glacial lobation into the Erie Basin formed the Hamburg Moraine (Frontispiece II) southwest of Buffalo while the ice margin reached a position at or south of the Waterloo-Auburn Moraine in central New York (Connally and Sirkin, 1973; Muller, 1977b). At the same time, glacial advance in Michigan formed the Port Huron Moraine and initiated the westward-draining glacial Lake Whittlesey in the Erie-Huron Basins. Oscillatory retreat and moraine formation in the Erie Basin is correlated successively with glacial Lakes Warren I and II, Wayne, Warren III and possibly lower, short-lived Lakes Grassmere, Lundy and Early Algonquin before initiation of Early Lake Erie and Lake Iroquois about 12,400 yr BP (Calkin, 1970; Muller, 1977b). During this interval, ice movement was dominantly southwestward in the field area as shown by alignment of drumlin forms, bedrock fluting and striation.

Impounding of water in the Ontario Basin below the Niagara Escarpment began during retreat from the Batavia, Barre and Albion Moraines in the Erie-Ontario Lowlands. Eastward drainage to the Mohawk was initiated by ice marginal withdrawal from the Onondaga bench north of Skaneateles. Fairchild (1928) mapped shore features of Lake Dawson at 470 to 480 ft (143 to 146 m) locally in the Rochester area, but the extent of sediment contribution by this lake and its predecessors was limited along the present Ontario bluffs.

Renewed glacial recession in central New York allowed expansion into central New York by glacial Lake Iroquois, controlled by the col at about 440 ft (134 m) near Rome. Muller (1977b) indicates that inception of Lake Iroquois preceded the main readvance of the ice front to the Carlton Moraine (Frontispiece II).

Work of Gilbert and Taylor (Kindle and Taylor, 1913) suggests that early Lake Erie drained first to a short-lived low stage of Lake Iroquois called Newfane, whose beaches are now at about 360 ft (109 m) near Lewiston. Subsequently, uplift of its outlet raised the Iroquois waters 25 to 40 ft (7.6 to 12 m) to the most persistent beach-forming stage. The prominent Iroquois beach ridge (Frontispiece II) has been strongly tilted by glacial rebound. The strand line now rises from 360 ft (109 m) to 545 ft

(165 m) between the Niagara River and the east end of Lake Ontario (Fairchild, 1916). Rebound apparently continues even to the present time. As indicated by long term records at gauging stations, the outlet of Lake Ontario is rising faster than the southwest end by about .23 m/century (Clark and Persoage, 1970; Kite, 1972), thus continuing gradually to drown river valleys and raise lake level along the south coast.

An analysis of dates and events in the Ontario - St. Lawrence area led Karrow and others (1975) to suggest that Lake Iroquois drained to much lower "post-Iroquois" levels (Prest, 1970) shortly after 12,000 yr BP, but at least before 11,000 yr BP. Evidence of post-Iroquois stages, including those of early Lake Ontario are not known in exposure in western New York.

The present coastline is cut into a surface of low relief, broken by very subtle northeast-southwest trending ridges or "giant fluting" (Kindle and Taylor, 1913) paralleling the direction of former glacier flow. Low hummocks of the Carlton Moraine are also distributed in a narrow generally east-west band (Muller, 1977a, 1977b).

BEDROCK

Lake Ontario is underlain by Middle and Late Ordovician sedimentary rocks with a regional east-west strike and dip of about 40 ft/mi (7.5 m/km) south or slightly west of south. This sequence as measured in borings along the southern Lake Ontario Lowland, includes from youngest to oldest: 200 to 600 ft (61 to 183 m) of sandstone and shale of the Queenston Formation; 950 ft (290 m) of Lorraine Group rocks including the Oswego and Pulaski sandstones and the Whetstone Gulf siltstone and shale; 150 to 250 ft (46 to 76 m) of Utica Shale; and 450 ft (137 m) of limestone of the Trenton Group (Fisher, 1977). The Late Ordovician red Queenston rocks underlie bluffs along the south coast of Lake Ontario.

Figure 1B shows the linear distribution and vertical relief of bedrock and unconsolidated units in bluff exposure. Variable elevation of the bedrock surface is primarily a consequence of glacial erosion. Outcrops of Queenston bedrock form many of the "points" or lakeward projections of land west of Sodus Bay. The main exposures are south and east of Thirty Mile Point (75) where the Queenston rises to near its maximum height of about 4 m above mean lake level (Stop 6).

Queenston rocks exposed in bluffs between the Niagara River and Rochester include laminated to thick-bedded, red to dark red (purplish or cherry red) fine- to very fine-grained calcareous argillaceous sandstone and red calcareous shale or siltstone. Beds of green or gray sandstone and shale make up less than 10 per cent of the exposed rock. Red shale is most common in exposures near the Niagara River with more siliceous sandstones to the east along the coast.

The attitude of beds in the regional homocline is relatively uniform but dips as steep as 4^{0} occur 20 km west of Rochester (Dames and Moore,

1965) and locally near some of the many points of land where secondary fold axes occur oblique or normal to the regional east-west strike. Small, but prominent tight anticlinal structures have been described at or near the shoreline east and west of Thirty Mile Point (Stop 6)(Gilbert, 1899; Dames and Moore, 1965) and a few kilometers west of Olcott (near sta. 54)(Kindle and Taylor, 1913).

Wave-cut platforms in the field area display prominent and consistent joint patterns with a predominant set striking between 65° and 75°, dipping at 80° to 90°. A second set strikes between 330° and 350° with 60° to 90° dips. The spacing is generally 0.5 to 1.5 m (Dames and Moore, 1965, 1974; Fakundiny and others, 1978). A number of small faults occur along the coast (Kindle and Taylor, 1913; Dames and Moore, 1974), but the only major fault known to transect the area is the north-south Clarendon-Linden normal fault system, expressed as a drift-filled bay on the Ontario coast just east of the field trip area near Troutburg (Van Tyne, 1975; Hutchinson and others, 1979).

QUATERNARY STRATIGRAPHY

A maximum of six stratigraphically superimposed lithostratigraphic units may be distinguished within the drift between the Niagara River and Rochester. Figure 2 shows a composite stratigraphic section. Only very locally are all of these units exposed together in one section. Two tills with interbedded glaciolacustrine units are distinguished and correlated laterally on the basis of moist field color, relative stratigraphic position, and associated primary structures as well as texture (in order of decreasing reliability) (Brennan and Calkin, in press). However units may also be locally distinguished and correlated using gross lithology and compaction due to minor differences in ice-flow trajectories (Salomon, 1976).

Lower Glaciolacustrine Deposits

The oldest unit is a red, or less commonly, gray glaciolacustrine clay and silt up to one meter thick. This unit crops out in the Somerset bluff area (61) during times of strong wave erosion and is distinguished in test boring in the region (Dames and Moore, 1974; Pendleton, personal communication, 1975) beneath a lower red stony till and above the Queenston bedrock. It is locally stony and/or well-laminated in upper parts and absent or unrecognized over most of the bluff exposure where the lower red stony till either lies directly on bedrock or is itself not distinguished from the upper gray silty till.

Red Stony Till

A very stony, weak red (2.4YR 4/2), compact basal till overlies the lower glaciolacustrine unit or in other locations lies directly on the Queenston bedrock with gradational contacts (Fig. 2). At its base this till displays evidence of minimal reworking or glacial transport but locally includes small, well-striated and polished stones. Textural maturity is proportional to thickness and height above bedrock. This unit is reported to reach a thickness of 2 m in the field trip area (Dames and Moore, 1974). Borings in the Somerset area (59 to 71) reveal thicknesses of less than one meter.

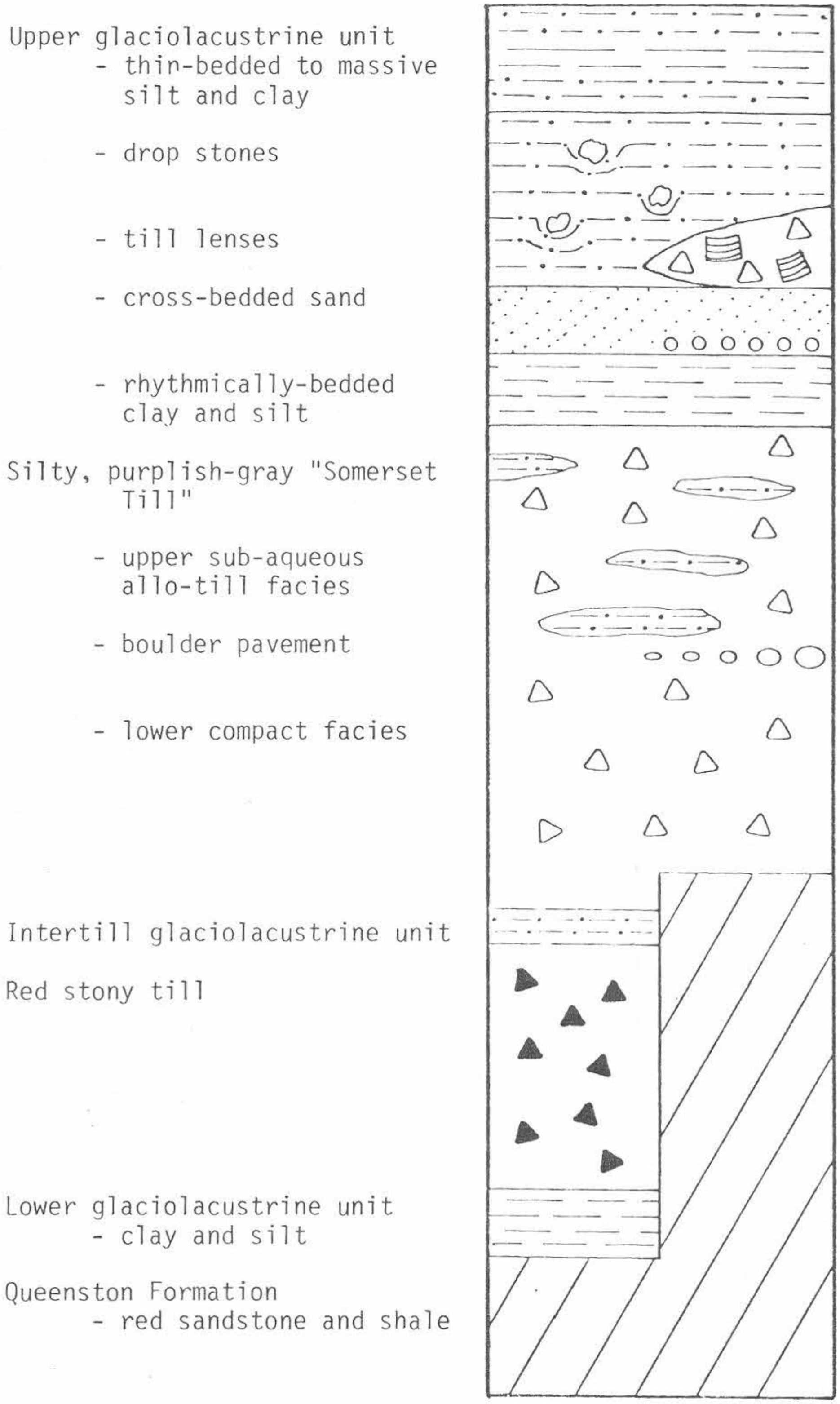

Figure 2. Composite stratigraphic section of the bluff stratigraphy of the south coast of Lake Ontario, Niagara River to Rochester, New York.

Till matrices are poorly sorted and composed of silty fine sand, sand silt clay, or less commonly sandy or clayey silt where shaly or weathered. Salomon (1976) showed that percentages of silt and clay are closely correlated with those of red (Queenston) clasts in the till. Stones scattered irregularly in the sandy matrix comprise up to 80 per cent by weight and consist predominantly of fine to coarse red brown, micaceous Queenston sandstone. Westward, near the Niagara, the percentage of Queenston clasts may be equaled by that of fine to medium-grained micaceous Oswego Sandstone. The stones are angular to subangular and tabular in all but small-pebble sizes. Locally, reworking is indicated by discontinuous lensoid silt and fine sand at the upper contact.

Exposures of the red stony till and any underlying glaciolacustrine unit are uncommon in the coastal reach west of Rochester, partly because they are discontinuously preserved and partly because they are at the base of the bluff and readily obscured by slumping. Exposures have been reported most frequently near Somerset (61), and from the Wilson area (34 and 48) by Salomon (1976). Some exposures of stony red till lying directly on Queenston bedrock may display characteristics misleadingly similar to those indicated above because of assimilation of underlying rock material, yet may be shown to be a facies of the younger purplish-gray till described below.

Intertill Glaciolacustrine Deposits

Glaciolacustrine deposits or till overlie red stony till. Where superjacent till is exposed in the bluff, as near stations 48 and 61, it may be separated from the underlying red stony till by discontinuous gray, or less frequently, red glaciolacustrine clay to fine sand units up to 0.5 m thick. Near Roosevelt Beach, Gilbert (1898) described a boulder pavement which may represent this interval between deposition of two till units.

Silty Purplish-Gray Till

The predominant till of this reach of coast is a silty gray or purplish deposit (5 YR 5/1 or 10 YR 6/2) which weathers to a red brown (Fig. 2). This unit is here referred to as the "Somerset Till" after the town in Niagara County, New York where it is particularly well exposed. This till has been locally observed directly on the red Queenston Formation in a few stations where it typically shows sharp color and textural contacts with the bedrock (e.g. near 59 and 83). However, in most areas it lies over fine glaciolacustrine deposits and/or lower red stony till (61). The stratified deposits were the sources of its finer texture and gray color (Pendleton, personal communication, 1975; Salomon 1976).

The "Somerset Till" consists of a lower, compact, texturally and lithologically homogenous silty till unit. Preliminary study suggests that it is largely a basal lodgement till but that some stratified subaqueous till is typical as well. The compact till facies generally grades upward to a subaquatic allo-till facies with similar matrix but enclosing much stratified material. We interpret it to have been deposited near the glacial margin by secondary processes much like the well-published Catfish Creek Till of Ontario, Canada (Dreimanis, 1976; Evenson and others, 1977; Gibbard, 1980; Dreimanis, 1982). The Somerset subaquatic till facies has indistinct upper contacts with overlying glaciolacustrine sediments which blanket most of the bluff top. One or both till facies may be present in any one exposure and maximum thicknesses reach about 3 m.

The"Somerset Till"is generally distinctly siltier and less stony than the underlying red till. Sand-silt-clay to clayey silt matrices are typical. Stones average about 4 percent by weight. Slightly higher percentages are characteristic in the lower than in the upper facies. Larger stones show strong evidence of glacial handling, particularly in the compact till facies. The subangular red Queenston clasts and gray to green Oswego sandstones are subequal in number with subordinate content of well-rounded dark fossiliferous limestones. The lithologic assemblage is much like that of the red stony till below except that the ratio of greenish-gray to red sandstone or siltstone is slightly higher (Salomon, 1976). Clasts of lacustrine clay and of the older red stony till are also reported (Dames and Moore, 1974; Pendleton, personal communication, 1974).

The upper, subaquatic allo-till facies is up to 3 m thick and composed of massive to laminated till enclosing subhorizontal, blue, green, gray, yellow, red, or brown lenses, stringers, or wisp-like beds of very fine to coarse sand, silt or clay. These may make up from 20 to 80 percent of the unit. Clay is less common than silt or sand lenses. The individual sorted and bedded units are from 1 to 50 cm thick, locally contain small-scale current structures and drop stones, and are rarely continuous laterally for more than a few meters. The beds may also be wrinkled, or grossly tilted. Isoclinal-flow folds (Evenson and others, 1977) occur on a scale of less than a meter within some individual till units.

Stones associated with the subaqueous facies in some places occur along distinct horizons in the waterlaid units as lag deposits or pavement. For example, on either side of the Wilson Inlet (34 and 38; Stop 3) a stone lag deposit bearing parallel striations occurs between the contact of the compact till facies and the upper weathered subaqueous till.

The subaqueous allo-till deposits have remained unweathered and at a distance are not readily distinguishable from the compact lower facies where overlain by more than 3 or 4 meters of relatively impermeable lake silt and clay. However, they appear to be more readily oxidized and display colors of higher chroma than the underlying compact till when nearer to the ground surface. For example, purplish-gray (2.5 YR 4/1) has been oxidized to red (2.5 YR 4/2) and except for the paucity of stones, resembles the red stony till unit. The contacts between purplish-gray (unaltered) and overlying red (oxidized) tills is typically sharp. Horizontal and vertical partings which develop in the weathered till allow it to maintain nearly vertical slopes emphasizing the apparent differences in the two facies.

A model suggesting possible mixed subaqueous origins of the purplish gray "Somerset Till" is shown in Figure 3 with inset. As the ice margin retreated across the current coastal position it was fronted by Lake Iroquois waters more than 70 m deep. While grounded, the temperate-based ice had deposited compact lodgement or meltout till. However, the thinning margin became increasingly buoyant, shedding debris by meltout, marginal or submarginal flowage and settling.

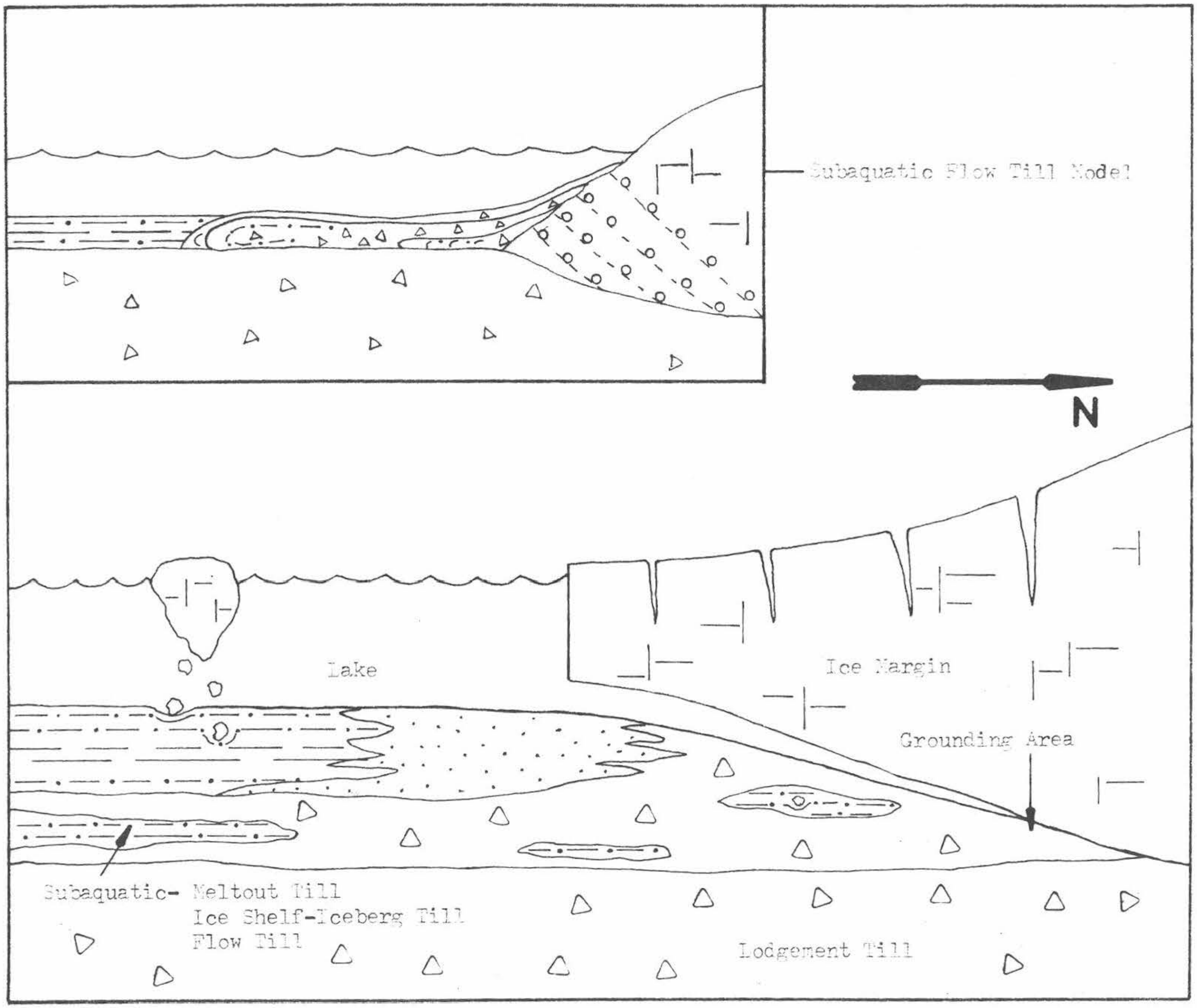

Figure 3. Models for till deposition along the south coast of Lake Ontario, Western New York.

Upper Glaciolacustrine Deposits of Lake Iroquois

Glaciolacustrine deposits averaging 3 to 4 m, but as thick as a maximum of 10 to 15 m (57), overlie the "Somerset Till" or older deposits (Fig. 2). These are considered to be largely Lake Iroquois deposits; however southwestern parts of the Ontario shore bluffs may include Lake Warren III through Hyper-Iroquois deposits and northeastern parts may include some post-Iroquois lake sediments. Red or red-brown, oxidized, massive to thin-bedded silt layers predominate, but rhythmic gray clay and silt units with couplets up to 8 cm thick lie directly on "Somerset Till". Fine yellow brown, oxidized, sandy beds are also locally an important component in upper parts of the glaciolacustrine unit.

Drop-stones up to cobble size are common locally, but the fine lacustrine beds also enclose ice-marginal deposits in several localities as discussed below. Lower contacts may be diffuse, or, in more than 10 per cent of the reach, may display a pebble or boulder lag on the till/lake clay interface.

Ice-Marginal Deposits

Gravelly silt, coarse sand and gravel, and pebbly lag deposits and/or intercalated silty till lenses interpreted as subaquatic flow till (Evenson and others, 1977) occur within the upper glaciolacustrine unit at lateral intervals generally less than 2 to 3 mi (3 to 5 km)(Fig. 2). Because of their composition, form and location adjacent to remnants of the Carlton Moraine (Frontispiece II), they are interpreted as near-ice or ice-marginal deposits related to an active glacial stand or short glacial readvance with subsequent oscillatory retreat soon after initiation of Lake Iroquois (Muller, 1977a). They are typically separated from underlying purplish-gray "Somerset Till" by fine lacustrine deposits and/or by an erosional unconformity with this lag concentration of clasts. These units are particularly developed in at least two locations in the field trip area (Stops 4 and 7). Just east of the field trip area, near Hamlin Beach State Park, flow till lenses occur within the cross-bedded, lacustrine sand unit (Drexhage and Calkin, 1981, p. 55).

CORRELATION OF TILL UNITS

The lower red stony till is tentatively correlated eastward with thicker but similar tills through the Sodus Bay area and with some tills of the inner cores of the drumlins beyond to Oswego. The purplish-gray "Somerset Till" can be traced eastward into the gray clayey tills of the Rochester-Sodus Bay area and perhaps the pink and gray upper drumlin tills. Properties of the tills, but particularly the lower one, mirror changes of regional bedrock geology and minor differences in ice-flow trajectory along the coast (Salomon, 1976; Calkin and Brennan, in press).

Southward from the Lake Ontario bluffs, the till units are generally buried beneath lake deposits. Borings in the Somerset area (Dames and Moore, 1974) showed both tills separated by lake clay; however in this area the purplish-gray till has not been traced more than 1600 to 8400 ft (488 to 2500 m) south of the shoreline. Elsewhere, abundant subsurface data (unpublished) verify the occurrence of the two contrasting till units, at least southward to about the Iroquois Beach. Systematic tracing and correlation of these units southward across the Niagara Escarpment has not been established in New York.

Detailed work in the Niagara Peninsula of Ontario may provide a valid working hypothesis for correlation in New York. Gray to brownish-gray silty or clayey till exposed directly beneath postglacial lake sediments in the bluffs west of the Niagara River and underlain by, or interbedded with, red sandy silt till are correlated with the Halton Till (Feenstra, 1972a, 1972b, 1981). This is, in turn, traced southward in the Niagara-Welland areas by buried drift valleys across the Escarpment and represents the last advance of the Ontario glacial lobe "across the Niagara Peninsula into the Lake Erie Basin during the Port Huron Stadial" (Feenstra, 1981, p. 87), Karrow (1963, p. 44) notes that in the Hamilton-Galt area of Ontario, the "Halton Till is predominantly a silt till that is red brown when oxidized and dark purple when fresh". He further indicates that at the type locality it contains an upper waterlaid zone that is stratified.

Borings along the eastern half of the Lake Ontario coast in the Canadian Niagara Peninsula reveal a red sandy silt till. This is traced southward beneath the fine textured gray till and is correlated with Late Wisconsin glacial advances of Nissouri-Port Bruce Stadials (Calkin, 1982, Fig. 2).

SHORE EROSION

Shore erosion rates may be variously measured, for instance, in terms of bluff recession and of sediment loading on the lake system. Bluff recession rates are of immediate consequence to coastal structures built atop of the receding bluffs. Sediment loading rates are of concern relative to beach maintenance and shoaling of navigation channels.

Shore erosion rates are related to a variety of factors, among them, bluff stratigraphy, geotechnical properties of bluff sediments, groundwater conditions, beach characteristics, offshore gradients and wave climate. Variations in Quaternary stratigraphy and associated properties of materials in shore bluffs of Lake Ontario lead to corresponding variability of coastal morphology and shore erosion rates.

Among the factors mentioned above, bluff materials and morphology, beach characteristics and offshore gradients are both affected by and themselves affect rates of shore erosion. They are dependent variables in the erosion system. Lake stage, and to a lesser degree, wave climate, are external or independent variables imposed upon the system. Higher lake stage and greater storm frequency, by steepening offshore gradients and undercutting shore bluffs initiate new cycles of accelerated shoreline erosion (Emery and Kuhn, 1982). The succession of high-water years through the mid-seventies initiated just such a cycle of accelerated erosion. For this reason, bluff recession rates averaged over a 13 to 18 year period prior to 1955 were compared with rates averaged over 99 years prior to 1974. As would be expected from the episodic nature of accelerated erosion, greater extremes in bluff erosion rates are recorded in short term data (Drexhage and Calkin, 1981).

"Classification of sea cliffs in just a small region ... involves more generalizations than can be accepted for engineering purposes." (Emery and Kuhn, 1981, p. 652). With full recognition of this fact, the following generalizations are offered relative to shore erosion in the field trip area.

A general decrease in bluff recession rates is found from west to east across the field trip area. Most of the bluffs in Niagara County (1 thru 75) face north-northwest. Such bluffs are exposed to wave action induced, for instance by strong westerly and northwesterly winds which follow frontal passages and to waves generated by northeasterly winds with maximum fetch. Bedrock elevations are higher in eastern Niagara County, reaching a maximum in the vicinity of Thirty Mile Point. Approximately 2×10^5 m^3/yr average erosional loading occurs from bluffs in that portion of the field area included in Niagara County (Fig. 1B). However, due to generally steep nearshore slopes, typically 10 to 27.5 ft/mi (5 to 14 m/km), and the large amount of fine material present in the bluffs, little sediment remains on the shoreline to protect the bluffs from wave attack. The lack of well developed beaches permits wave onslaught against glacial till and associated glaciolacustrine deposits. This occurs particularly during intervals of high lake levels and severe storms, resulting in high recession losses in a short time. For Niagara County, the mean recession rate between 1875 and 1934 was 46 cm/yr, whereas between 1938 and 1954 the rate was 79 cm/yr .

The portion of Orleans County included in the field trip area (75 to 99) has generally experienced less recession than Niagara County. Bluffs face more northerly (Fig. 1A) and are less subject to direct wave attack. At Stop 6 (75 and 76) less than 30 cm/yr recession was evidenced between 1875 and 1974. Recession in this area has been fairly uniform, reflecting the relative regularity of the coast and similarity of the bluffs. Annual erosional loading for Orleans County was computed at an average of 2.5×10^4 m^3/yr, an order of magnitude lower than for Niagara County. Low bluffs, thin drift and relatively slow bluff recession all contribute to poor development of beaches along much of this coast. An apparent paradox lies in the fact that greatest long-term bluff recession rates in Orleans County have been observed where beaches are relatively well developed, east of Brighton.

The greatest erosion rates in the field trip area are recorded in the vicinity of Roosevelt Beach (Fig. 4). This area experienced 2.37 m/yr average recession from 1938 to 1951 and 1.28 m/yr over the longer term from 1875 to 1974. Recession has been so severe that Twelvemile Creek which in 1874 entered Lake Ontario through Tuscarora Bay has been truncated and now enters separately more than a mile to the west. Numerous residences and several streets in Roosevelt Beach have been lost to bluff erosion. Bluffs in the vicinity have steep faces, without bedrock exposure above lake level. Beaches are generally less than 10 ft (3 m) wide and in present lake stage, essentially nonexistent. They are largely composed of cobble-sized material (Corps of Engineers, 1945, 1973) affording little protection against wave action (Fortune and Calkin, 1981). Tributaries which might nourish the beach are insignificant and long-shore drifting is minimal.

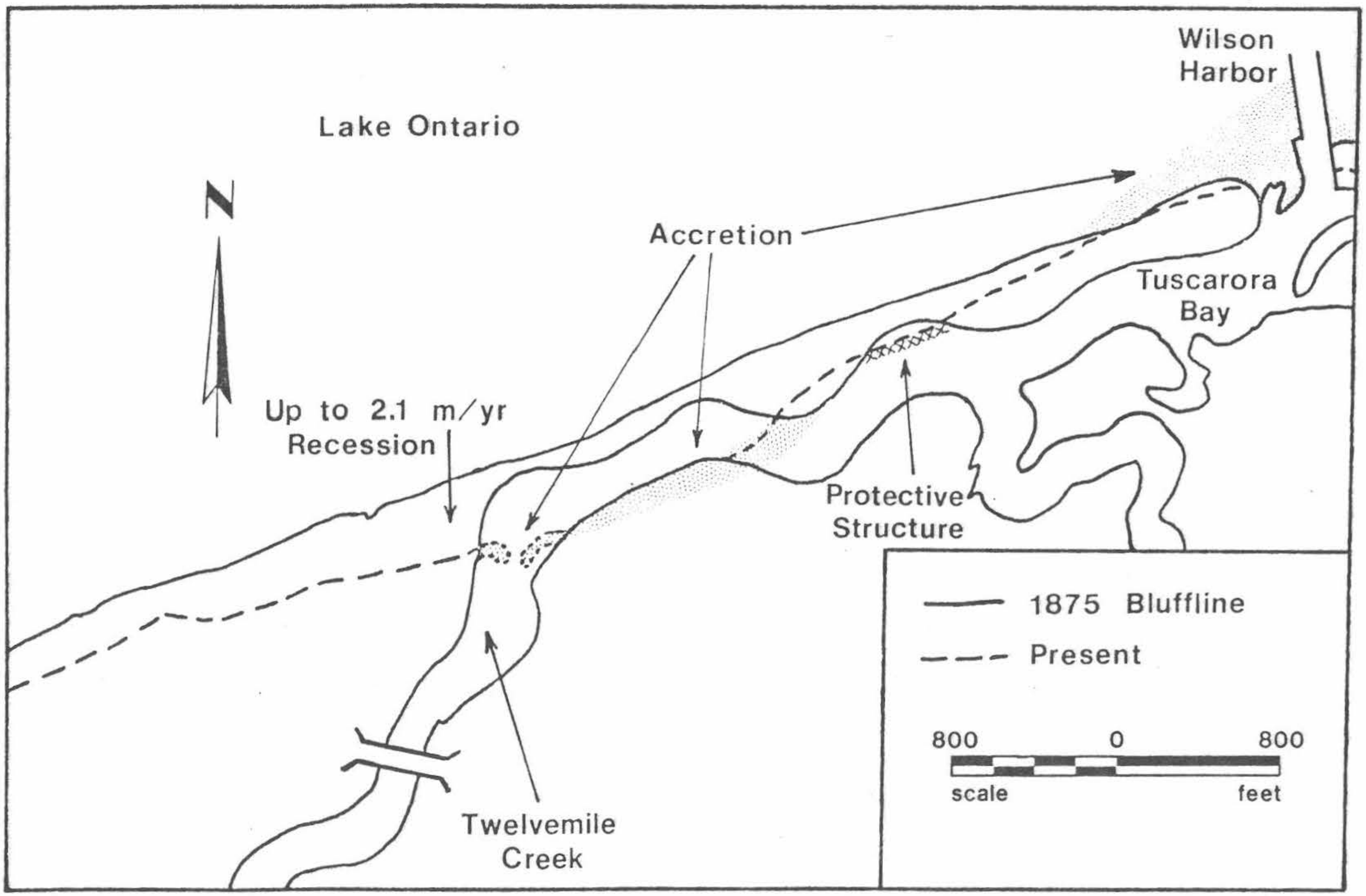

FIGURE 4 : Map of Twelvemile Creek - Wilson, N.Y. area, showing the 1875 and 1974 shoreline positions. Note the change in location ofthe mouth of Twelvemile Creek during the 99-yr period (after Fortune and Calkin, 1981).

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ROAD LOG
QUATERNARY STRATIGRAPHY AND BLUFF EROSION
WESTERN LAKE ONTARIO, NEW YORK

(Route and location of stops are shown on Figure 1a)

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	From Buffalo Marriott Inn turn right at light onto Millersport Highway and immediately right onto Expressway (I-290) west.
		On Lake Warren plain (note red clay exposures at right). We are just south of the edge of Lake Tonawanda plain.
6.0	6.0	Exit right to Route I-190 N to Niagara Falls
7.3	1.3	Toll barrier, South Grand Island Bridge. Cross Tonawanda (east) Channel of Niagara onto Grand Island (Erie County, N.Y.).
		Subdued topography due to subsequent deposition tion in Lake Warren and washing by initial stages of Niagara River system
10.7	3.4	Crest of Niagara Falls Moraine
13.0	2.3	North Grand Island Bridge across Tonawanda Channel of the Niagara. Note spray of Falls at left.
14.0	1.0	Exit right off I-190 to Robert Moses Parkway to Falls. Niagara Falls Water Treatment Plant and Hooker Chemical Plant on right, west of bridge.
15.4	1.4	Structures at left house the gates for water intakes to Robert Moses Power Plant.
		Pass Carborundum Co. and Niagara Falls Sewage Treatment Plant on right; Grass Island Pool and control weir (Canadian side) on distant left.
16.1	2.6	Road bears right under Goat Island Bridge to stop sign.
18.4	0.4	Turn right at first opportunity onto Niagara Street and right again onto Rainbow Blvd.

18.7	0.3	Turn right onto First Street; proceed through intersection with light over American Rapids onto Goat Island. Pass Horseshoe Rapids to main parking for Falls and Terrapin Point.

STOP 1. TERRAPIN POINT, GOAT ISLAND, NIAGARA FALLS. We will take time only for photographs. See Calkin and Wilkinson (this volume, Stop 1) for details.

20.5	0.6	Leave Goat Island across bridge over American Rapids; proceed straight past Hotel Niagara along First Street to 4th traffic light.
21.2	0.7	Turn right from middle lane onto Main Street at 4th light; turn left almost immediately at blinking light onto Robert Moses Parkway north toward Whirlpool. Pass Schoelkopf Geological Museum along Gorge on left (Calkin and Wilkinson, this volume, Stop 2).
23.4	2.2	Turn left and back to Whirlpool State Park, then right into parking lot.

STOP 2. WHIRLPOOL STATE PARK. This again is only a photostop. See Calkin and Wilkinson (this volume, Stop 3) for details.

		Exit right onto Robert Moses Parkway and immediately turn back left going northward to first right turnoff.
24.7	1.3	Turn right off Robert Moses Parkway through parking lot for Devils Hole. See Calkin and Wilkinson (this volume, Stop 4) for details. Proceed left onto Route 104 north past Niagara University.
25.7	0.7	Pass under walkway to Robert Moses Power Plant and Power Vista. See Calkin and Wilkinson (this volume, Stop 5) for details.
26.9	1.5	Cross Barre Moraine at Country Club atop the Niagara Escarpment. View north of Lake Ontario (if clear) across Lake Iroquois plain in foreground below Escarpment.
27.1	0.2	Turn right off Route 104 onto Route 18E (Creek Road) and descend Escarpment.
28.2	1.1	Pass under Route 104 across wave-formed bluff and strand of Lake Iroquois. Proceed north onto Iroquois lake plain on Route 18.
32.1	3.9	Cross Fourmile Creek; in Blairsville, bear right at fork, staying on Route 18. Follow field trip route, referring to Figures 5 through 25.

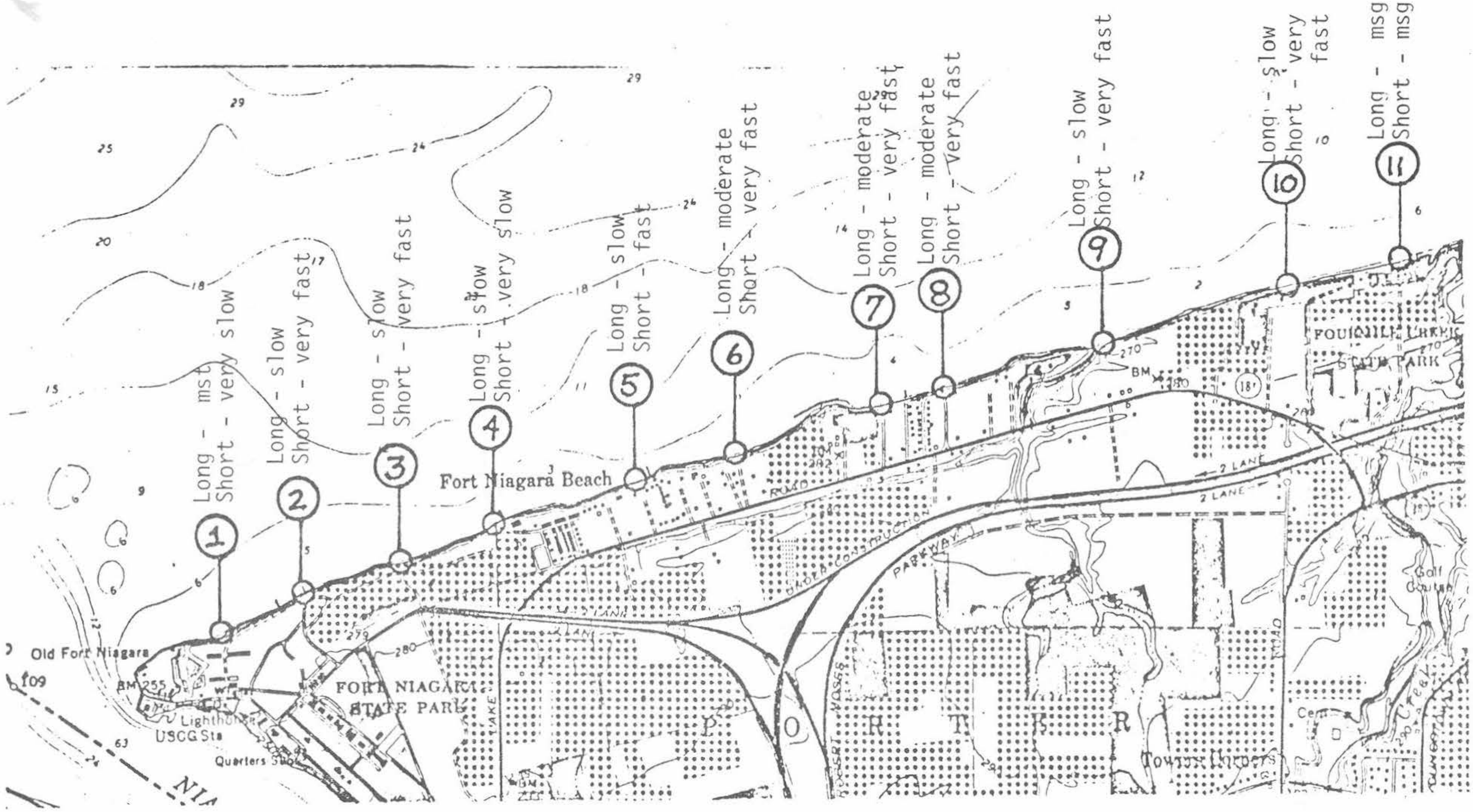


FIGURE 5
Bluff recession rates after Drexhage and Calkin, 1981. Very slow = less than 30 cm/yr; slow 30-60 cm/yr; moderate 60-90 cm/yr; fast 90-120 cm/yr; very fast = more than 120 cm/yr.

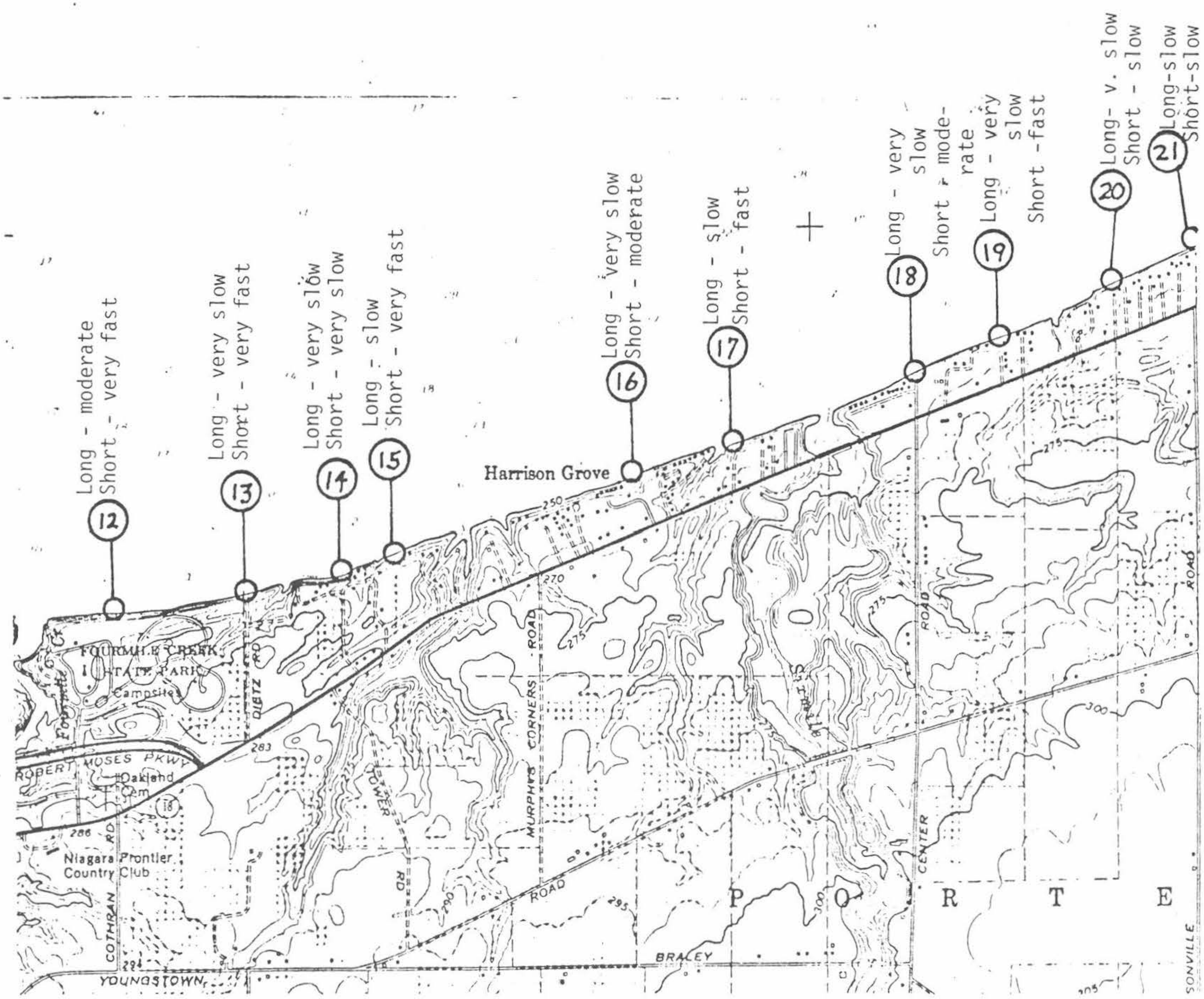


FIGURE 6

Bluff recession rates after Drexhage and Calkin. See Figure 5 for explanation of terms

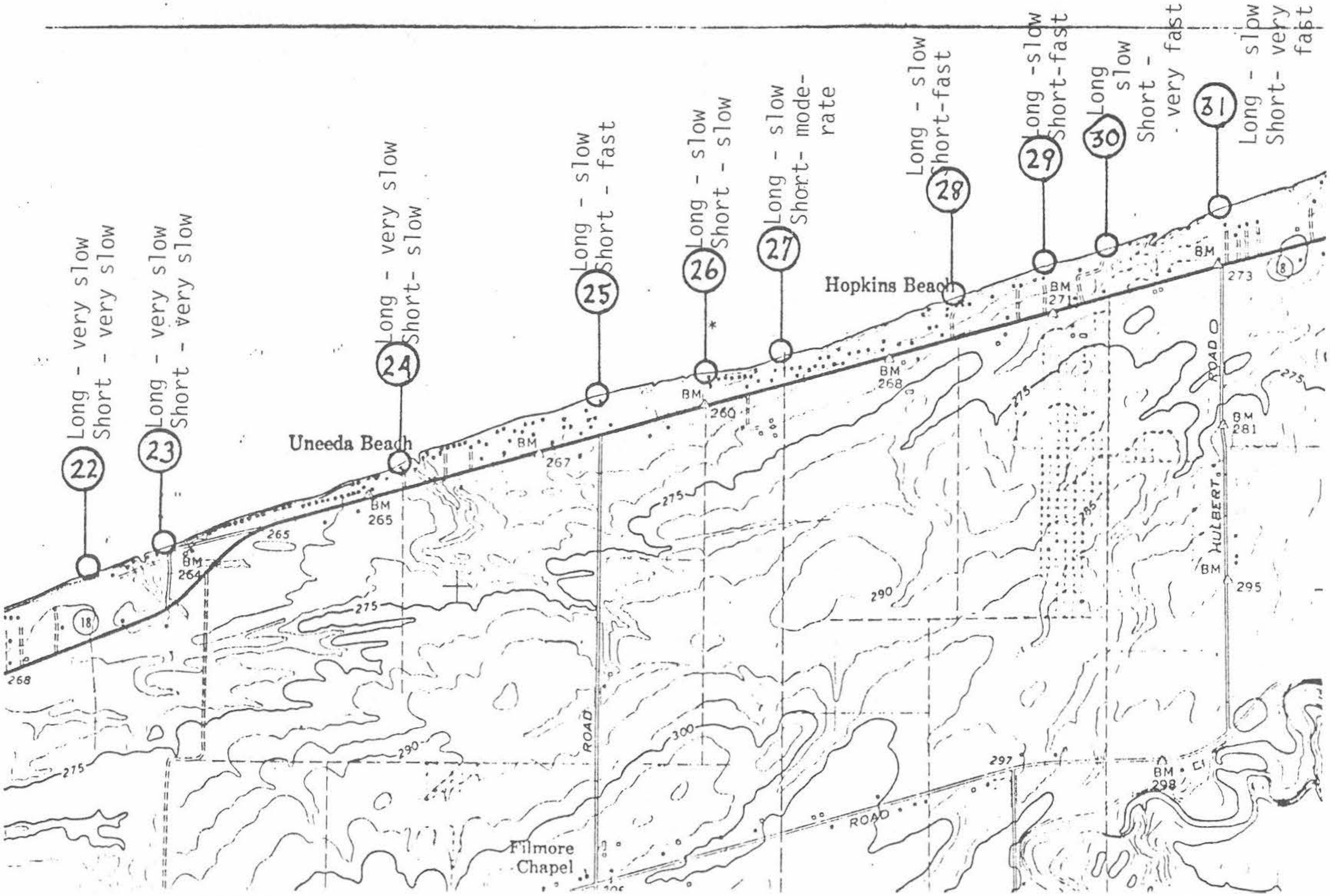


FIGURE 7

.Bluff recession after Drexhage and Calkin (1981). See Figure 5 for explanation of terms.

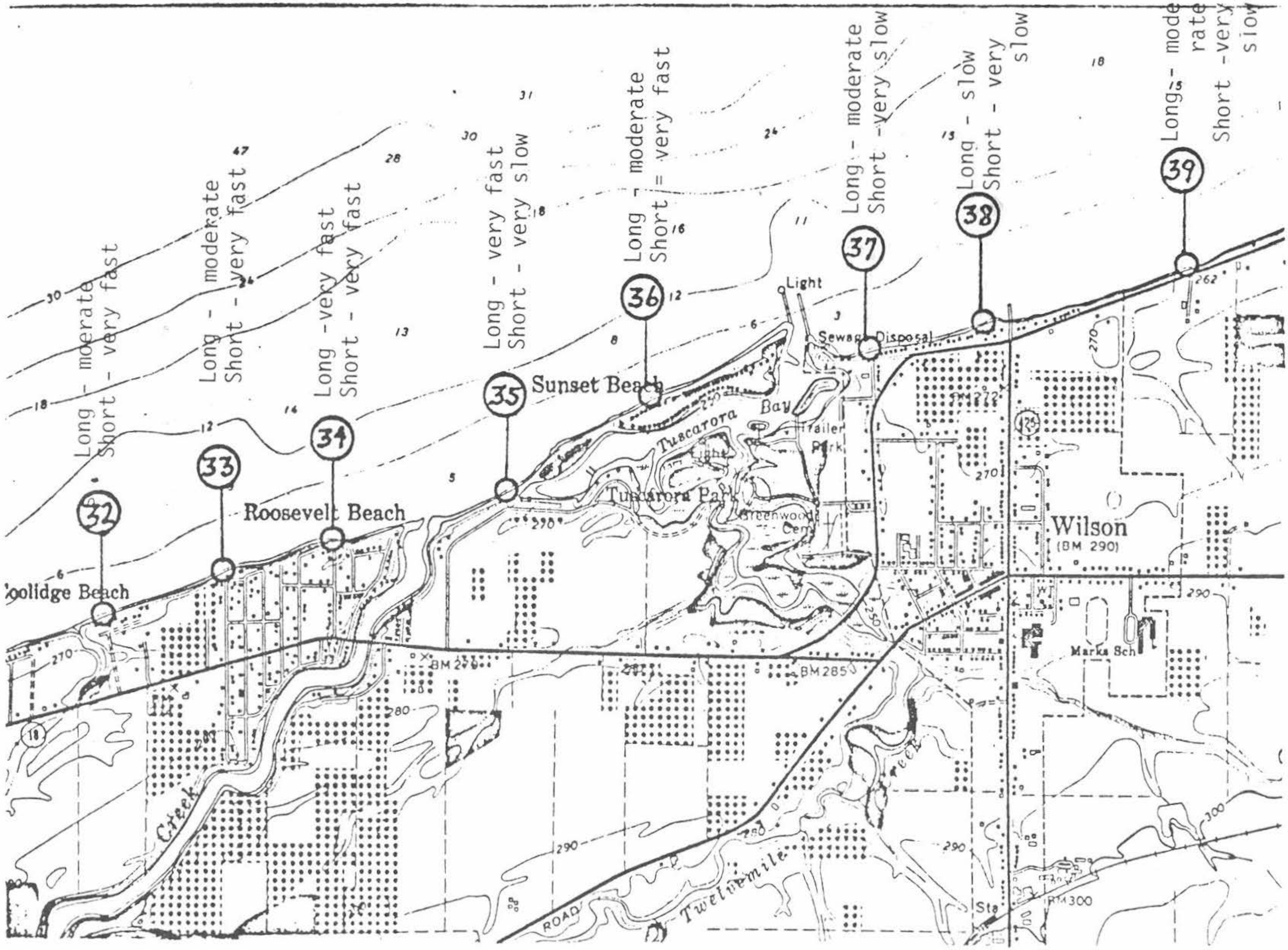


FIGURE 8
Bluff recession after Drexhage and Calkin (1981). See Figure 5 for explanation of terms.

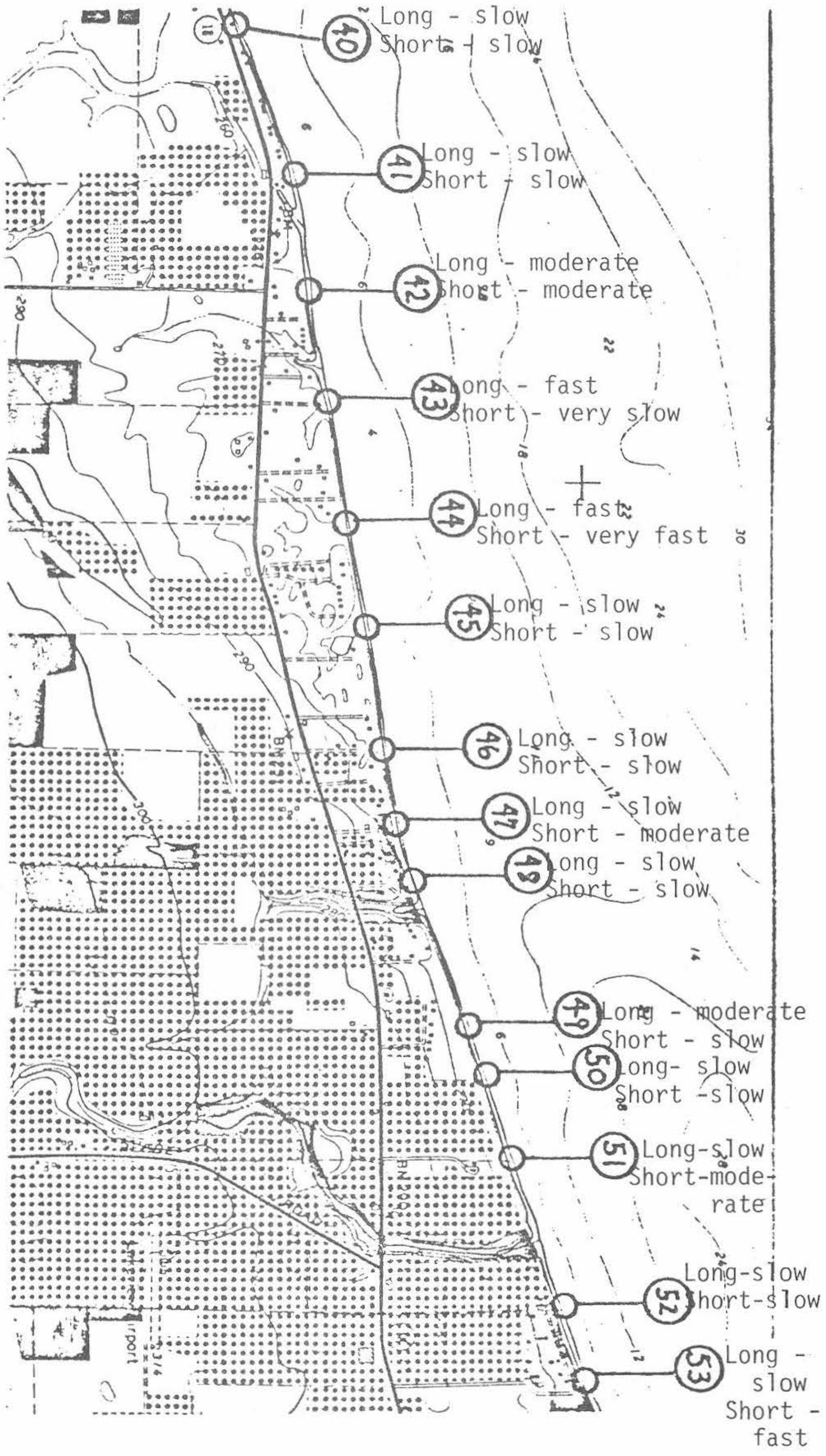


FIGURE 9.

Bluff recession after Drexhage and Calkin (1981). See Figure 5 for explanation of terms.

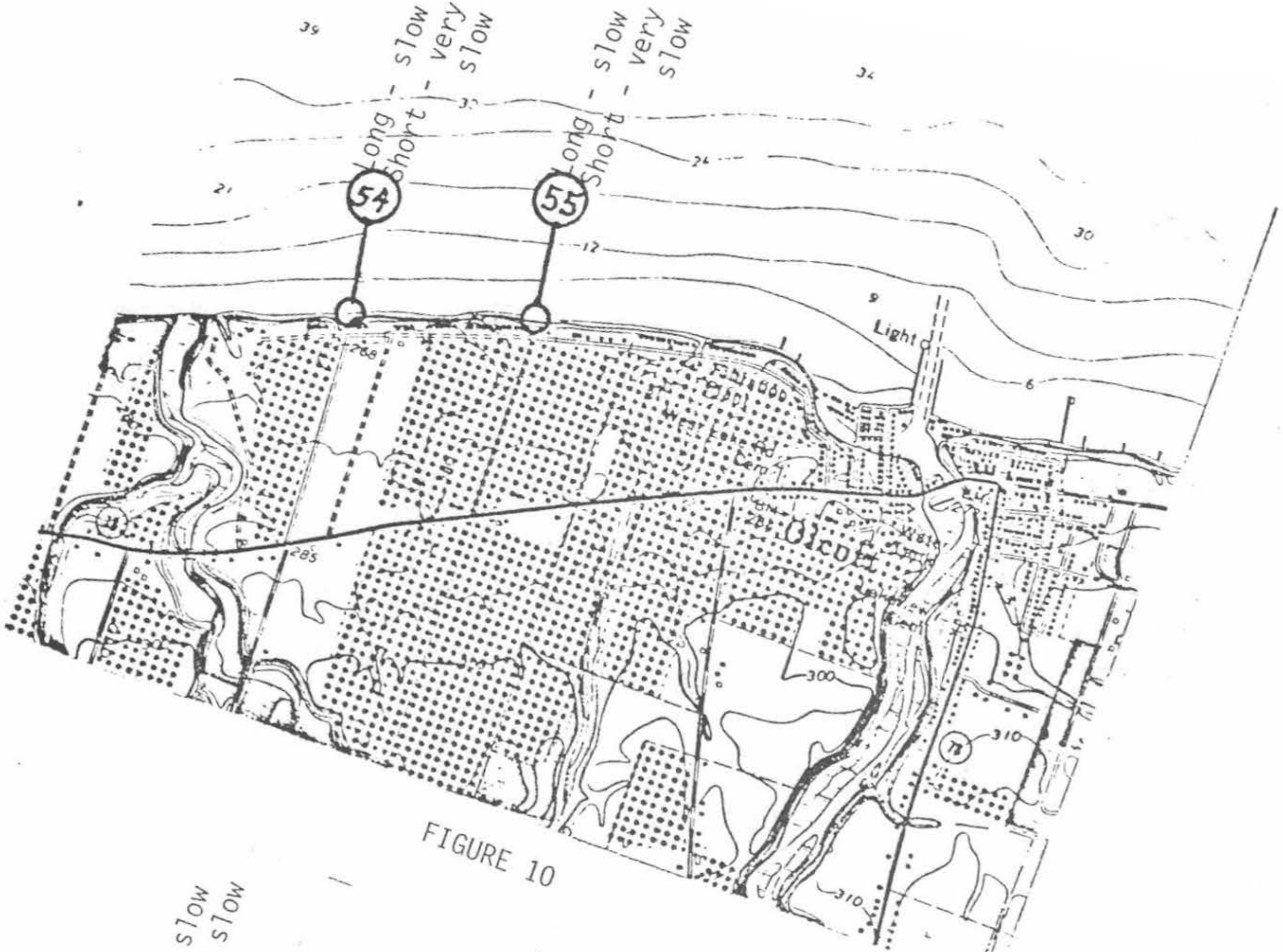


FIGURE 10

FIGURE 11

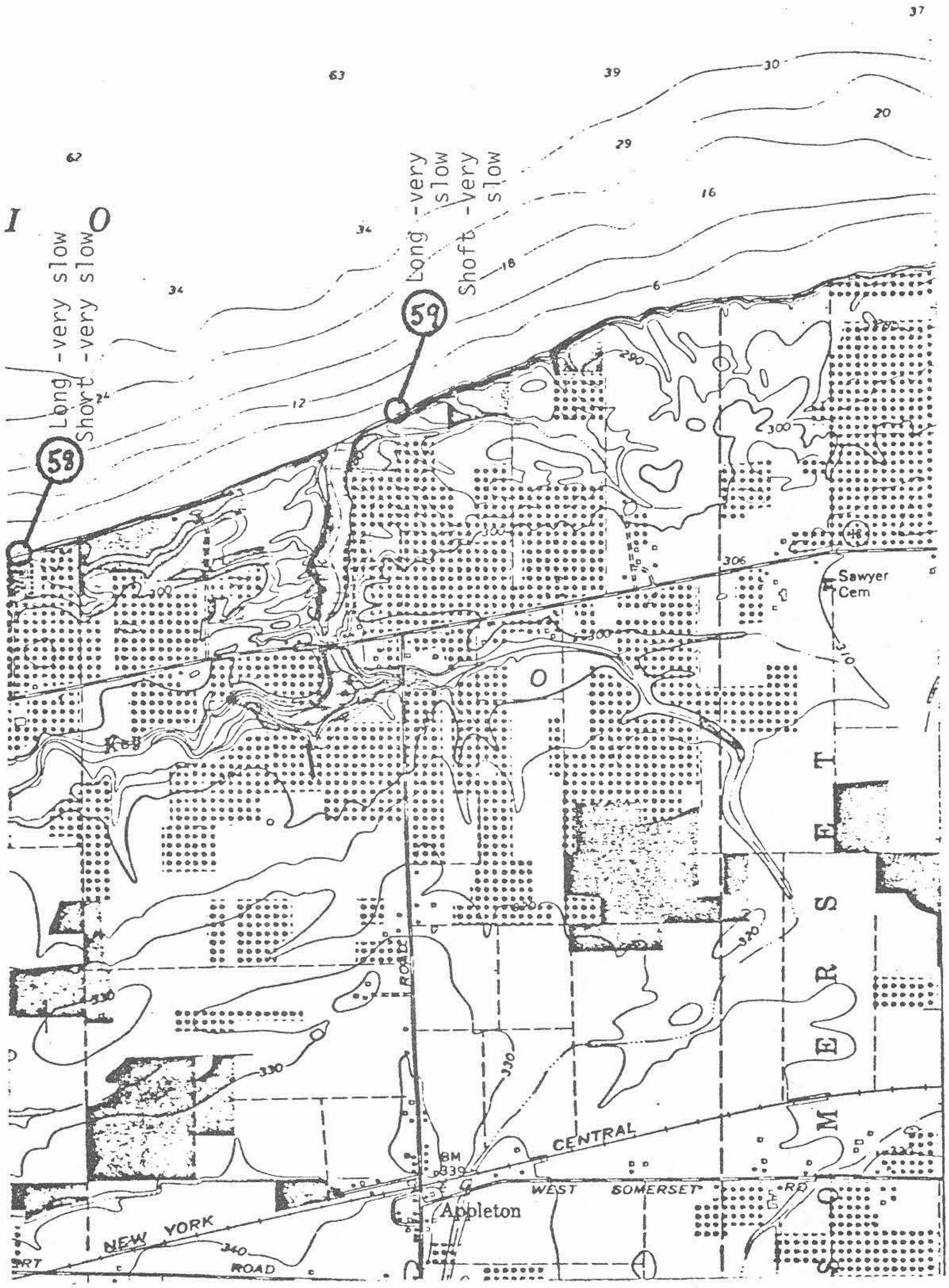

58
Long -very slow
Short -very slow
59
Long -very slow
Short -very slow
Sawyer Cem
NEW YORK CENTRAL
WEST SOMERSET RD
ROAD
BM 339
Appleton
SOMERSET

FIGURE 12

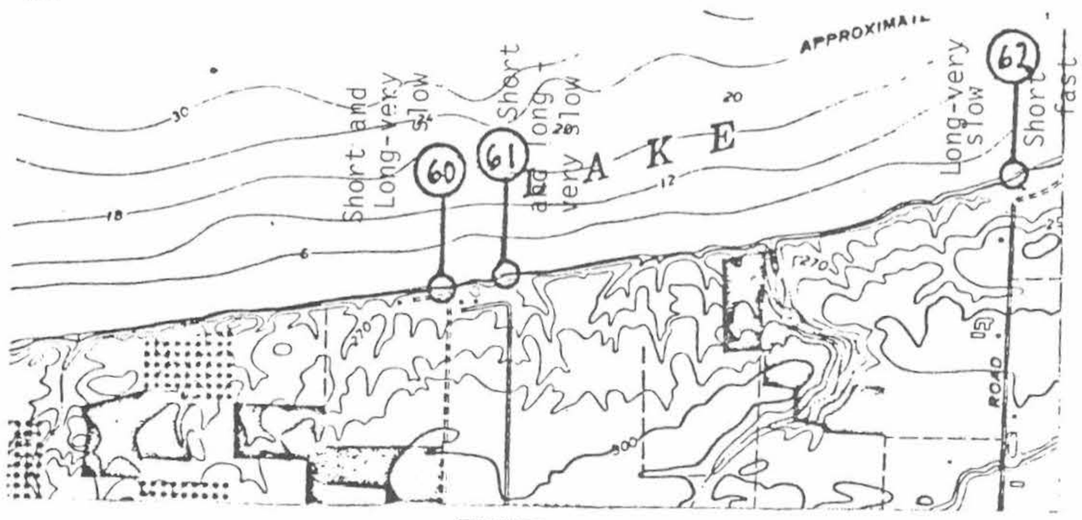


FIGURE 13

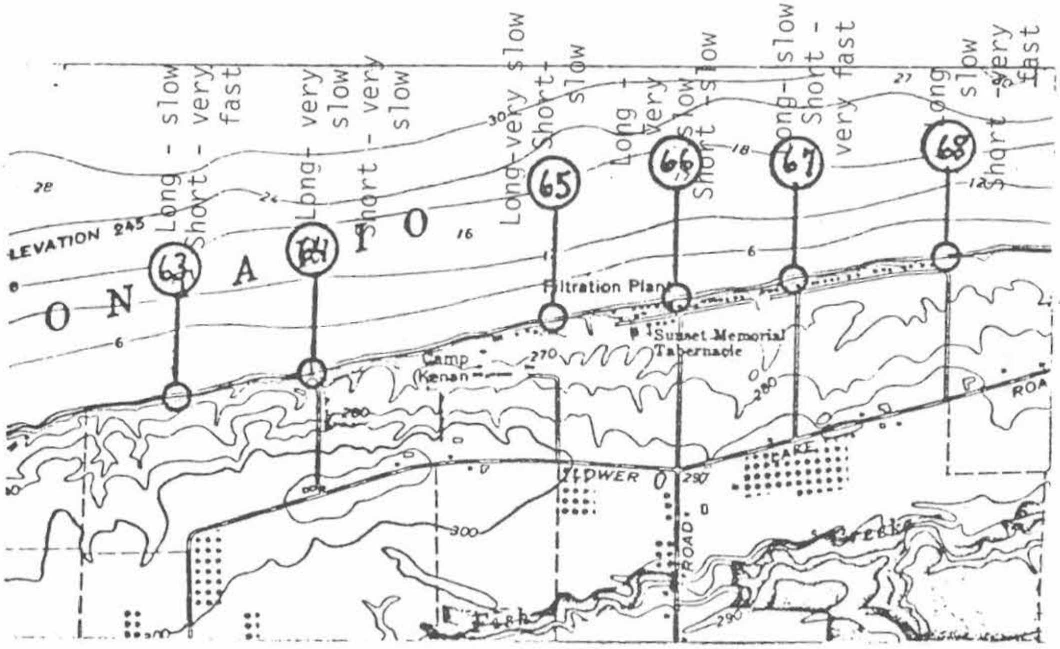


FIGURE 14

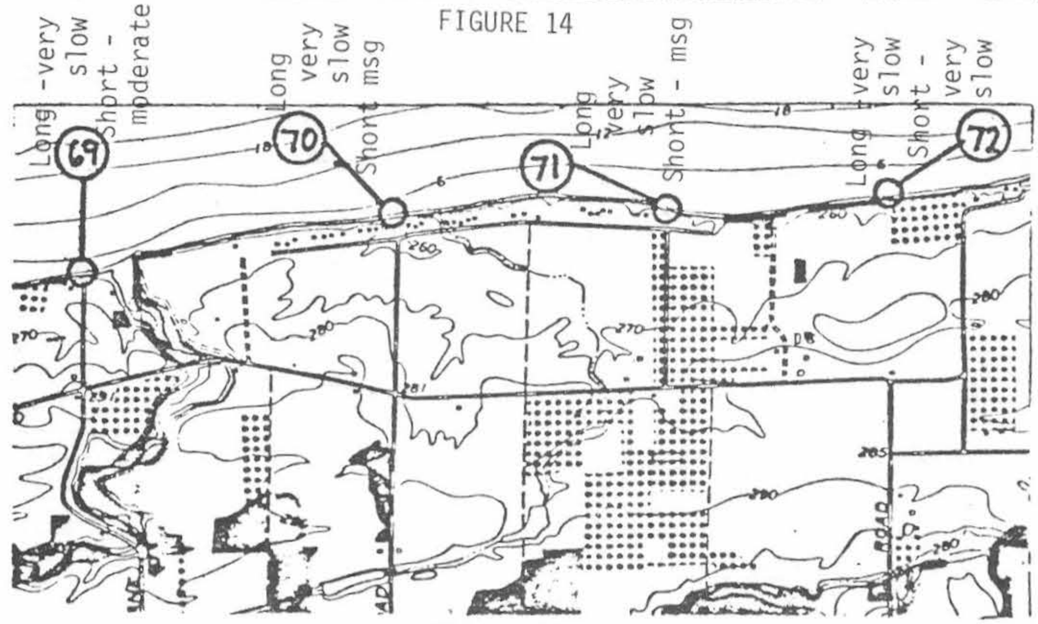
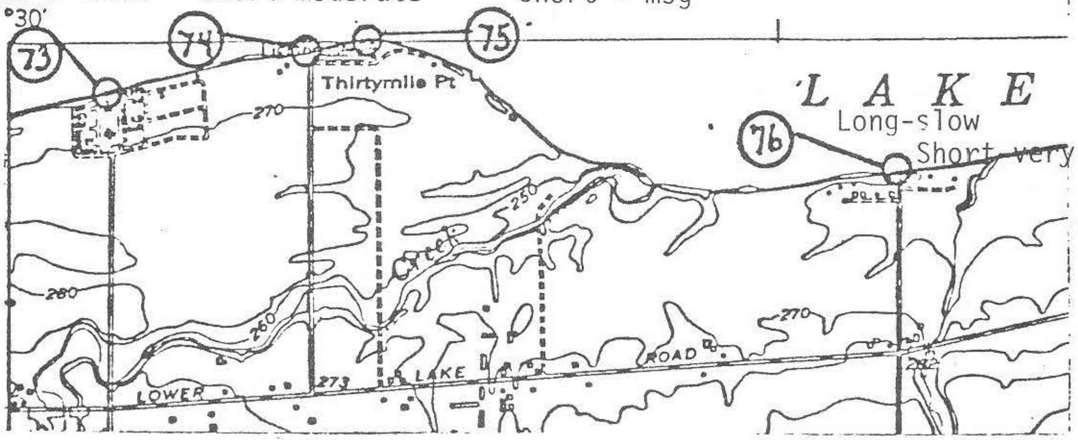


FIGURE 15

Long-v. slow
Short- slow

Long-v slow
Short-moderate

Long-v. slow
Short - msg



Long-slow
Short-very fast

FIGURE 16

Long-slow
Short -
fast

Long-very
slow
Short-
slow

Long -
very
slow
Short
. mode-
rate

Long-very
slow
Short-slow

Long-very
slow
Short-slow

Long-very
slow
Short-very
slow

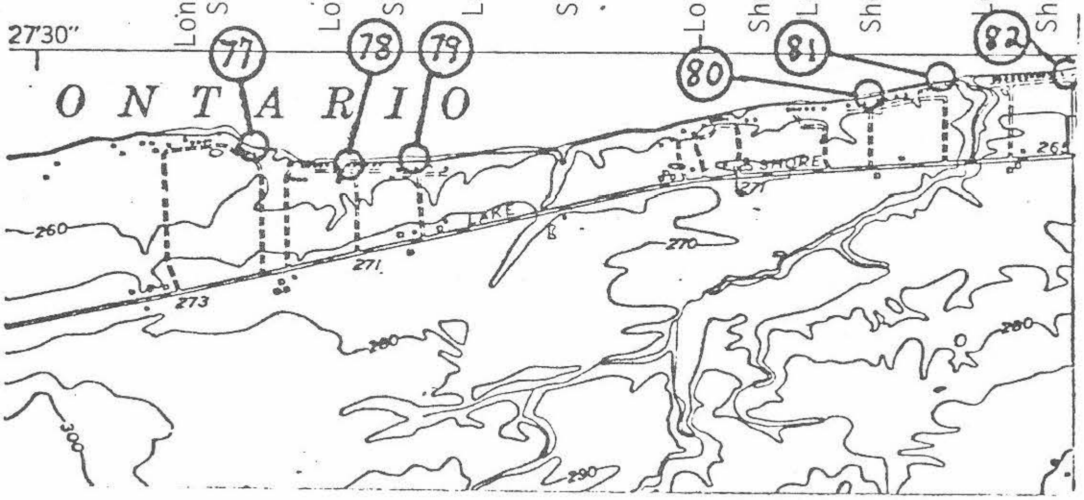


FIGURE 17

Long and short
both very slow

Long-very slow
Short-slow

Long and short
both very slow

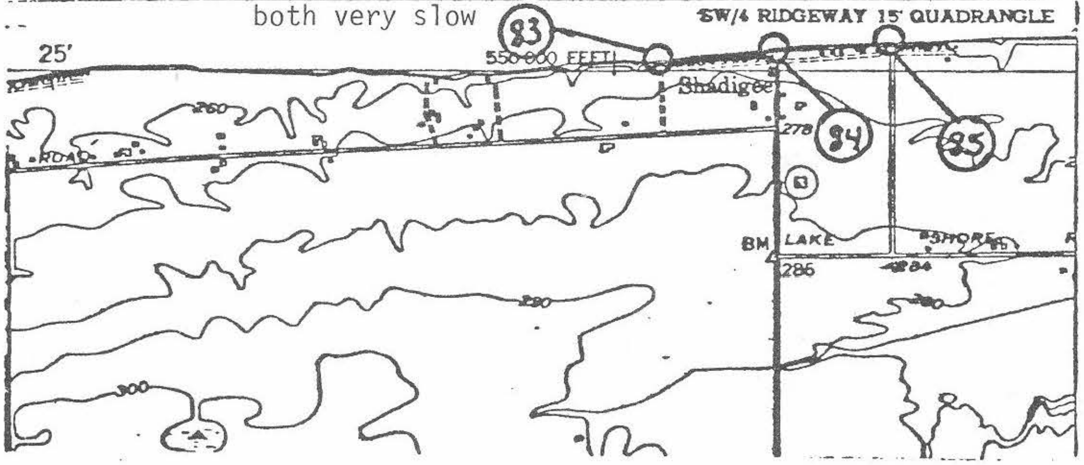


FIGURE 18

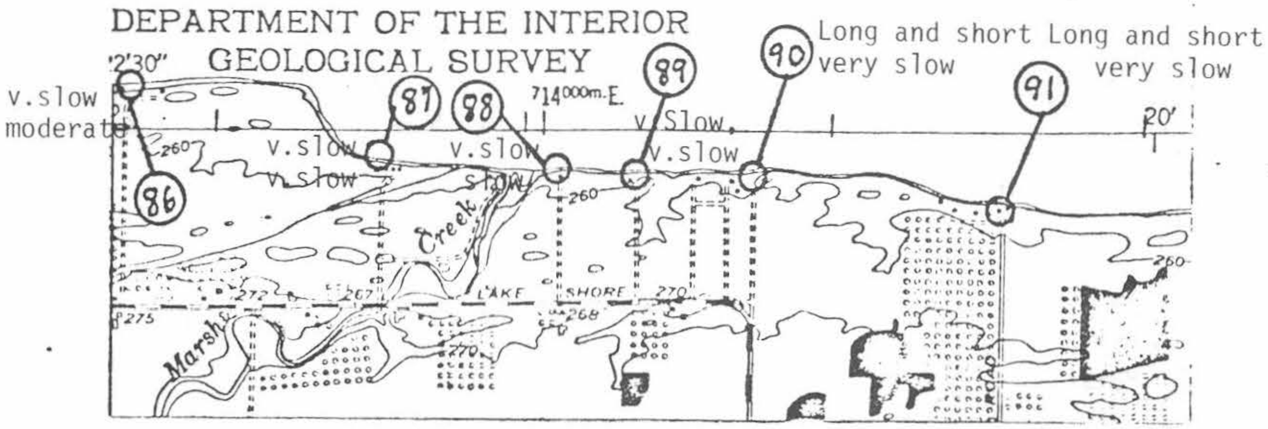


FIGURE 19

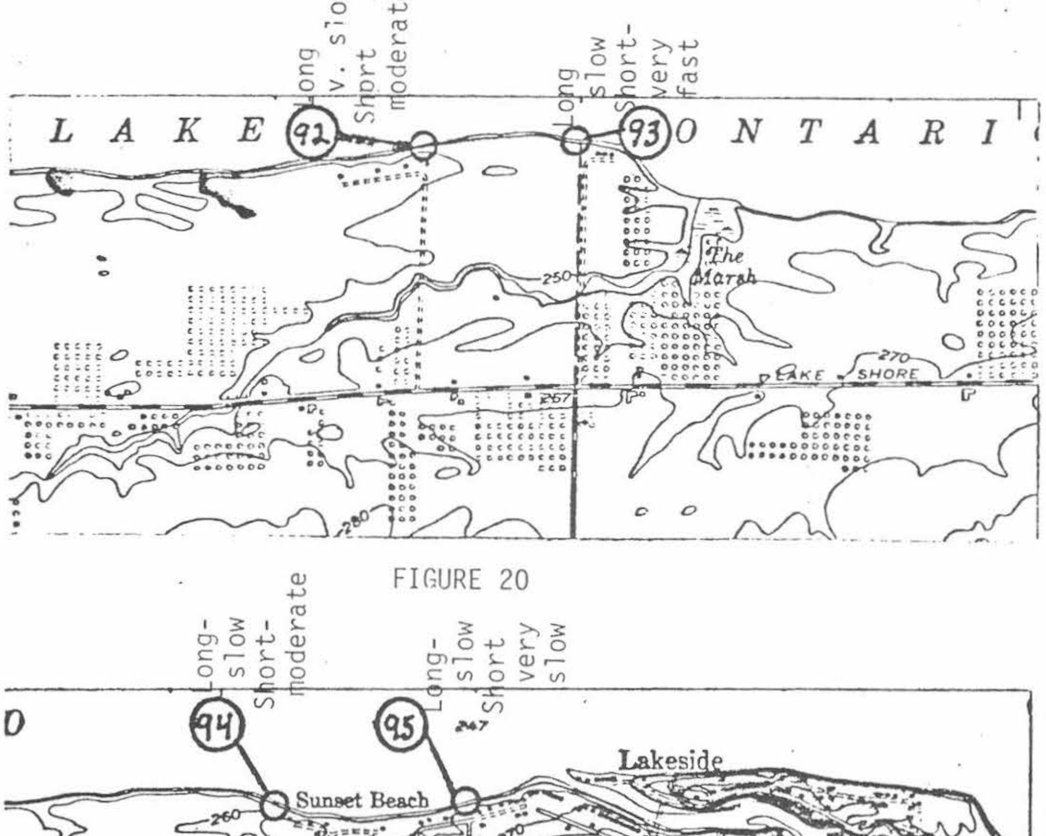


FIGURE 20

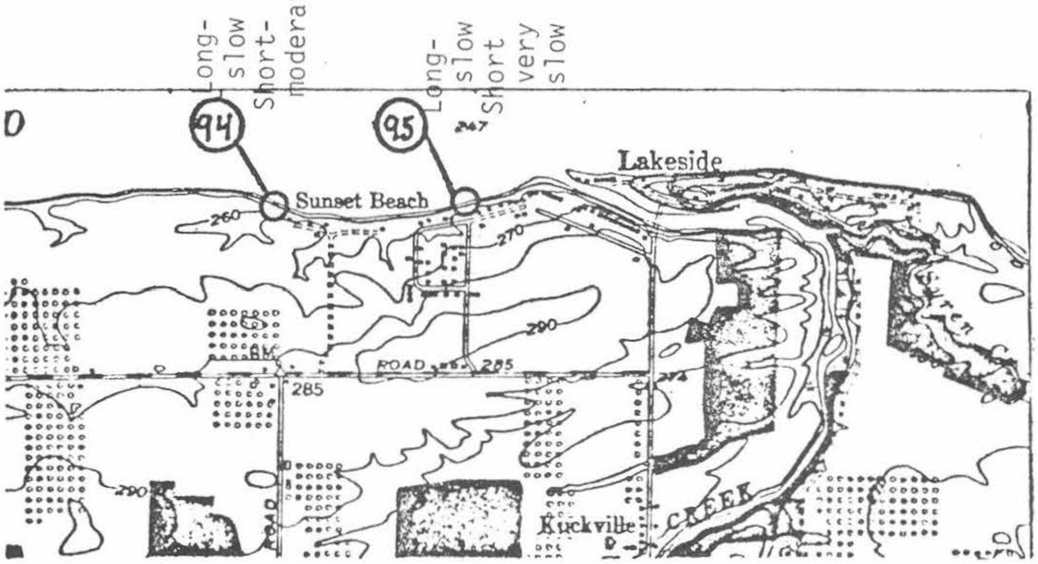
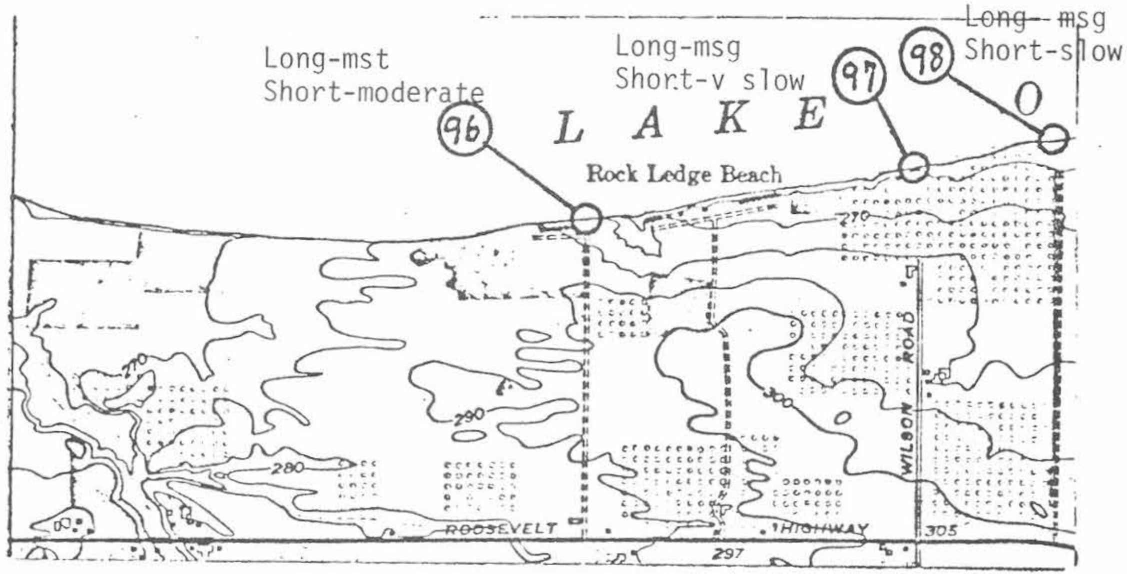


FIGURE 21


Long-mst
Short-moderate

Long-msg
Short-v slow

~~Long-~~ msg
Short-slow

FIGURE 22

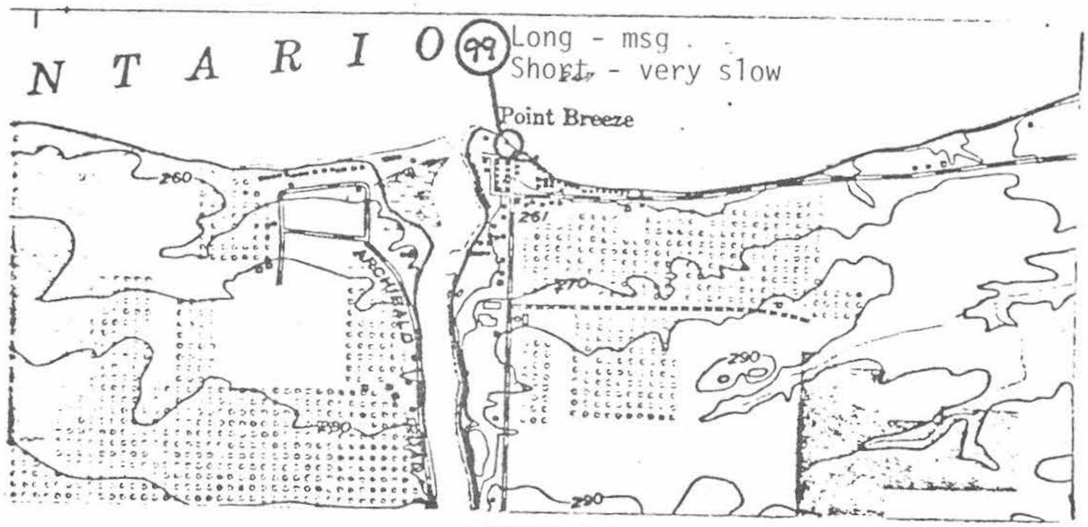
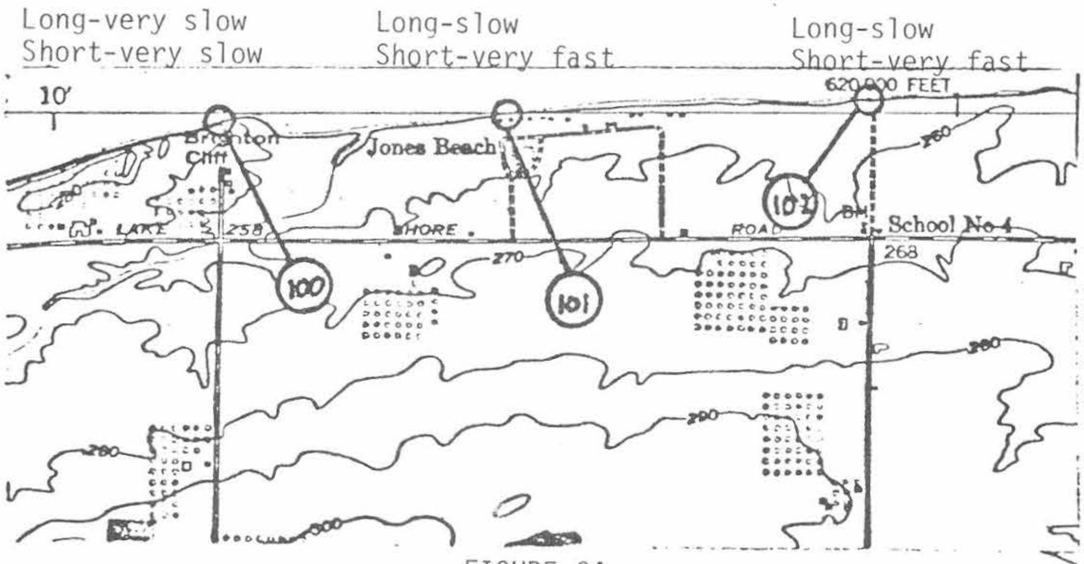

Long - msg
Short - very slow

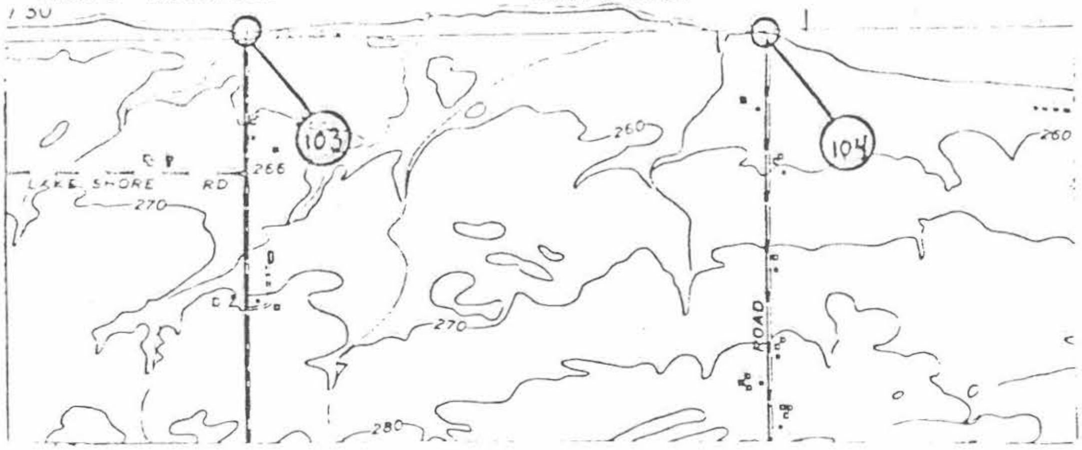
FIGURE 23


Long-very slow
Short-very slow

Long-slow
Short-very fast

Long-slow
Short-very fast

FIGURE 24



Long- slow
Short- moderate

Long=slow
Short-slow

FIGURE 25

Bluff recession rates after Drexhage and Calkin, 1981.

For Figures 5 through 25

Very slow = less than 30 cm/yr
Slow = 30 to 60 cm/yr
Moderate = 60 to 90 cm/yr
Fast = 90 to 120 cm/yr
Very fast = more than 120 cm/yr

Long term rate is the average rate from 1875-1974
Short term rate is the average rate from 1938-1951 for Niagara County and 1938-1954 for Orleans County.

34.0	1.9	Pass on Route 18 east across Fourmile Creek and entry to Fourmile Creek State Campground
37.5	3.5	Cross Sixmile Creek.
38.8	1.3	Turn left and drive on loop bypass to view Lake Ontario and bluff at 23 (Fig. 7). Nearshore gradient is about 8.6 m/km; both short- and long-term recession average under 30 cm/yr. (Drexhage and Calkin, 1981). Return in 0.7 mi turning left east onto Route 18.
44.7	5.9	Turn left at bridge before crossing Twelvemile Creek onto Riverview Road; take second left onto Lakeview Road.
45.1	0.4	Park at boat ramp site enclosed by storm fence and gate. You are 100 m east of Station 34.

STOP 3. ROOSEVELT BEACH. The bluff stratigraphy as exposed in 1975 was:

Top	0.5 m	Lake clay, red, massive, scattered pebbles (Lake Iroquois). Till pockets locally in base.
	2.0 m	Till, red (weathered); sand:silt:clay per cents 41:35:24; incorporates lenses and discontinuous beds of yellow silt or fine sand; cobbly at base.
	2.0	Till, purplish to red (5 YR 4/1); sand:silt:clay per cents 22:57:21; compact (denser than overlying till); clast content 5%.
Water	2.0	Rip rap protecting base of bluff

Approximately 1200 m to the west, the lower compact till is separated from the overlying till by a stone pavement. Gilbert (1898) described a well developed stone pavement exposed in shore bluffs for a half mile east of the mouth of Tuscarora Bay. Marked parallelism of striae on the flat upper surface of 10 of these boulders indicated deposition of the upper till to have been by ice flowing S50W. He interpreted the stone pavement as distinguishing two tills. An alternative explanation recognizes the upper till as a subaqueous allo-till facies; the lower till as lodgement facies representing the same glaciation.

The highest bluff recession rates in Niagara County are measured at Roosevelt Beach (Drexhage and Calkin, 1981). Between 1938 and 1951 the bluff receded at an average rate of 2.1 ft/yr. Prior to 1902, Twelvemile Creek entered Lake Ontario through Tuscarora Bay. In 1902, the receding shore bluffs breached the left bank of Twelvemile Creek. Subsequent sedimentation has built a barrier across the former channel, isolating the mouth of Twelvemile Creek from that of its East Branch and tying the "Island" east of the State Park to the mainland. (See also Brennan, 1979, Fic. 13, Stn. 11, pp 36-37, and Fortune and Calkin, 1981.)

		Turn left onto Hamilton Street, right on Riverview Road and back to Route 18; turn left to the east.
45.3	0.2	Cross West Branch Twelvemile Creek; continue east on Route 18, pass Wilson-Tuscarora State Park entrance.
46.4	1.1	Bear left at fork, continuing on Route 18 through village of Wilson toward Olcott.
48.8	2.4	Note elongate, northeast-trending ridge at right. This is the general trend of ground moraine ridges in this part of the lake plain. Though very subdued, this grain controls orientation of minor drainage lines. In part, at least, it is considered to reflect fluting of underlying bedrock by glacial erosion.
53.1	4.3	Cross Eighteenmile Creek at Village of Olcott at left; cross Route 78 and continue east on Route 18.
54.8	1.7	Turn left off Route 18 opposite creek and park beside Newfane Wastewater Treatment Plant.

STOP 4. OLCOTT BLUFFS. Located between Stations 56 and 57 (Fig. 11). This is the eastern edge of a somewhat uneven silt-topped sand plain that stretches along the coast from Olcott and inland at least one mile to a low ridge, 10 to 20 ft. high and correlable with the Carlton Moraine. Ice-contact features have not been recognized in the thick cross-bedded, subaqueous sands, but their occurrence above abnormally thick clay-silt rhythmites and below fine silt suggests ice marginal oscillation. Figure 26 shows the section as measured 1 km to the west. Seeps near base of the stratified drift induce mass wasting which now largely obscures stratigraphic relationships at this site. Queenston bedrock crops out at bases of bluffs on headlands adjoining this stretch of shoreline. Bluff recession less than 30 cm/yr.

		Proceed east on Route 18
59.1	4.3	Turn left into New York State Electric and Gas Fossil Fuel Generating Plant, Somerset. Permission to enter must be obtained at gate.

STOP 5. SOMERSET BLUFFS. Located between Stations 60 and 61. In 1974, the wave-eroded bluffs here recorded two tills, a red stony till overlain by purplish-gray silty till. This section is also revealed in borings for the facility. The following section was measured in 1975:

Top	0.4 m	Lake clay, silty, oxidized
	0.55 m	Lake silt, yellow; contains convoluted beds and dropstones.

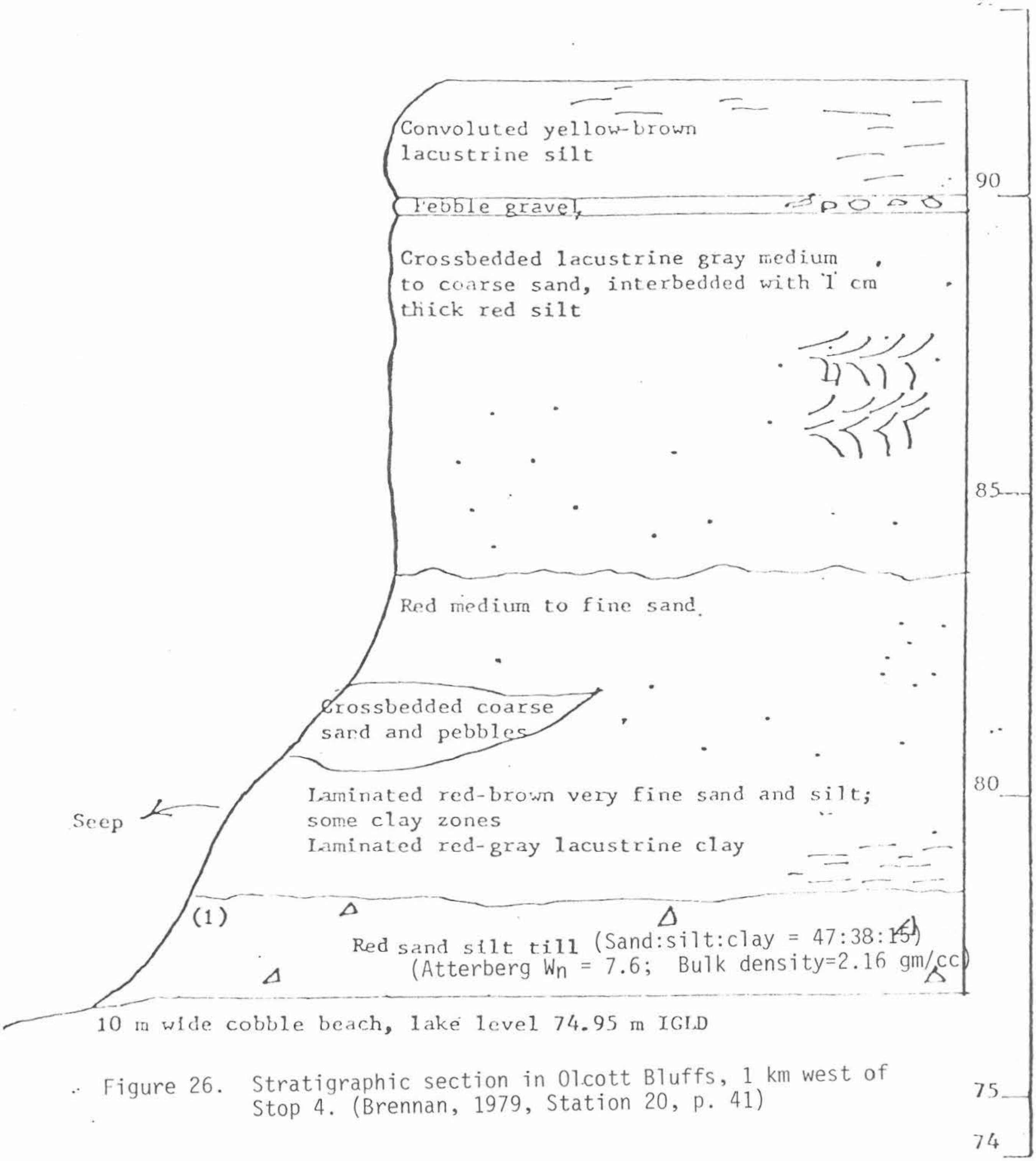


Figure 26. Stratigraphic section in Olcott Bluffs, 1 km west of Stop 4. (Brennan, 1979, Station 20, p. 41)

1.1 m	Till, interbedded yellow sand, locally gravelly; subaqueous allo-till (?)
2.1 m	Till, purple-red, 10% stones, compact; lodgement and subaqueous till.
0.5 m	Queenston bedrock

As at Stop 3, the question is raised whether the two till units can be assigned to a single glaciation as different depositional facies of the same till, or whether two glaciations are represented. Salomon (1976) at a nearby exposure reported 4 ft of silt, clay and sand between the two tills. Both short- and long-term bluff recession rates are "very slow", i.e. less than 30 cm/yr (Drexhage and Calkin, 1981).

Continue east on Route 18

60.4	1.3	Turn left (north) on Hartland Road and follow around bend east onto Lower Lake Road.
65.8	0.9	Turn left into Golden Hill State Camp Site and Thirtymile Point. Proceed to parking location immediately east of lighthouse.

STOP 8. THIRTY MILE POINT. This is Station 75 (Fig. 16). Bedrock reaches its greatest elevation above lake level in shorebluff of the south coast of Lake Ontario at Thirty Mile Point. Lake silts and sandy silt till overlie some 3 to 4 m of Queenston bedrock.

Of particular interest is the small, fractured bedrock anticline with northwest-southeast trend paralleling the coastline. As described by Gilbert (1899), the crest was broken by a steeply northeasterly dipping fracture, the northeast side displaced upward 2m with overturning of fold axis to the southwest, enclosing till. Although continuing below lake level, the deformation seems to die out downward. Evidence suggests glaciotectonic thrusting by southwesterly moving ice following initial till deposition (Kindle and Taylor, 1913).

Gilbert wrote "Should this description rouse enough interest to induce others to examine the locality, their visits should not be long delayed. This part of the coast is specially exposed to the attack of storm waves and is rapidly beaten back." Eighty years later, however, the exposure appears much as illustrated by Gilbert with apparent bluff recession of no more than 2-3 m in that interval.

67.3	1.5	Leave Park and proceed east on Lower Lake Road.
68.5	1.2	Turn right (south) at first road, County Line Road.
69.8	1.3	Turn left (east) onto Route 18, Roosevelt Highway .
73.6	3.8	Cross Route 63, Lyndonville Road.

77.7	4.1	Note very gently hummocky topography of Carlton Moraine trending parallel to route.
83.6	5.9	Turn sharp left off Route 18 at three-pronged intersection and cross Orchard Creek on Marsh Road. Take first left onto Route 98N; pass under Lake Ontario State Parkway to Point Breeze. Orchard Creek has been incised deeply into bedrock by early postglacial stream erosion. Like other creeks on this south coast of Lake Ontario, its gradient has been diminished and its debouchment into Lake Ontario drowned by postglacial tilting. Shore bluff retreat partly counters the estuary development that tilting has produced.
85.0	1.4	Turn right (east) onto Lake Shore Road at Point Breeze.
86.1	1.1	Park along road adjacent to Station 99.

STOP 7. BRIGHTON CLIFF. Bouldery to sandy supraglacial drift correlated with ridges of the Carlton Moraine 1 to 2 mi south. Underlying weakly bedded till overlies compact till similar to the main till unit of the Niagara River to Rochester reach of the Ontario coastline. The stratigraphy in the bluff is depicted in Figure 27 from Brennan (1979)."At the top of the till, a deformed boulder layer lies on a distinct erosion surface; above the boulder layer pebbly sand grades upwards to fine sand and silt". (Brennan, 1979, p. 47). Pods of till within the sand and small-scale normal faults further suggest ice contact deposition. Features like the fault in Figure 27b may represent deformation during the Carlton glaciation.

		Retrace route westward along Lake Shore Road to Point Breeze and follow Route 98 south.
87.7	1.6	Pass southward under Lake Ontario Parkway.
88.5	0.8	Cross Orchard Creek on Route 98 and proceed through type area of Carlton Moraine at the railroad tracks.
95.9	4.5	Cross Lake Iroquois beach ridge at Route 104 intersection.
98.0	2.1	Albion Village limit; continue south, crossing New York Barge Canal.
99.1	1.1	Cross Route 31 and pass over Albion Moraine
101.0	1.9	Turn right (west) off Route 98 onto Route 31A (West Lee Street). Cross esker.
106.3	5.3	Turn left (south) onto Eagle Harbor Road. Note esker ridge angling obliquely toward road.

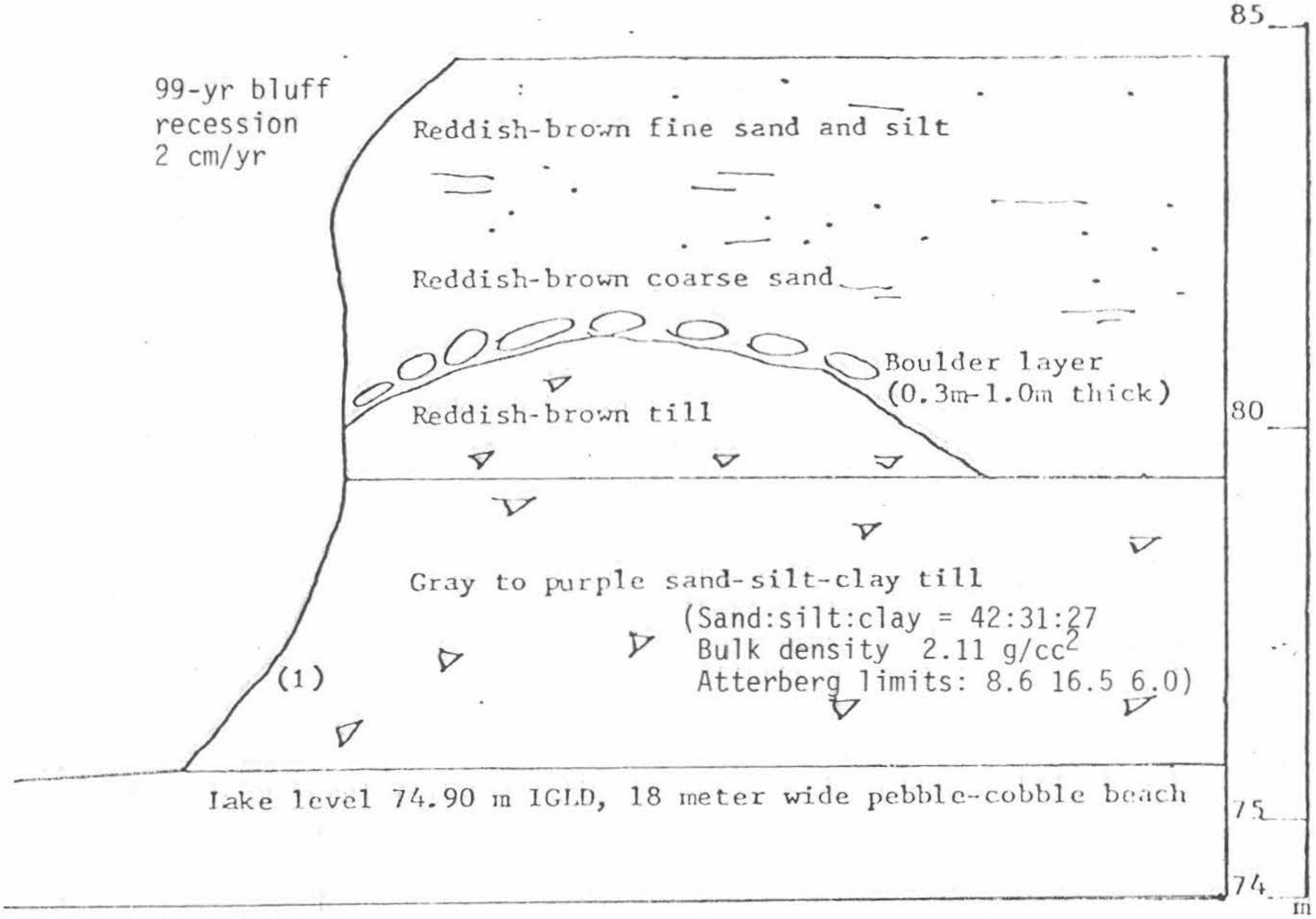


Fig. 27A. Bluff section near Brighton (after Brennan, 1979).

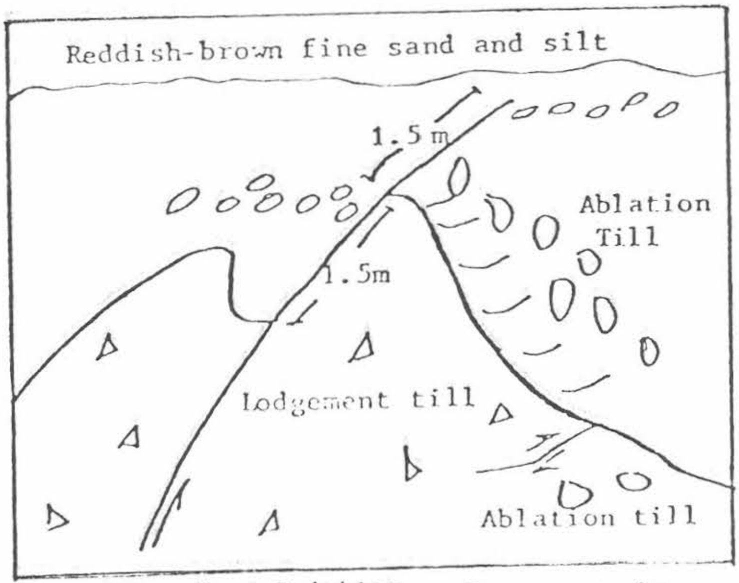


Fig. 27B. Near Brighton. Structure in till showing lodgement and ablation facies. (after Brennan, 1979).

106.8	0.5	Bear right at fork onto Kams Road and along esker ridge.
107.9	0.8	Turn right onto Maple Street across the Burma Woods kames.
108.0	0.4	Turn left onto Pine Hill Road and proceed south over Burma Woods kames toward intersection with esker.
109.4	1.4	Turn off road into gravel pit.

STOP 8. BURMA WOODS ESKER/KAME COMPLEX. The extensive area of glacier disintegration topography traversed for the past three miles developed during wastage of the glacier front from the Barre Moraine, about .5 miles south of this point. The stagnating ice margin apparently fronted on Lake Lundy (Lake Dana (?)) at a stage when it was too shallow to float large ice bergs. The Burma Woods Esker can be readily traced for 4 mi (6.4 km) and conceivably extends all the way to the Albion Moraine, making it perhaps the longest esker in western New York. It consists of a number of discrete segments, the last to be deposited being at the north end. One of the segments terminates in a kame delta at about 735 ft. suggesting the level of Lake Lundy into which it was deposited. Distinct deltaic foreset bedding can be observed in this pit. See Figure 28 for location.

		Leave pit, continuing south
109.6	0.2	Turn right on Gray Road
110.3	0.7	Turn left onto Hemlock Ridge Road. This is the frontal ridge of the Barre Moraine. Proceed east through West Barre on Root Road (continuation of Hemlock Ridge Road) and cross lake flats with several closely spaced drumlin ridges oriented northeast-southwest.
115.0	4.7	Turn right (south) onto Quaker Hill Road which leads to Route 98 southbound. Cross eastern end of Oak Orchard Creek headwaters and surrounding swamp, as well as several southwest-oriented drumlins.
119.4	5.4	Elba Town Line -- the "onion capital of N.Y.S."
122.3	2.9	Cross Onondaga Escarpment and rise onto Onondaga Bench. The Batavia Moraine crosses Route 98 at top of the scarp.
123.9	1.6	Turn left onto New York Thruway and west towards Buffalo.

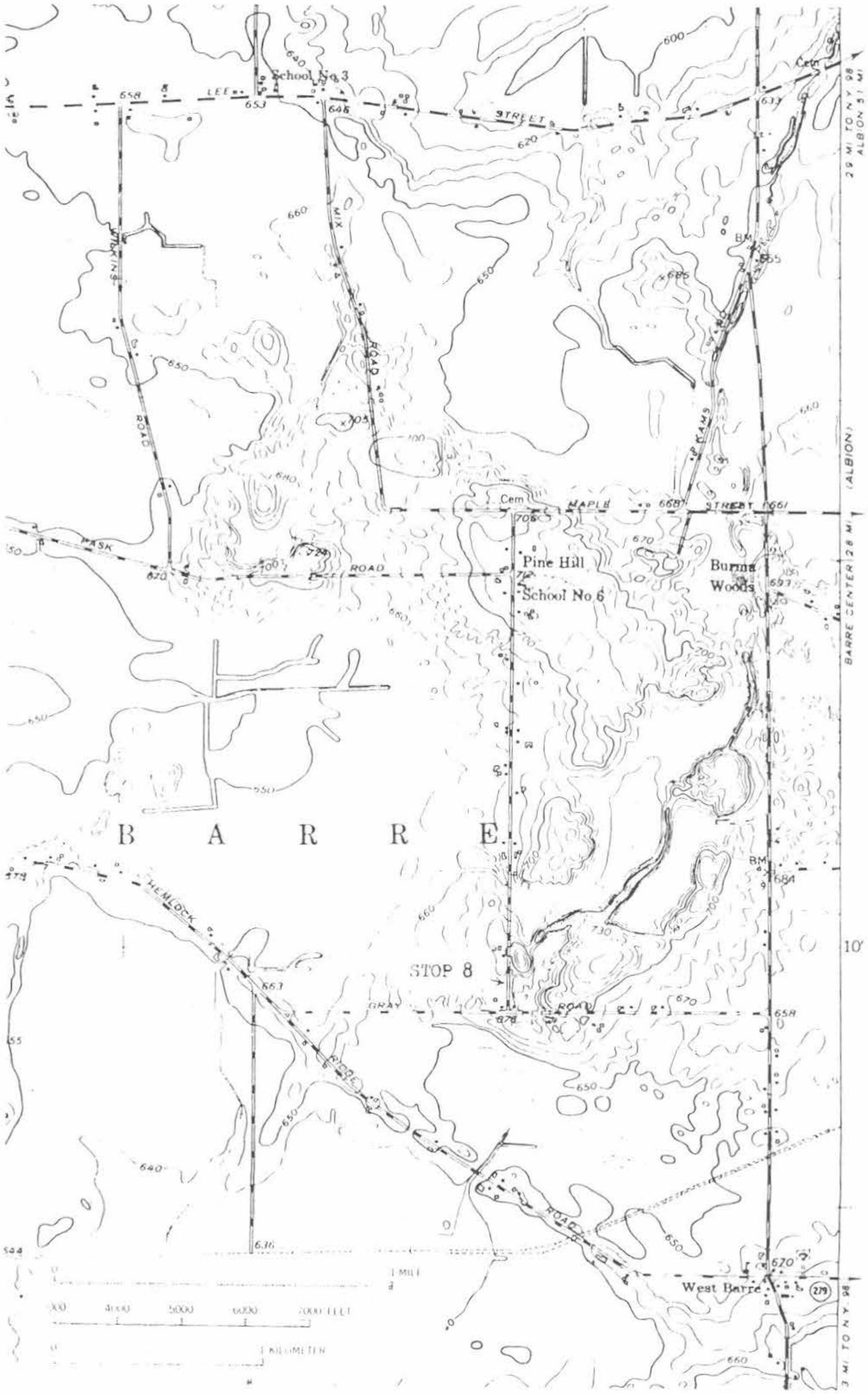


Figure 28. A portion of the Knowlesville, N.Y. 75' Quadrangle showing the Burma Woods esker/kame complex and the Barre Moraine (Hemlock Ridge Road).

124.2	0.3	Pass west on New York Thruway back under Route 98. Gravel kame topography correlated with the Buffalo Moraine trends northwest away from Thruway on right.
129.4	5.2	Cross through partly quarried-out kames related to the Buffalo Moraine.
143.1	13.7	Pass gravel pits in thick gravel associated with Buffalo Moraine (Calkin, this volume, Figure 2).
147.9	4.7	Quarry on right next mile in Onondaga Limestone
153.1	5.2	N.Y.S. Thruway Toll barrier. Take first exit right onto Route I-290 after leaving barrier. On I-290 move promptly into middle lane.
154.1	1.0	Cross Onondaga Limestone Escarpment and under Route 5 (Main Street).
156.3	2.2	Exit right (north) onto Millersport Highway
157.0	0.6	Turn left into Marriott Hotel parking lot.
		HAVE A SAFE TRIP HOME !!!