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An Aerial Photogrammetric Study of Erosion and Accretion Boston Harbor Islands, Massachusetts

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AN AERIAL PHOTOGRAMMETRIC STUDY OF EROSION AND ACCRETION
BOSTON HARBOR ISLANDS, MASSACHUSETTS

BY

PAUL WILLIAM RIEGLER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

GEOLOGY

UNIVERSITY OF RHODE ISLAND

1981

ABSTRACT

The amount and size of sediment eroded and accreted on the erosional shorelines of the Boston Harbor Islands has been determined from a photogrammetric analysis of the high tide line and cliff line over the period of 1938 to 1977 (the dates of the earliest and latest aerial photographic coverage). Photogrammetric areal measurements of the Boston Harbor Islands were made using a Zoom Transfer Scope and Digital Plainmeter for five series of aerial photographs (1938, 1952, 1963, 1971,and 1977). By using the Coastal Engineering Research Center's (1973) estimate of the volume of beach lost ($0.76m^3$) per $.09m^2$ change in the areal extent of the shoreline; one can derive a value of $8.44m^3$ in volumetric change per $1m^2$ change in areal extent of the shore line. The volume of cliff erosion was determined by using cliff heights actually determined in the field and topographic maps.

The total volume of material eroded from the Harbor Islands high tide line and cliff line between 1938 and 1977 was $2,034,327m^3$. The total accretion of the high tide line during the same time span was $363,599m^3$. This amount of accretion accounts for 18 per cent of volume of material eroded.

The percentages of sediment sizes present in an average sample of drumlin till was compared to the percentage of sediment sizes in a shoreline of accretion. The drumlin till is composed of approximately 25% gravel, 20% sand, 40 to 45% silt and less than 12% clay. From analysis of sediment from the area of accretion, it was seen that 21% of the gravel sized sediment eroded was redeposited in areas of accretion. 21% of the sand sized sediment aroded was

redeposited. Only 1% of the silt to clay-sized sediment was redeposited.

The major areas of accretion all lie at or near the southern or southwestern extremeties of the Islands. "Northeasters" may cause the littorial drift to lie in a southern or southwesterly direction.

ACKNOWLEDGEMENTS

I would like to thank Dr. J. Fisher for his guidance in preparing this paper, Dr. R. Jones of Boston State College for his help in field work and in supplying the 1952 series of aerial photographs, Ms. Lillian Kraetzer for her typing and editing, the Metropolitan Boston Redevelopment Authority loaning of the 1963 and 1971 series of aerial photographs. I would like to extend a special thanks to my parents for their unending financial aid and moral support.

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Introduction

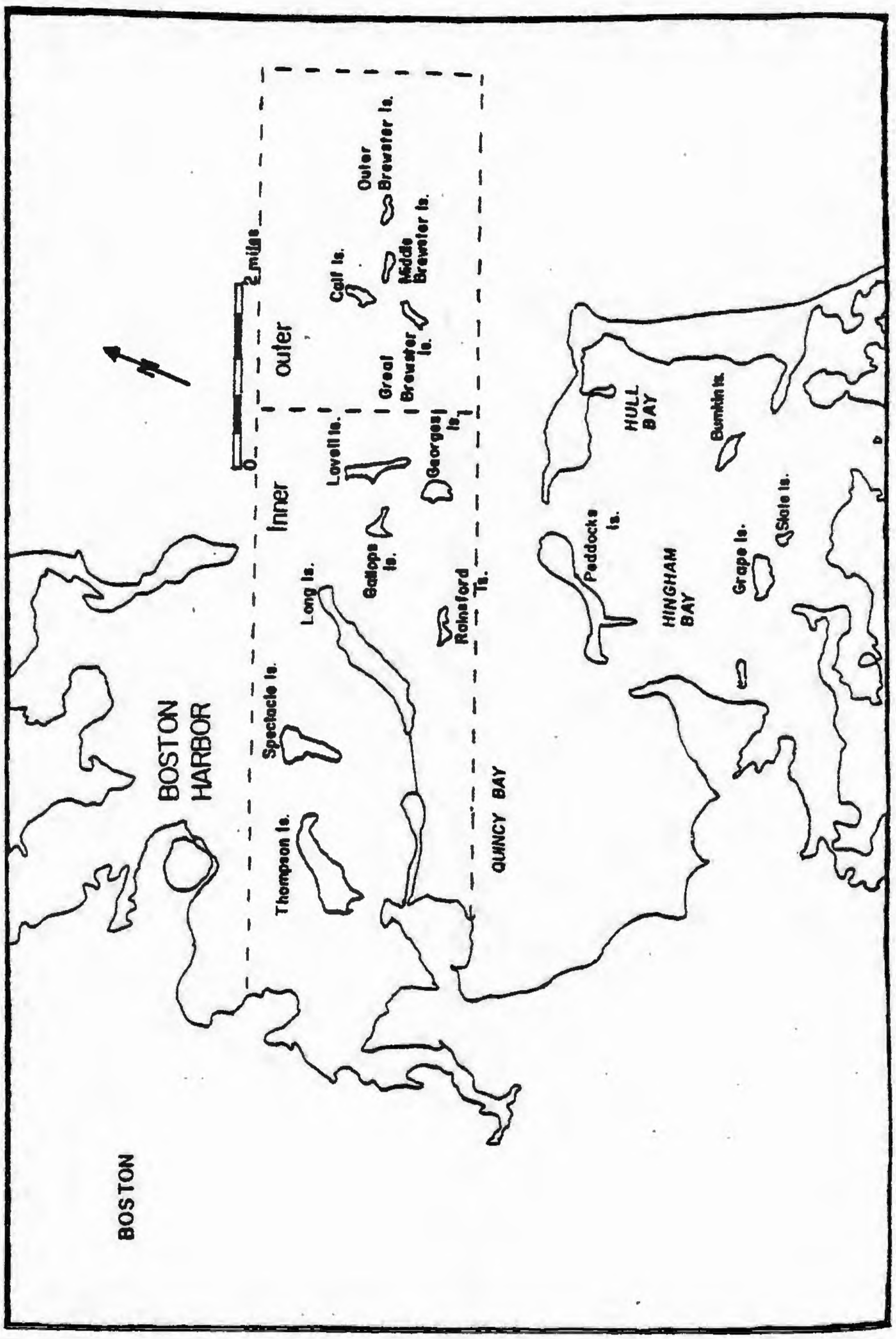
Twenty-one islands are located within the confines of Boston Harbor, Quincy Bay and Hingam Bay. Eleven are located within the confines of inner and outer Boston Harbor (Figure 1). This study is based on these eleven islands. Three of the outer islands, Calf Island, Middle Brewster Island and Outer Brewster Island, are composed almost entirely of resistant bedrock. No change in their areal extent was detected during the study period. With pressures exerted by an expanding urban population for more recreation areas, planners have begun to look at the Harbor Islands and their potential use.

The operation of various geologic processes and physical forces have changed the shape of the Harbor Islands. Areas where the islands are composed of resistant bedrock may show little or no change while areas of unconsolidated or semiconsolidated material may have undergone relatively rapid changes. Historical accounts from the 1800's speak of many areas undergoing erosion. For planners to properly place recreational areas and associated support structures, knowledge of an area's stability is important. Failure to do so could result in the erosion of the recreational area or in the construction of costly unnecessary shoreline protection structures.

Collecting coastal data is not a simple task. Extensive field measurements are usually very expensive and are time consuming. It is much more difficult because the methods for measurement in the field do not alway permit the precision which is commonly claimed (Tanner, 1977). Field surveys are also seriously complicated by the problem of extrapolating results obtained from short term field observations into long term erosional or accretional trends.

FIGURE 1

Location Map


BOSTON
BOSTON HARBOR
Thompson Is.
Spectacle Is.
Long Is.
Gallops Is.
Lovell Is.
Georges Is.
Rainsford Is.
Inner
outer
0
2 miles
Calf Is.
Great Brewster Is.
Middle Brewster Is.
Outer Brewster Is.
QUINCY BAY
Peddocks Is.
HULL BAY
HINGHAM BAY
Bumkin Is.
Grape Is.
Slate Is.

Aerial photographs offer an alternative to field surveys by providing long term data that is relatively inexpensive when available. Aerial photographs represent a permanent record of the location and configuration of the coastline at the time the photographs were taken. An aerial photograph captures an almost infinite amount of detail, while a map records a selected amount of detail. Aerial photographs depict such features as the dune line, high water line, and the part of the beach that is uncovered at tides lower than high tide.

Description and quantification of the long-term erosional and morphologic changes of the Harbor Islands was accomplished by preparing overlays of the shoreline and cliffline from sequential aerial photographs. Aerial photographic coverage of the islands was available for the years of 1938, 1952, 1963, 1971, and 1977. Of the eleven islands included within this study, nine are totally covered by the five series of photographs. Spectacle Island and Thompsons Island were not covered by the 1971 series of photographs.

The 1977 aerial photographs were enlarged and used as a base photograph. Aerial photographs from the four other years were optically enlarged and superimposed on the larger base photograph. This was accomplished through the use of the Baush and Lomb Zoom Transfer Scope. The Zoom Transfer Scope has an anomorphic feature imcorporated into it. It allows the operator to compensate for geometric anomalies in a photographic image, such as tilt, relief, radial distortion, earth curvature, lens distortion and film shrinkage.

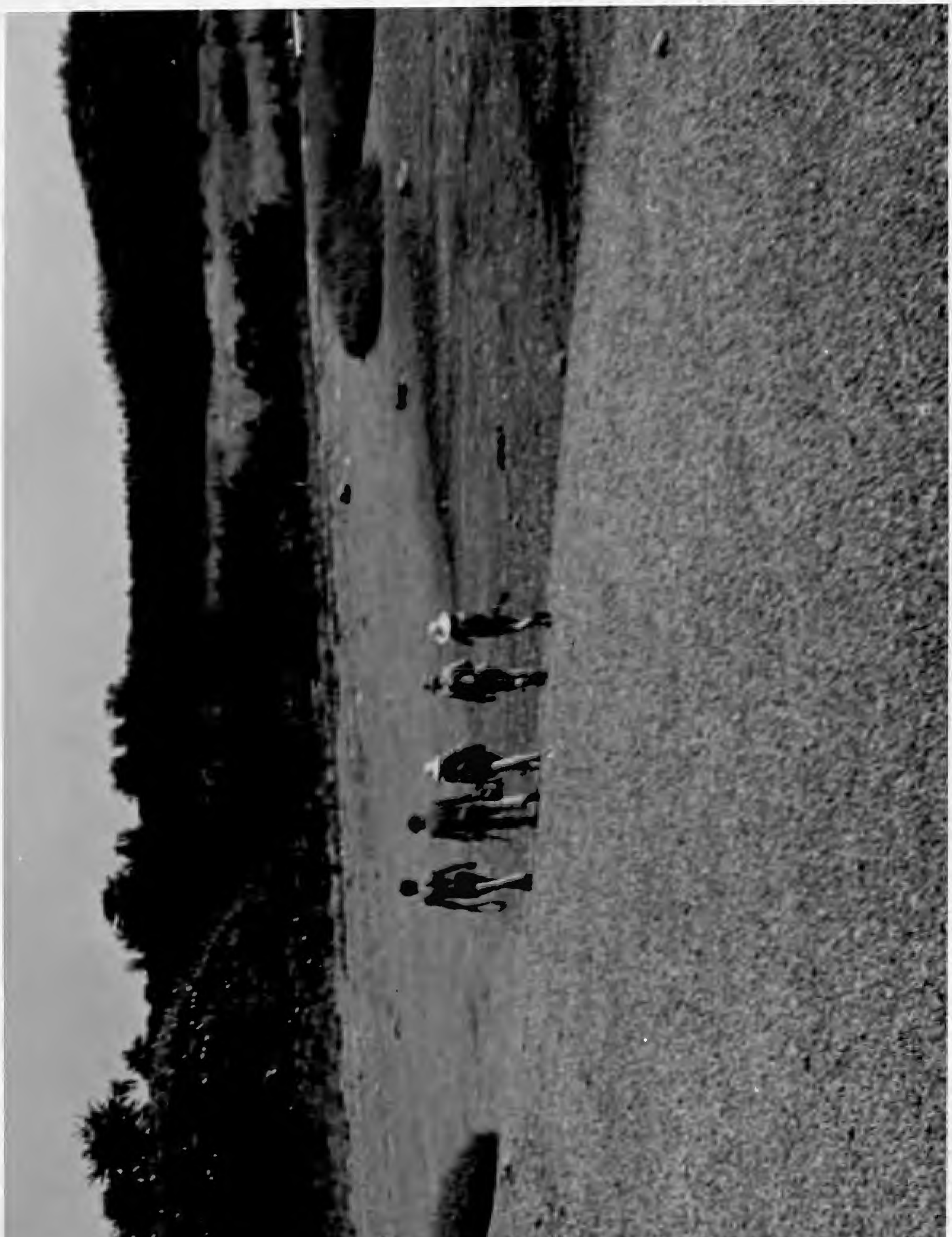
The Harbor Islands shorelines are composed of sand, shingle, cobbles, boulders, bedrock and mussel shell beaches (Figures 2, 3, 4). Mussel shells and other debris commonly constitute the high tide line and make

FIGURE 2

Boulder and Cobble Beach

FIGURE 3

Glacial Erratic



it easily observable. The high tide line and glacial till cliffline, where present, were used as survey lines from which measurements were made. Approximately one month was spent on the Harbor Islands to conduct ground control surveys for photographic scale verification and to become familiar with the island morophology.

Surficial Geology

The Boston Harbor Islands are contained with the Boston Basin. The Basin is a topographic, structural and sedimentary basin. It contains, at its deepest extent, over 17,000 feet of argillaceous and conglomeratic sedimentary rock with some associated volcanics. Their age has been debated for some time with suggestions ranging from Ordovician to Permian. Today a Carboniferous Age has been assigned to the Boston Basin sequence. The rocks of this basin rest with mapped uncomformity on the Dedham Granodiorite, which is dated Precambrian (Kay, 1976).

Boston Harbor lies close to the margins of the Pleistocene ice sheets. Stratigraphic evidence of five ice advances and three marine trangressions is present around and within the Boston area (Kaye, 1976). Pronounced variations in the direction of ice flow were controlled by deep basins in the Gulf of Maine, to the east. The ice at Boston flowed in a southerly direction only at maximum glaciation. Less extensive ice sheets flowed eastward at Boston toward the area which is now Massachusetts Bay. These changes in flow directions have seriously complicated the pattern of glacial deposits.

Most of the inner Harbor Islands are submerged drumlins. Three of the outermost Islands: Outer Brewster, Middle Brewster and Calf are composed of bedrock. About 180 drumlins have been recognized in the Boston Area (La Forge, 1932). The average trend of all drumlins in the Boston area is south 55^0 east (Brenninkmeyer, 1976). Submarine seismic profiling in the Harbor and in Massachusetts Bay to the east shows many drumlins that are entirely submerged and more or less buried in later marine clays.

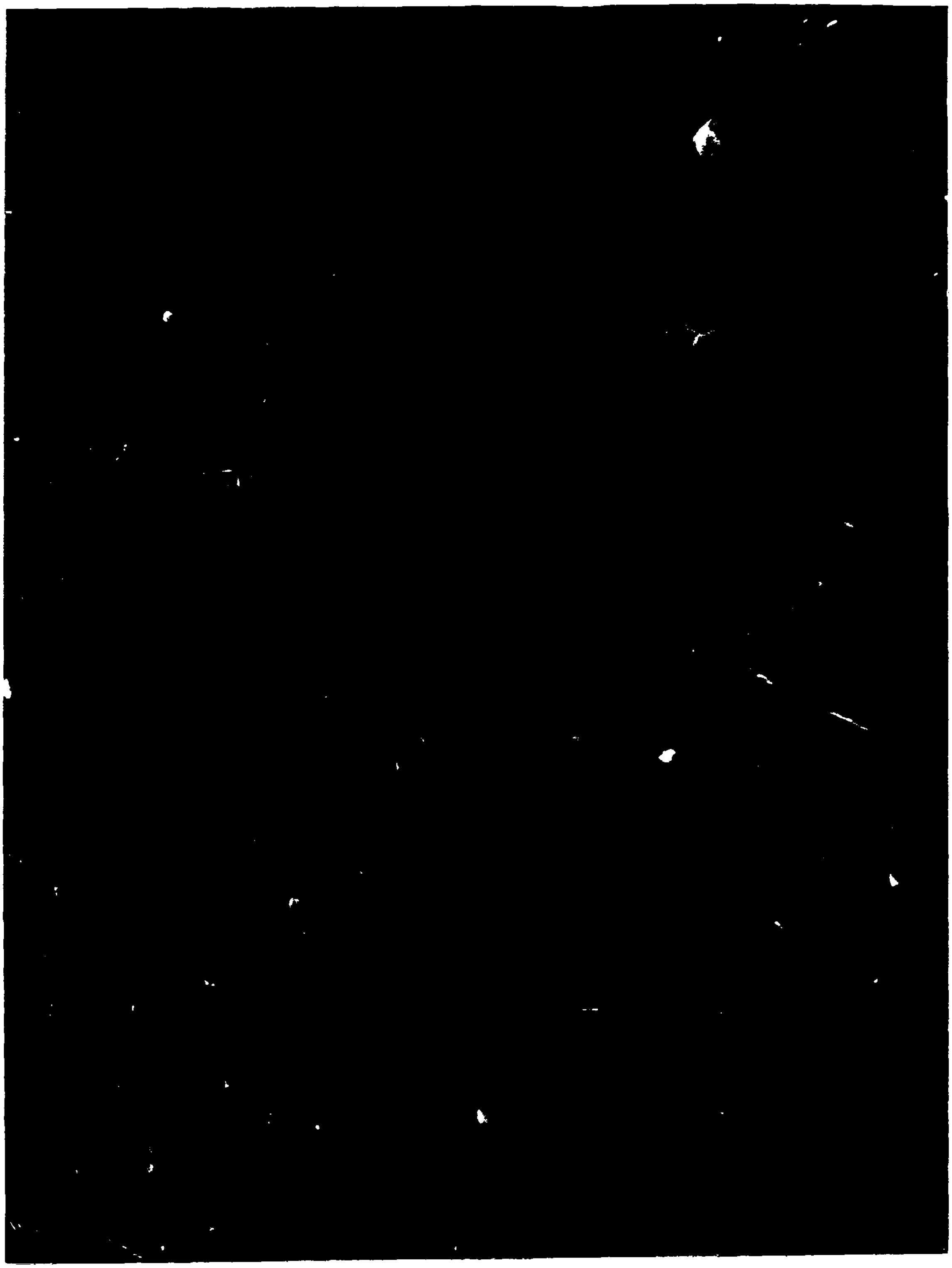
Most of the drumlins consist of compact, very-well graded, greenish gray till with a cohesive sandy, clayey-silt matrix (Figure 5). Boulders are sparse and cobbles and pebbles are predominantly of very local rock types. The drumlin material may be stratified or consist of unstratified till deposits. Some drumlins are known to overlie bedrock directly, but borings indicate the others overlie deposits of sand, gravel, or clay. The sand, gravel, and clay beds appear to have been deposited earlier than the drumlins.

Previous Aerial Studies

Aerial photographs have been used in the past to obtain qualitative evidence regarding coastal changes. Lee (1922) was one of the first to see the potential uses of aerial photographs in the coastal zone. Quantitative measuring of changes in shoreline areas was developed by Stafford (1968). He measured distances between stable reference points and the dune and high tide line. This technique has since been used by many workers to identify and quantify various geologic processes active in the coastal zone. El-Ashry (1967,1973) studied qualitative shoreline changes along various locations of the Gulf and Atlantic coasts of the United States resulting from hurricanes and severe storms. Kaye (1973) and Ogden (1974) used historical data and sequential aerial photographs to obtain long-term shoreline changes on the island of Martha's Vineyard. Kidson and Manto (1973) used photogrammetric and

FIGURE 5

Drumlin Till



computer-aided techniques to calculate coastal change. Zarillo (1974) measured inlet migration at New Jersey. Regan (1976) measured the erosion and accretion along the southern coast of Rhode Island. Simpson (1977) calculated the back barrier shoreline changes on Rhode Island's southern coast. Tanner (1977) compiled a working draft for the standards of measuring shoreline changes using aerial photographs.

The Zoom Transfer Scope has been employed by Baker (1977) in mapping inlet migration at North Carolina and more recently by Goetz (1978) in determing long-term shoreline change at Nantucket Island, Massachusetts. Fisher and Simpson (1979) also used the Zoom Transfer Scope in calculating back-barrier accretion.

Advantages and Disadvantages of Aerial Photographs

Aerial photography has been available for mapping and coastal interpretation since the 1930's. Considerable progress in the use of aerial photography has been evident since 1937 when the Tennesee Valley Authority adopted the first complete standard quadrangle mapped by aerial photographic methods (Abrams, 1963). Aerial photographs are particulatly invaluable in coastal geologic studies, both long and short term. Aerial photographs permanently record the location and conditions of the beach and its related coastal features at the time the photographs were taken. Aerial photographs provide an almost unlimited amount of ground detail whereas maps and charts show only selected detail. Coastal regions of the United States have been photographed more frequently than maps or charts have been updated (Stafford and Langfelder, 1971). The low cost of measuring change with aerial photographs makes it more desirable than costly and time-consuming aerial surveys. In the case of Boston Harbor, photographs have been taken at approximately ten year intervals over the last forty years. The last revision of U.S.G.S. quagrangle maps in the Boston area took place in 1961.

Tides, seasonal changes in wave climate, storms, sediment supply and relative sea level changes produce variable effects in shoreline changes. Averaged, long-term rates probably more closely approximate the historical shoreline changes, while short term rates may indicate the temporal, fluctuating changes occurring along the shoreline. There are disadvantages in using aerial photographs for mapping shoreline features and shoreline changes. Some problems such as film shrinkage and lens variation may cause some distortion but would be difficult to determine (Avery, 1977). Each aerial photograph has its own scale, which can be expressed as a representative fraction, or ratio between a given distance on the ground and that same distance measured on the photograph. Presently most aerial photographs used are at a scale of 1;20,000 to 1:10,000, although variations on this range are commonly used. This range of scale provides a limit because of the measurements which the human eye can make consistently on an aerial photograph. A distance of 0.5mm is conceivably the smallest unit of length which some persons might be able to use advantageously and consistently. A distance of 0.2mm is considered to be a stricter limit employed by some workers in the aerial photography field (Tanner, 1977). This distance of 0.2 to 0.5mm, when converted into an actual length using a photograph's scale, can be a considerable distance. There are two sources of error because two photographs are necessary in any determinations of rate. These two sources of error should be added together to obtain the total error possible.

Scale verification was performed on each aerial photograph. The published scale is an average and should not be used for coastal change calculations. During summer field work, ground distances between permanent stations, such as buildings, military installations, and natural land, marks, that were present during the time span covered by the aerial photographs, were measured. These distances were used to calculate the scale of individual photographs. Photographs can vary in scale within as well as between photographs. This scale variability results from several factors. Relief distortion occurs because the photographic image records only horizontal distances. The recorded image on a photograph of an object of considerable relief will appear to lean radially outward from the center of the photograph (Avery, 1977). This problem was minimized in scale verification by using reference points that were at the same elevation. Radial distortion is produced by the lens of the camera and causes fratures to be displaced outward from the optical center of a photograph. Tanner (1977) suggested that for flat terrain and with modern camera lenses, this may be ignored. Tilt distortion is usually less than 2 degrees on the photographs due to government standards. Tilt provides that the scale will change radially outward from the center of the photograph so that these problems would be minimized. This is possible because flight lines contain 60% overlap and 30% sidelap.

Acquisition of Aerial Photographs

Five sets of aerial photographs were obtained for the study of the Harbor Islands. The 1938 photographs were purchased from the National Archives and Records Service with a nominal scale of 1:24,000. The 1952 series is on loan from Boston State College and have a nominal scale of 1:20,000. The 1963 photographs are on loan from the Boston Metropolitan Redevelopment Authority and have a nominal scale of 1:14,000. The 1971 photographs are also on loan from the Boston Metropolitan Redevelopment Authority and have a nominal scale of 1:12,000. The 1971 photographs were copied from originals flown for the city of Boston, Planning and Mapping divison. The scale of the copied photographs varies from 1:3475 to 1:8986.

Reproductions of the 1977 photographs were purchased from the city of Boston, Planning and Mapping division at a nominal scale of 1:4000. THese reproductions of the 1977 aerial photographs, were used to record pertinent data during 1978 summer field work on the Harbor Islands. Except for the 1952 series of photographs, which were taken during August, all of the other of photographs were taken during the fall or spring months. This is the best time to take photographs for topographic mapping, when the deciduous vegetation is bare and the ground is essentially free of smow cover (avery, 1977)

Photogrammetric Technique

Through the use of a Bausch and Lomb Zoom Transfer Scope, the 1938, 1952, 1963, and 1971 series of photographs were optically enlarged to obtain the same scale as the 1977 photographs whose scales range from 1:3475 to 1:8986. The instrument is able to optically enlarge a small scale photograph and superimpose that image on a large scale base photograph. The instrument allows for a magnification of one to fourteen time the original scale. The magnification provides more useful details per photograph. The Zoom Transfer Scope has an anomorphic feature incorpoorated into it. This featue enables the instrument to compensate for geometric anomalies in a photographic image, for example, due to tilt, scale variations, radial distortion, lens variation and paper shrinkage.

Dimensionally stable acetate sheets were used to record the changes in the high tide and cliff lines. The 1977 aerial high tide lines were first identified on the 1:400, 1977 aerial photo-reproductions. The large scale of these reproductions made it much easier to identify features as the high tide and cliff line. The 1977 photographs were used as base photographs to which all of the other years were enlarged.

The shorlines of the islands were divided into segments of equal length through the use of a digital linear measuring probe, which has a resolution of .01 inches (.25mm). Since the scales of the 1977 base photographs ranged form 1:3475 to 1:8986, two different segment lengths were used to provide adequate coverage. Stafford (1968) indicated that a spacing of 300m would provide suitable accuracy. Because of the small size of some of the islands, 100m and 150m increments were chosen. The change in area of each year's high tide and cliff line was measured against the 1938 high tide and cliff line. The areas were measured with a Lasico Digital Plainmeter. The Plainmeter has a special "Auto Scaler" feature built into it. The scale of each photograph is entered into the digital section of the Plainmeter and measurements from the photographs are automatically converted into their true scale, square meters. Areas of individual segments were the average of three to five traces over the area. Scales for each Island were determined by measurement of permanent stations (buildings, sea Walls) on the photographs that were previously measured in the field the summer of 1978. The 1:400, reproduced, 1977 aerial photographs assisted in the scale measurements and in identiying objects suitable for measurements.

Accuracy of Photogrammetric Technique

To assure the best possiblity of documenting significant shoreline change, the generally accepted procedure is to have the time interval between photographs as large as possible. The time interval is subject to the availability and condition of certain aerial photographs. For these reasons, aerial photographs of the Boston Harbor Islands taken the years of 1938, 1952, 1963, 1971, and 1977 were obtained. This allows for approximately forty years of coverage. The average time interval between the aerial photographs is ten years. This time interval between photographs makes it possible to record short term changes instead of just the overall forty year trend. Short term changes in rate and reverses in erosional or accretional trends can be detected with frequent aerial photographic coverage. A shoreline that shows twenty meters of erosion over a forty year period may have had a period of accretion that would be undetected if only two photographs, forty years apart, were used. Tides, seasonal changes in wave climate, storms, sediment supply and relative sea level changes produce the variable effects that cause changes in the rate of erosion or accretion of the high tide line of cliff line.

Using Tanner's (1977) "smallest field distance measurable", 0.5mm was the smallest unit of length that could be measured consistently and advantageously. The smallest ground distance measurable on the island with the largest scale, Thompson's (1:8986), and the island with the smallest scale, Gallops (1:3475), is 4.5m and 1.4m, respectively. The "smallest measurable change per year" is obtained when the "smallest field distance measurable" is divided by the amount of years covered by the aerial photographs. For Thompsons Island and Gallops Island the "smallest measurable change per year" is 0.115m/yr. and 0.036m/yr., respectively. Erosion or accretion smaller than this can not be determined.

Goetz (1978) compared actual ground measurements with measurements made on the actual photograph and obtained an average accuracy of with 2.4%. Simpson (1977) compared linear and areal ground measurements and obtained a mean linear variation of 2.1% and a mean areal variation of 3.9%. Values of erosion and accretion are presented in calculated form and were not reduced to signigicant figures. This accuracy variation should therefore be applied to all values.

High Tide Line Shoreline

The high tide line has been used to measure shoreline changes by Stafford (1968), Stafford and Langfelder (1971), Regan (1976), Simpson (1977) and Goetz (1978). Mean high water is also used to indicate the shoreline on may maps and charts. The U.S. Geological Surveys topographic maps uses the approximate line of mean high water to represent the shoreline. The U.S. Coast and Geodetic charts uses the low water line to represent the shoreline. Because the tidal stage was not the same on each photograph, photointerpretations were made so that the high tide line could be properly identified. A one-meter tidal difference, between two photographs of different dates, provides for a horizontal difference of 28.6 meters on a beach having a slope of 8 degrees, Tanner (1977). The majority of the beaches contained with The Harbor Islands are fairly steep, being composed mostly of shingle, cobble, and boulder.

The position of high tide line was identified on the aerial photographs by a change in tone on the shoreline. This tonal change is caused by a higher water content contained within the beach material below the high tide line (Stafford, 1968). A debris line, at the upper limits of the high tide swash line, was also used as a high tide line indicator. Mussel shells, abundant in Boston Harbor, composed a considerable part of the debris line. The debris line and tonal change were easily identifiable on the 1:400, reproduced, 1977 base aerial photographs.

Abnormal wave conditions or extremely high tides associated with storms may move the postion of the high tide line higher on the beach. For this reason, meterological data was reviewed for a month preceding each series of photographs. The change in water level by tides and surges is a significant factor in sediment transport, since, with a higher water level, waves can then attack a greater range of elevations on the beach and cliff profile, CERC (1973). Care was taken not to delineate storm associated features such as storm berms and debris lines located inland from the normal high tide line on the aerial photographs.

The "mean range of tide" is the difference in height between the mean of all high waters and the mean of all low waters. Schureman (1928) determined an average mean range of Boston Harbor for a 39 year period to be 9.71 feet. He recorded a diminishing mean range over time but not by a uniform amount. Changes in the mean range of tide, in the harbor, due to various changes in configuration of the shoreline and bottom is not unusual. Marmer (1944) recorded a mean tidal range of 9.46 feet for the time period of 1922 to 1932 and 9.55 feet for the time period of 1933 to 1943. He also concluded that sea level was rising, for the time period of 1902 to 1943, at .3 feet per 41 years.

The time of high and low waters within the Harbor differs by only a small amount, the tides at the Navy Yard occurring about a quarter of an hour later than at Boston light. Boston light is located approximately six miles east of the Navy Yard. Corrections for this difference in tidal stage level were not necessary because it was within acceptable error limits. The mean range of the Navy Yard is about 0.7 feet greater than at Boston light. Another variable is that tidal datums are not always the same.

Tidal datums have annual variations caused by factors such as increased or decreased runoff during the spring and the loss of water due to freezing during the winter months.

Tidal Currents

In its rising and falling the tide is accompanied by a horizontal and backward movement of the water, called the tidal current. Tidal currents are the dominant currents within Boston Harbor. Velocities, of up to 2.5 knots per hour, have been recorded among the Islands. Non-tidal currents within the Harbor are brought about by causes such as winds, fresh water run-off, and differences in density and temperature. Tidal and non-tidal currents occur together in the open sea and in inshore tidal waters. The actual currents experienced at any point is the resultant of the two types of currents. Tidal currents, because of their periodicity and strength, overshadow non-tidal currents in most areas. Tidal currents generally attain considerable velocity in narrow entrances to bays and in passages from one body of water to another.

At the times of spring and perigean tides, the velocities will usually be greater and at the times of neap and apogean tides, less than usual. Near the times of high and low water, the currents slaken and are more or less irregular in direction. The maximum velocity is reached three or four hours after high and low waters. The average velocity at the maximum strength of the current through the entrances to the Harbor is approximately 1.5 knots. Inside the Harbor this velocity diminishes to about one knot or less.

In localized areas, currents may have a daily effect upon sedimentation. A 2.5 knot tidal velocity is approximately 130 cm per second. This velocity is well within the range to initiate movement in sand to shingle-sized material. Even though these are within the channel confines, sediment transport may occur where the channels are in close proximity to the Island.

Meteorological Climate

The Massachusetts coast is affected seasonally by violent air-sea interactions originating in the tropical regions and producing storms that follow along paths across sea and land of the neighboring temperate zone. Coastal tidal inundations on the Atlantic coast of the United States are primarily caused by hurricanes. Harris (1959) demonstrated that storm surge height is approximately proportional to the central pressure depression, other factors being constant. Hurricanes and tropical storms attack the shoreline and cliffline not only from storm tides, but from the wind and from rain induced floods.

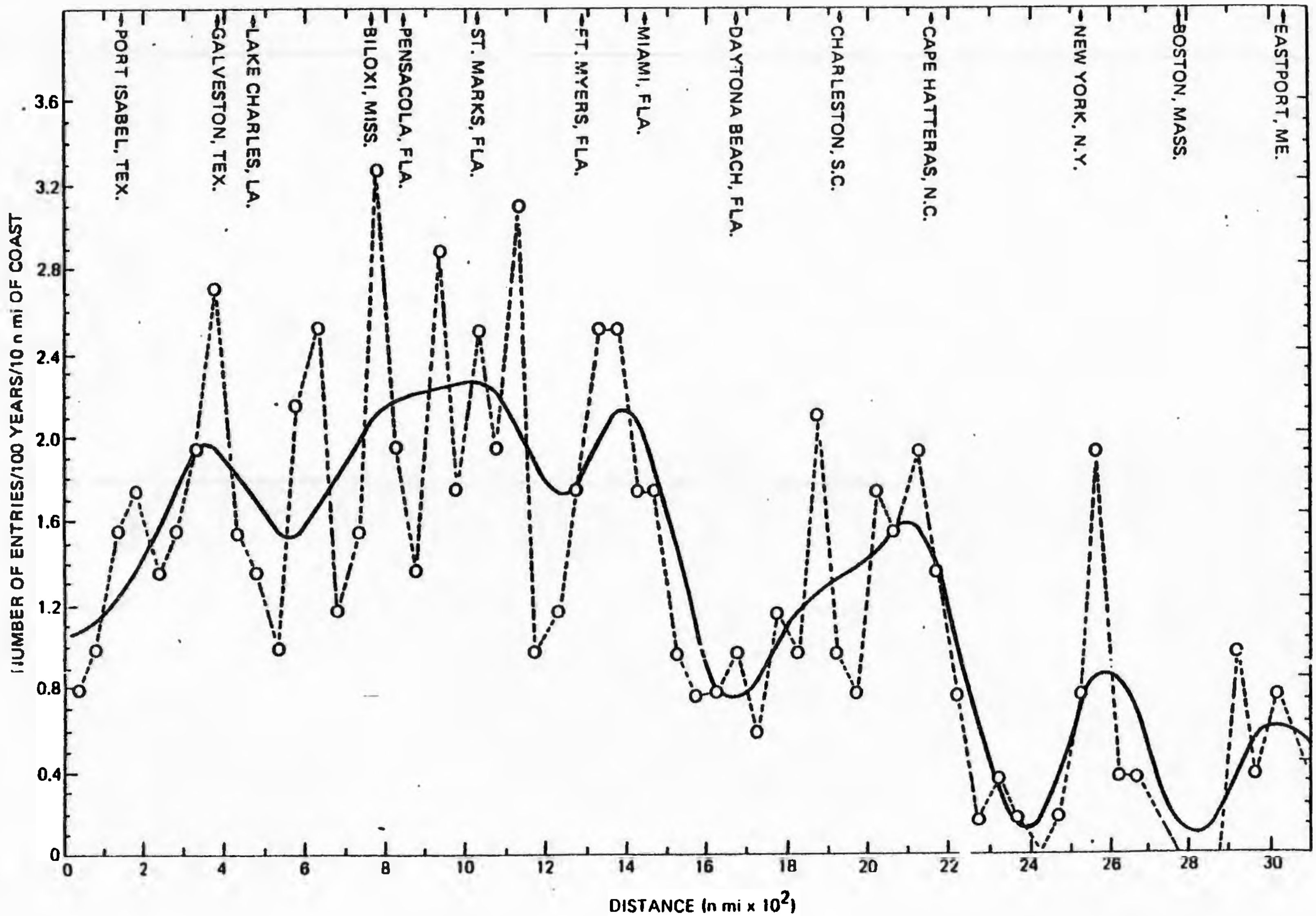
Prevailing winds within the Boston area are from the west as determined by the U.S. weather bureau for a nine year period. Of the total wind field, 51.1% have a westerly component (NNW-SSW) compared to 25.9% with an easterly component (NNE-SSE). Winds with a westerly component that exceed 10 knots account for 37.1% of the total winds whereas easterly winds over 10 knots account for 16.4%, Hobbs (1978).

According to Hayes and Boothryod (1969) storm centers generally pass southwest and northeast on the northeast coast at any time of the year. McIntire and Morgan (1963) stressed the importance of storm winds from the east, particularly "northeaster". Portions of the Harbor Islands are more susceptible to erosion from wave attack from the northeast because of direct exposure to the sea. A summary of gales compiled by the U.S. Weather Bureau, Boston, Massachusetts revealed that during a 75 year period, between the years 1870-1940, 160 gales occurred. Fifty percent came from the northeast and a total of 67% came from easterly quadrants.

Ho, Schwerdt and Goodyear (1975) constructed figure 6 for the purpose of defining climatologically the frequency of hurricanes and tropical storms influencing the Gulf and Atlantic coasts of the United States. It can be seen that there is a significant decrease in the number of landfalling hurricanes and tropical storms around the southern New England area. Northeastern storms are probably more important in the movement of sediment in the Harbor Islands. The eastward projection of the New England coastline south of Boston gives it a higher exposure to northward moving tropical storms and hurricanes. These storms rapidly lose energy upon entering the land. Northward moving offshore storms passing east of Cape Cod have a greater effect upon the Harbor Islands.

FIGURE 6

Count of Landfalling Storms and Hurricanes
(1871-1973)



Count of landfalling tropical storms and hurricanes (1871-1973) by 50-n.mi. segments of a smoothed coastline (points plotted and connected by dashed lines).

Shoreline and Cliff Line Changes

Each shoreline (high tide line) and cliff line (cliff base) is divided up into segments of equal length to record the changes in the high tide line and cliff line. Depending upon the size of an island, the shoreline was divided up into segment lengths of 100m and 150m. Cliffs with heights less than 5 feet were not examined. The 1938 high tide line and cliff line was used as the datum from which all measurements of erosion and accretion were made. The island outlines on figures 9, 12, 15-19 and 21-24 were drawn from the 1977 aerial photographs.

The measure of linear change in the high tide line or cliff line is significant for the planning of recreational and residential areas as well as for shore protection engineering purposes. These linear changes maybe different along segments of a shoreline because of changes in slope. Areal changes of individual segments in the high tide line and cliff line were changed into volume calculations to analyze each island's sediment budget. The heights of cliffs used in volume calculations were determined from summer field work and topographic maps and are included in the appendix. Cliff volume calculations are in parenthesis next to changes in the cliff line areal extent. Using the Coastal Engeneering Research Center's (1973) estimate of the volume of beach lost per areal unit of beach, volume calculations for the shoreline were determined. All three units of measurement; linear, areal, and volumetric, can supply insite into a shorelines evolution as well as information necessary for zoning regulations and coastal land use planning.

Thompsons Island and Long Island, because of their large size, were divided up into 2 and 3 sections, respectively. Match lines correspond to the end of another portion of the island.

Lovells Island

Island Geomorphology

Lovells Island is located east of Gallops Island and north of Georges Island. Between stations 1 and 15 the island is protected by a stone sea wall. All five series of aerial photographs covered Lovells Island. The segment length is 150m. The segment length of stations 8-9 is 70m. The center and northern end of the island is composed of man made fill constructed during the 1860's. Between stations 7 and 10 a well sorted sandy beach occurs. The beach material may have come from the erosion of the man-made deposits.

Shoreline Changes

The high tide line at stations 1 through 3 all experienced erosion between 1938 and 1977. Each segment lost an average of 8247m^2 from its high tide line between 1938 and 1977. This amount of erosion calculates to be a 1.4m/yr. landward retreat of the high tide line over the 39 year study period. Station 3-4 lost 11.583m^2 between 1938 and 1977, more than any other segment looked at in the study. The cuspate spit at station 4-5 changed its areal extent, moving progressively southward between 1938 and 1977. Material eroded from station 1 through 3 seems to have moved southeastward through stations 4-5 and 5-6. In 1977 the high tide line at station 4-5 was 1104m^2 less in areal extent than the 1938 high tide line. Station 5-6 lost 1891m^2 from its high tide line between 1938 and 1952. Accretion followed and the 1963 high tide line was 292m^2 greater than the 1938 high tide line areal extent. Erosion returned from 1963 to 1977 but by 1977 the high tide line was 1106m^2 greater in areal extent than the 1938 high tide line. Stations 5 through 8 all experienced periods of erosion and accretion between 1938 and 1977. In 1977 the high tide line of each segment closely approximated the 1938 high tide line. Station 9-10 lost $117m^2$ from its high tide line between 1938 and 1952. Accretion followed and by 1977 the high tide line was $2444m^2$ greater in areal extent than the 1938 high tide line. Station 10-11 added $2561m^2$ to its high tide line areal extent between 1938 and 1977. Between 1938 and 1971 station 11-12 approximated the 1938 high tide line. Between 1971 and 1977 the high tide line lost $473m^2$ in its areal extent. Station 12-13 accreted until 1963 when its high tide line was $1160m^2$ greater in areal extent than the 1938 high tide line. Erosion followed between 1963 and 1977 and in 1977 the high tide line was $482m^2$ greater than the 1938 high tide line areal extent. Station 13-14 was accretional throughout the entire study. In 1977 the high tide line was $3085m^2$ greater in areal extent than the 1938 high tide line. The sediment for this accretion may have come from the northeastern side of the island, where the sea wall is partially destroyed. Station 14 accreted until 1963 when the high tide line was $524m^2$ greater in areal extent than the 1938 high tide line. Erosion returned and by 1977 the high tide line was $161m^2$ greater than the 1938 high tide line areal extent.

Shoreline Development

Overall, Lovells Island experieced a net yearly loss of $452m^2$ from the areal extent of its high tide line between 1938 and 1977. Between stations 15 and 1 a stone sea wall protected the shoreline from erosion. During the time span of 1938 to 1952 and 1963 to 1971 the high tide line eroded at a rate of $1210m^2$/yr. and $1552m^2$/yr.

respectively. 25,041m^2 was lost from the high tide line between stations 1 and 4. Three stone jettys, located near the 1938 high tide line (Figure 7) are now located 70 meters offshore from the 1977 high tide line (Figure 8). Material eroded between stations 1 and 4 appeared to be transported in a southeasterly direction. During the time spans of 1952 to 1963 and 1971 to 1977 the high tide line accreted at a rate of 636m^2/yr. and 790m^2/yr. respectively. Areas of accretion, located between stations 9-11 and 13-14, can account for 36% of the material eroded from the high tide line between 1938 and 1977.

FIGURE 7

Lovells Island, 1938 Aerial Photograph

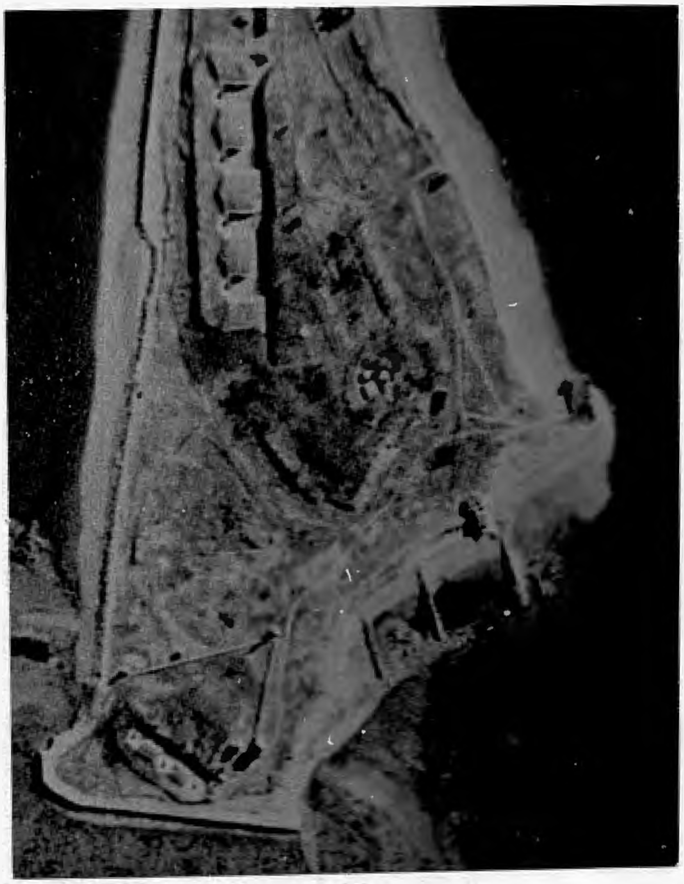


FIGURE 8

Lovells Island, 1977 Aerial Photograph

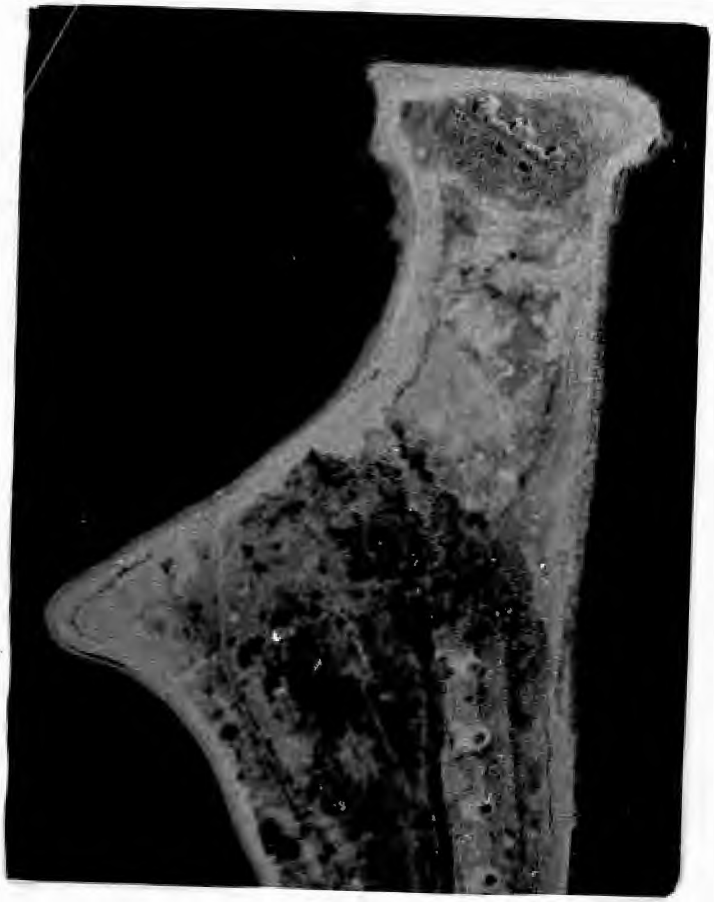
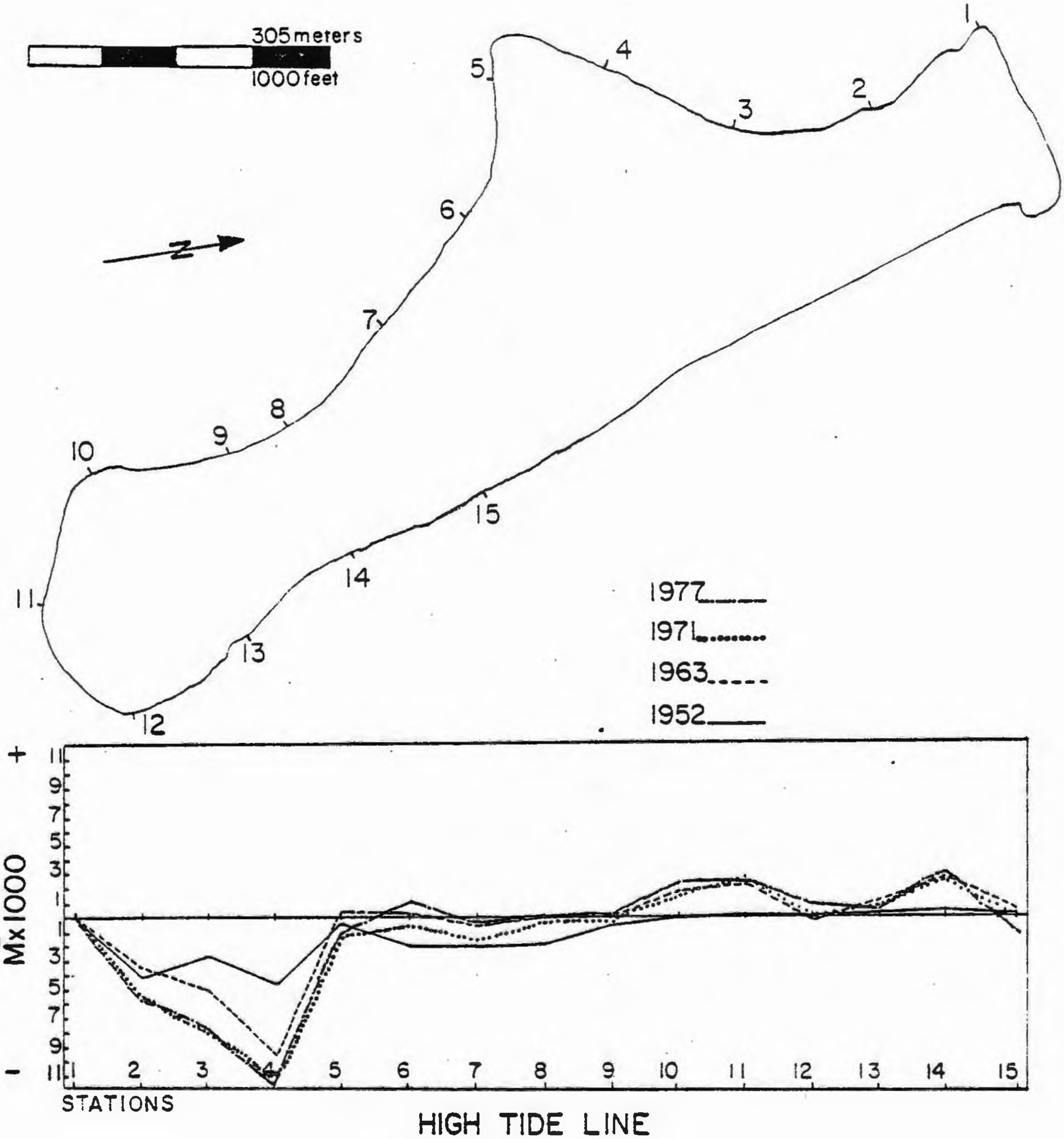


FIGURE 9

Lovells Island: High Tide Line Areal Change


305 meters
1000 feet
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1977
1971
1963
1952
+
-
11
9
7
5
3
1
M^2x1000
STATIONS
HIGH TIDE LINE

Gallops Island

Island Geomorphology

Gallops Island is located west of Lovells Island and east of Long Island. The Island was covered by all five series of aerial photographs. The segment length for the island was 100m. Stations 7-8 had a segment length of 54m. Between station 1 and 8 a stone sea wall protects the shoreline. The western half of the island is a drumlin deposit. The eastern half is a spit composed of beach material. A stone jetty, present at least since 1938, is located at station 8.

Shoreline Changes

The high tide line at stations 1-2 showed a 500m^2 loss in areal extent from the 1938 high tide line between 1938 and 1977. The majority of the erosion that occurred on Gallops Island, occurred at stations 2-3 and 3-4. The spit located at these stations lost 5395m^2 from 1938 to 1977. An average of 138m^2/yr. was lost from the high tide line of the spit between 1938 and 1977. Stations 4-5 and 5-6 were erosional from 1938 to 1971, each losing approximately 1100m^2 from their high tide lines. Between 1971 and 1977 each segment accreted and was slightly less than the areal extent of the 1938 high tide. Station 6-7 lost 499m^2 between 1938 and 1977. Accretion followed and in 1963 the high tide line was 259m^2 greater in areal extent than the 1938 high tide line. Another cycle of erosion and accretion occurred and in 1977 the high tide line was 23m^2 greater in areal extent than the 1938 high tide line. Stations 7-8 lost 162m^2 from 1938 to 1952. A stone jetty, present over the study period, seems to have stopped the longshore drift whose direction is to the west along the southern part of the Island. This can be seen by accumulation of sediment on the eastern side of the jetty (Figures 10, 11). From 1952 to 1977 station 7-8 accreted at an average rate of $50m^2$/yr. In 1977 the high tide line at station 7-8 was $1069m^2$ greater in areal extent than the 1938 high tide line.

Shoreline Development

Overall, Gallops Island experienced a net yearly loss of $128m^2$/yr. from its high tide line between 1938 and 1977. Stations 2-3 and 3-4 lost $5395m^2$ from the areal extent of their high tide line between 1938 and 1977. Stations 6-7 and 7-8 accreted $1092m^2$ in areal extent between1938 and 1977. Material eroded from stations 2-3 and 3-4 seems to be carried westward by the littorial drift. The jetty located at station 8 caused the deposition of 20% of the material eroded from stations 2-3 and 3-4.

FIGURE 10

Gallops Island, 1938 Aerial Photograph

FIGURE 11

Gallops Island, 1977 Aerial Photograph

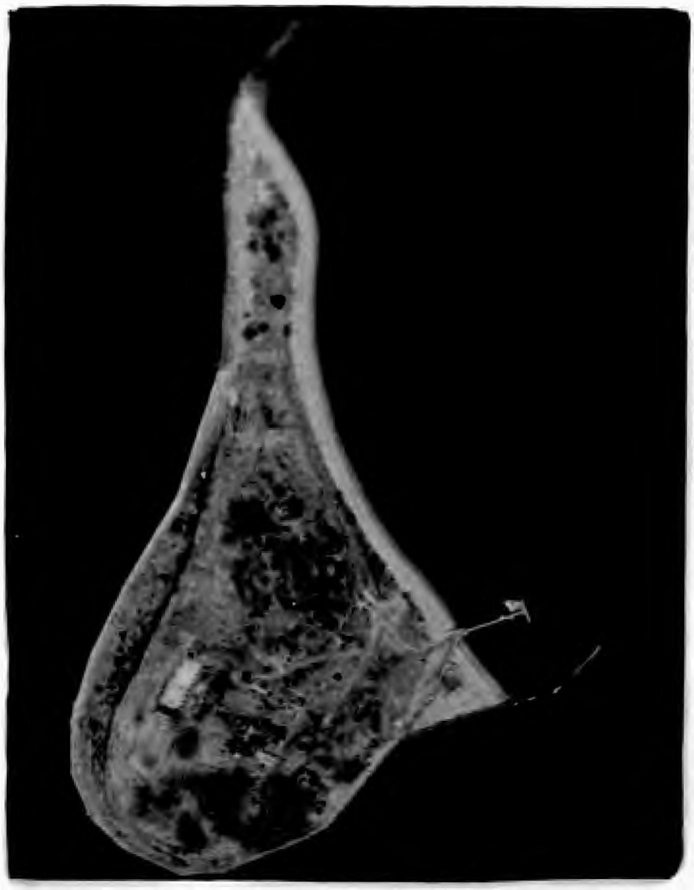
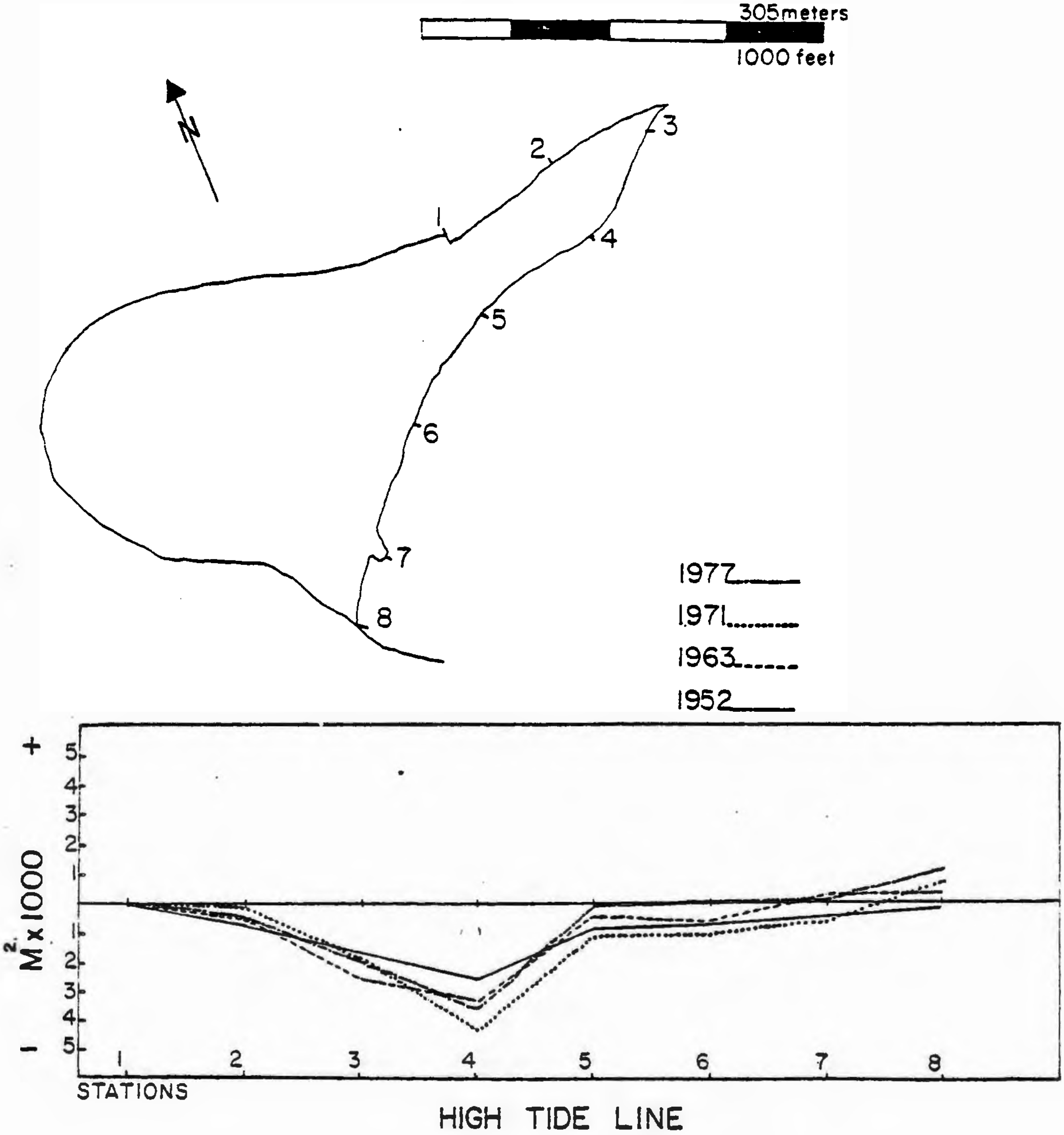


FIGURE 12

Gallops Island: High Tide Line Areal Change


305 meters
1000 feet
N
1
2
3
4
5
6
7
8
1977
1971
1963
1952
+
5
4
3
2
1
$M^2 \times 1000$
1
2
3
4
5
-
STATIONS
HIGH TIDE LINE

Spectacle Island

Island Geomorophology

Spectacle Island is located between Thompsons Island and Long Island. Up until 1920 Spectacle Island was originally two drumlin hills connected in the center by a sandy bar exposed at low tide. Starting in 1920 and continuing until 1960, Spectacle Island was used as a garbage dumping ground for the city of Boston. Cliffs up to 25 feet high, composed of burnt, compacted refuse, are present on Spectacle Island. Figure 13 shows the operation of the dump site in 1938. The erosion of this garbage has resulted in many beaches being almost entirely composed of garbage. The segment length for the Island was 150 meters. The scale of the base 1977 aerial photographs was 1:5322. Four series of aerial photographs were used. The 1971 series of aerial photographs did not cover Spectacle Island and Thompsons Island.

Shoreline and Cliff Line Changes

Stations 1-2 which showed an accretion in the high tide line of $3083m^2$ from 1938 to 1977, is landfill deposited by the city of Boston. Stations 2-3 experienced erosion of approximately $65m^2$/yr. or $2,438m^2$ between 1938 and 1977. Stations 3-4 was accretional from 1938 to 1952. Erosion followed and by 1977 the segment had lost $533m^2$. Stations 4-5 experienced the most accretion on Spectacle Island (Figures 13, 14). This area accreted at a rate of $234m^2$/yr. over the 39 year study period. From the large amount of accretion it would seem that the movement of sediment is from the north to the south. Accretionary ridges topped by vegetation are present on the aerial photographs at stations 4-5. A total of 9.125m^2 were added to the segment between 1938 and 1977. Stations 5-6 lost approximately 850m^2 from 1938 to 1952. The area remained stable from 1952 to 1963 but lost an additional 1,000m^2 from 1963 to 1977. Stations 6-7 was accretional from 1938 to 1952, gaining 457m^2. From 1952 to 1963 erosion occurred and the 1963 high tide line was 73m^2 less than the areal extent of the 1938 high tide line. Accretion returned from 1963 to 1977 and the 1977 high tide line was 206m^2 greater in areal extent than the 1938 high tide line. The high tide line at stations 7 through 9 were accretional from 1938 to 1977. As of 1977 stations 7-8 accreted 847m^2 and stations 8-9 accreted 4,248m^2. Stations 9-10 accreted 2171m^2 from 1938 to 1952. Erosion followed and from 1952 to 1977, station 9-10, lost area until the high tide line was 614m^2 greater in areal extent than the 1938 high tide line. The high tide line at stations 10 through 12 all lost approximately 2,500m^2 over the 39 year study period. An average of 64m^2 was lost for each year between 1938 to 1977. The high tide line of stations 13 through 18 all recorded erosion at a similar rate. Between 1938 and 1977 approximately 1,600m^2 were lost from each segment. The average rate of erosion was 41m^2/yr. from 1938 and 1977 for each segment. The high tide lost 2,629m^2 between 1938 and 1977 at stations 19-20. It retreated at an average rate of 67m^2/yr. for the 39 year period. Stations 20-21 lost 914m^2 from 1938 to 1952. By 1963 the areal extent of the high tide line was 304m^2 greater than the 1938 high tide line. Erosion returned and by 1977 the high tide line was 790m^2 less than the 1938 high tide line. Stations 21-22 were composed mostly of garbage and fill. In 1977 it had an areal extent 2,795m^2 greater than the 1938 high tide line extent.

The Drumline Cliff at stations 6-7 lost $838m^2$ ($2053m^3$) in areal extent over the 39 year period. It eroded backwards at an average rate of $22m^2$/yr. The cliffs at station 7-8 lost $1,470m^2$ ($7,782m^3$) from 1938 to 1952 but only lost an additional $142m^2$ ($778m^3$) between 1952 and 1977. The cliff line at stations 8-9 accreted from 1938 to 1963 and was $4663m^2$ ($6,995m^3$) greater in areal extent than the 1938 cliff line. The station lost $352m^2$ ($537m^3$) from 1963 to 1977. The cliffs were built out until 1960. When the dumping was stopped, erosion of the cliffs occurred at a rate of $25m^2$/yr. from 1963 to 1977. The average rate of erosion between 1952 and 1977 was $62m^2$/yr. The cliff line at stations 10-11, which are composed entirely of refuse, had the most erosion of any cliff area on Spectacle Island. From 1938 to 1977 the cliff line lost $3,228m^2$ ($17,744m^3$) from the areal extent of the 1938 cliff line. It eroded at an average rate of $83m^2$/yr. from 1938 to 1977. The cliff line at stations 11-12 and 12-13 lost $385m^2$ ($2,109m^3$) and $495m^2$ ($2,713m^3$) respectively between 1938 and 1977. The cliff line at stations 13 through 18 lost an average of $1,575m^2$ ($8,000m^3$) in areal extent between 1938 and 1977.

Shoreline and Cliff Line Development

Overall, Spectacle Island experienced a net yearly loss of $126m^2$/yr. from its high tide between 1938 and 1952. Due to the infilling of garbage on the Island, the cliff line at stations 8 through 10 accreted $6,784m^2$ in areal extent between 1938 and 1952. The infilling of the cliffs stopped in 1960 and by 1977 the cliffs were $2,090m^2$ less than the areal extent of the 1952 cliff line. In 1977 the cliff line at stations 10-11, also composed of garbage, was $3,238m^2$ less in areal extent than the 1938 cliff line. The drumlin cliffs at stations 11-12 and 12-13 eroded only an average of $400m^2$ between 1938 and 1977. In contrast, the cliff line at stations 13 through 18 lost an average of $1,575m^2$ in areal extent between 1938 and 1977. Greater exposure to significant wave attack is possibly the reason why stations 13 through 18 eroded at a greater rate than stations 11 and 12. Due to the dominant southerly littorial drift, stations 4-5 experienced more accretion to its high tide line than any other station studied. Between 1938 and 1977, the high tide line accreted $9,125m^2$ in areal extent. The average rate of accretion was $234m^2$/yr. between 1938 and 1977.

FIGURE 13

Spectacle Island, 1938 Aerial Photograph

FIGURE 14

Spectacle Island, 1977 Aerial Photograph

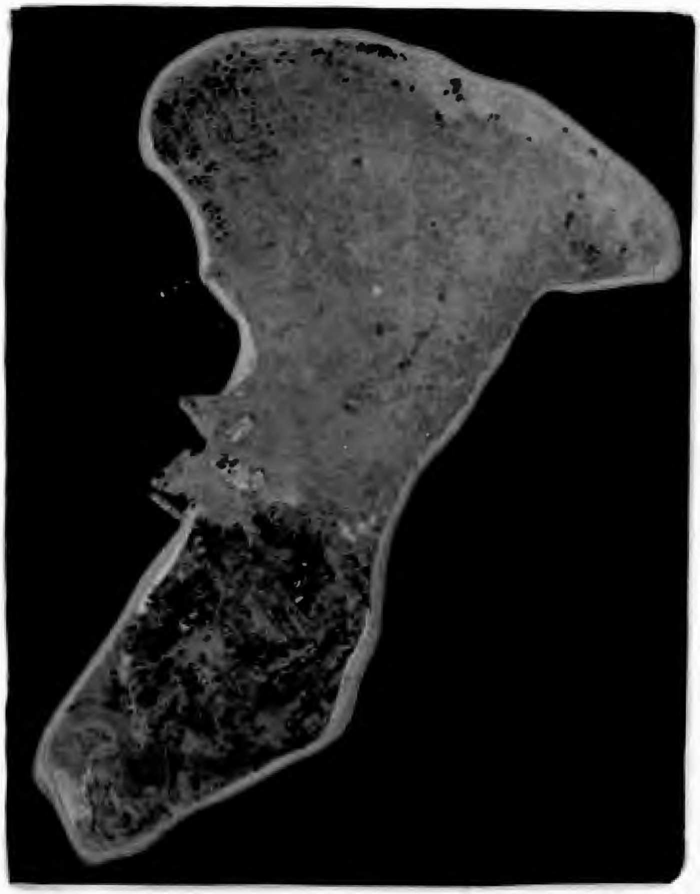
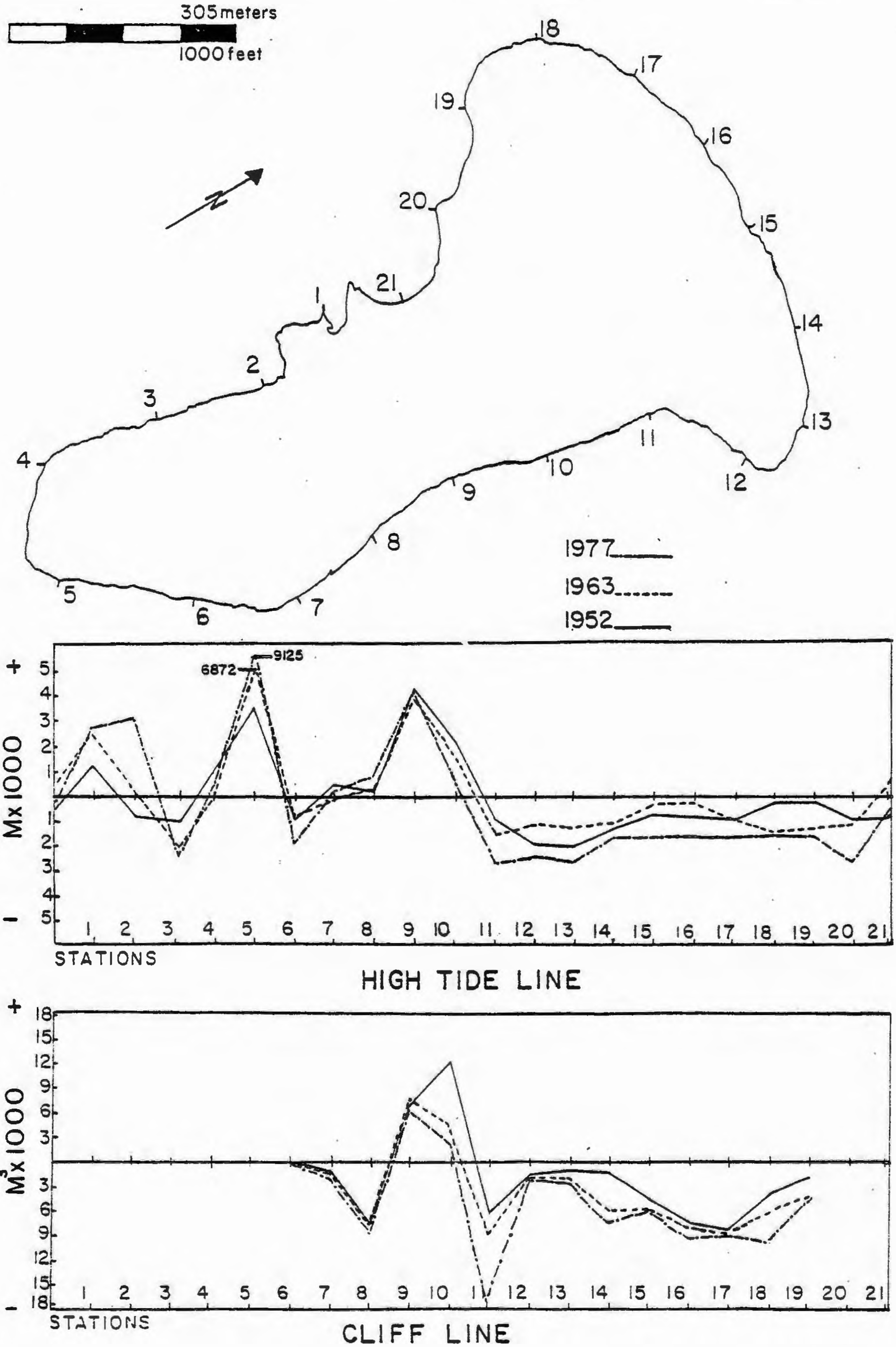


FIGURE 15

Spectacle Island: High Tide Line Areal Change
and
Cliff Line Volumetric Change


305 meters
1000 feet
N
1977
1963
1952
6872
9125
$M^2 \times 1000$
STATIONS
HIGH TIDE LINE
$M^3 \times 1000$
STATIONS
CLIFF LINE

Great Brewster

Island Geomorphology

Great Brewster Island is located south of Calf Island and south west of Middle Brewster Island. It is composed of Drumlin deposits at its northern and southeastern ends. Beach deposits lie between the two drumlin deposits. The northern drumlin cliff reaches a maximum elevation of 31.4m. This is the highest cliff present among the Harbor Islands. A stone sea wall protects the east and northeastern side of the island between stations 1 and 9. The island was covered by all five series of aerial photographs. The segment length for the island is 100m. The scale of the base 1977 aerial photograph was 1:3800.

Shoreline and Cliff Line Changes

"The Great Brewster spit" occurs between stations 1 and 4. Stations 1 through 3 lost an average of 1,125m^2 from 1938 to 1977. On the average, 29m^2/yr. was lost from the areal extent of the 1938 high tide line between 1938 to 1977. Stations 4-5 eroded 792m^2 between 1938 and 1952. Accretion occurred from 1952 to 1971 and the high tide line was 232m^2 less in areal extent than the 1938 high tide line. Erosion returned and in 1977 the high tide line was 465m^2 less than the 1938 high tide line. Stations 5-6 were erosional from 1938 to 1952 and lost 329m^2 from the high tide line. Accretion followed and in 1977 the high tide line was 116m^2 greater in areal extent than the 1938 high tide line. Stations 7-8 lost 445m^2 in areal extent between 1938 and 1952. In 1977 the high tide line was 145m^2 greater in areal extent than the 1938 high tide line.

Between 1938 and 1963 stations 8-9 lost 949m^2 from its high tide line. In 1977 the high tide line was 620m^2 less in areal extent the 1938 high tide line.

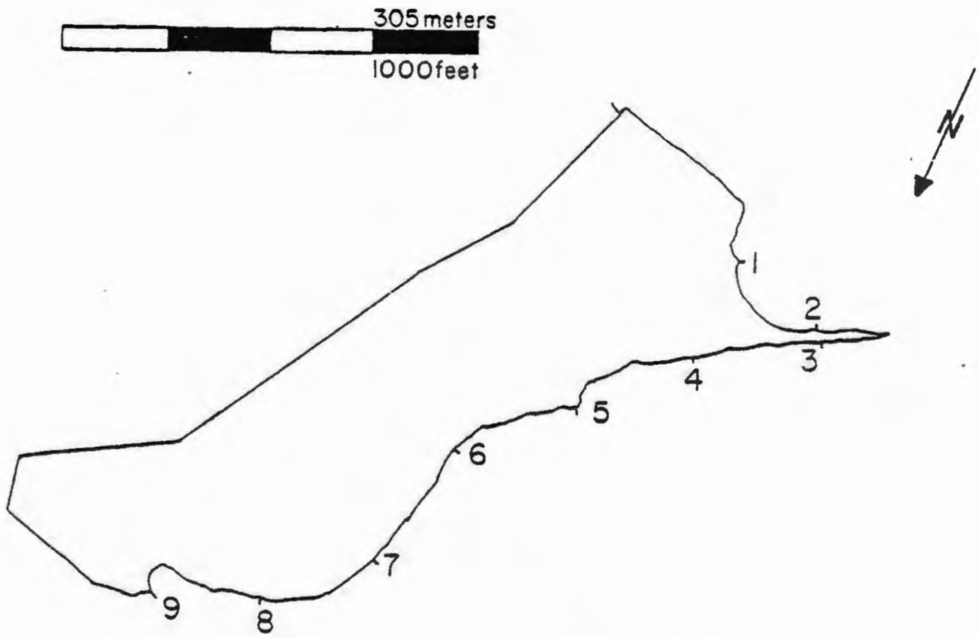
The cliffs at stations 6-7 lost 212m^2 (975m^3) in areal extent between 1938 and 1977. At stations 7-8 and 8-9, the cliff line lost 1000m^2 (23,537m^3) between 1938. For the three stations, the average loss was 10m^2/yr.

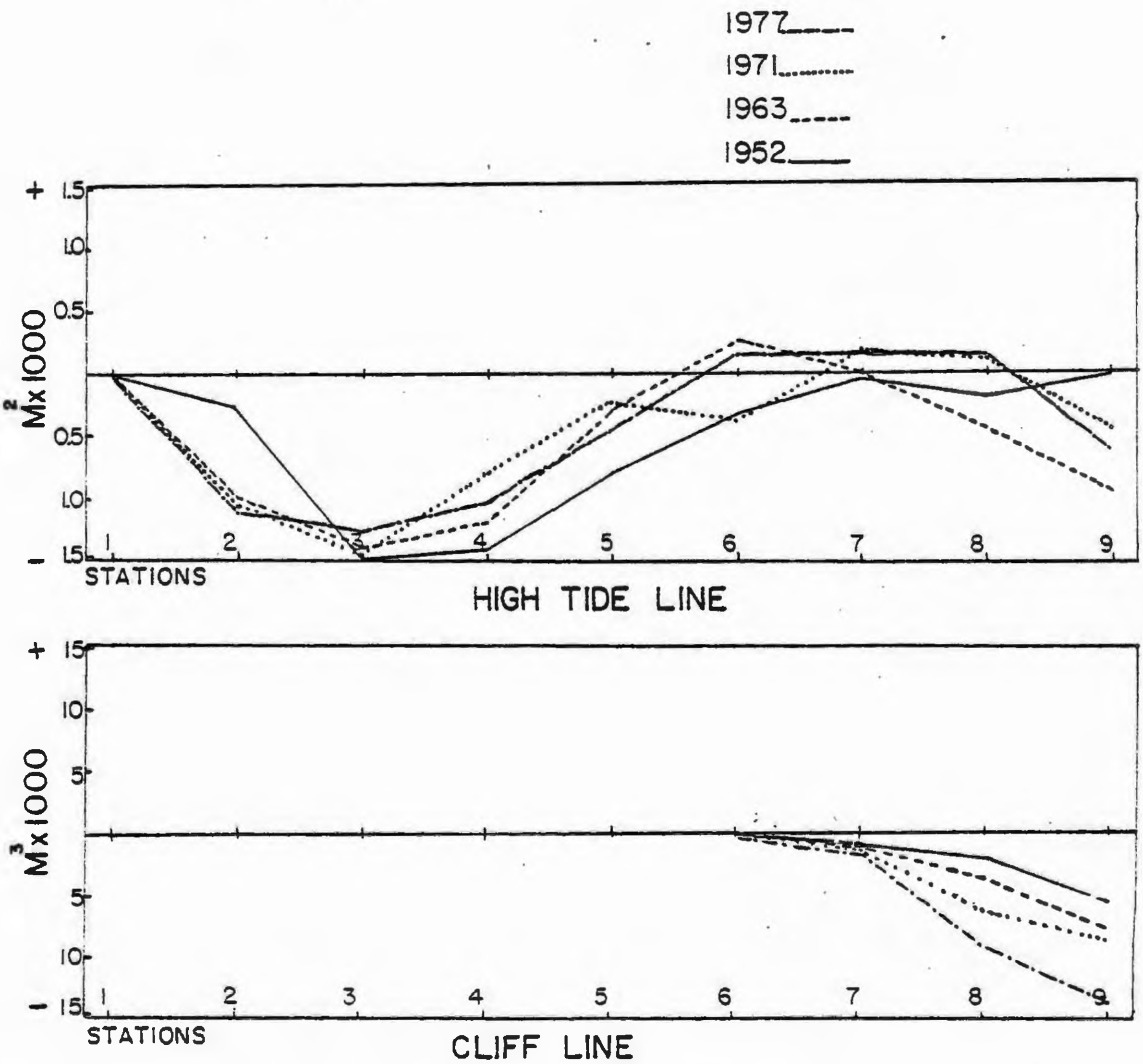
Shoreline and Cliff Line Development

Overall, Great Brewster Island experienced a net yearly loss of 104m^2 from its high tide line between 1938 and 1977. The "Great Brewster spit", located between stations 1 and 4, lost 3315m^2 from its areal extent between 1938 and 1977. In 1977, stations 5-6, 6-7 and 7-8 were on the average 138m^2 greater in areal extent than the 1938 high tide line. The material eroded from the adjacent cliff line may have been sufficient enough to account for the slight accretion in the extent of the high tide line. The maximum fetch of waves that can attack the cliff is 8 miles from the northwest. The island is protected from wave attack from the east by a stone sea wall and from the north by Calf Island. This may be the reason why Great Brewster Island had a low rate of retreat for its cliff line.

FIGURE 16

Great Brewster Island: High Tide Line Areal Change
and
Cliff Line Volumetric Change


305 meters
1000 feet
N
1
2
3
4
5
6
7
8
9


1977
1971
1963
1952
+ 1.5
1.0
0.5
0.5
1.0
- 1.5
$M^2 \times 1000$
1 2 3 4 5 6 7 8 9
STATIONS
HIGH TIDE LINE
+ 15
10
5
5
10
- 15
$M^3 \times 1000$
1 2 3 4 5 6 7 8 9
STATIONS
CLIFF LINE

Georges Island

Island Geomorphology

Georges Island is located east of Rainsford Island and south of Lovells Island. The island is composed entirely of drumlin deposits. Except for stations 2 through 5, the island is protected by a sea wall constructed in the early 1800's. Cliffs occur along the eastern extent of the island. The segment length for the island was 100m. The scale of the base 1977 aerial photograph was 1:3778.

Shoreline Changes

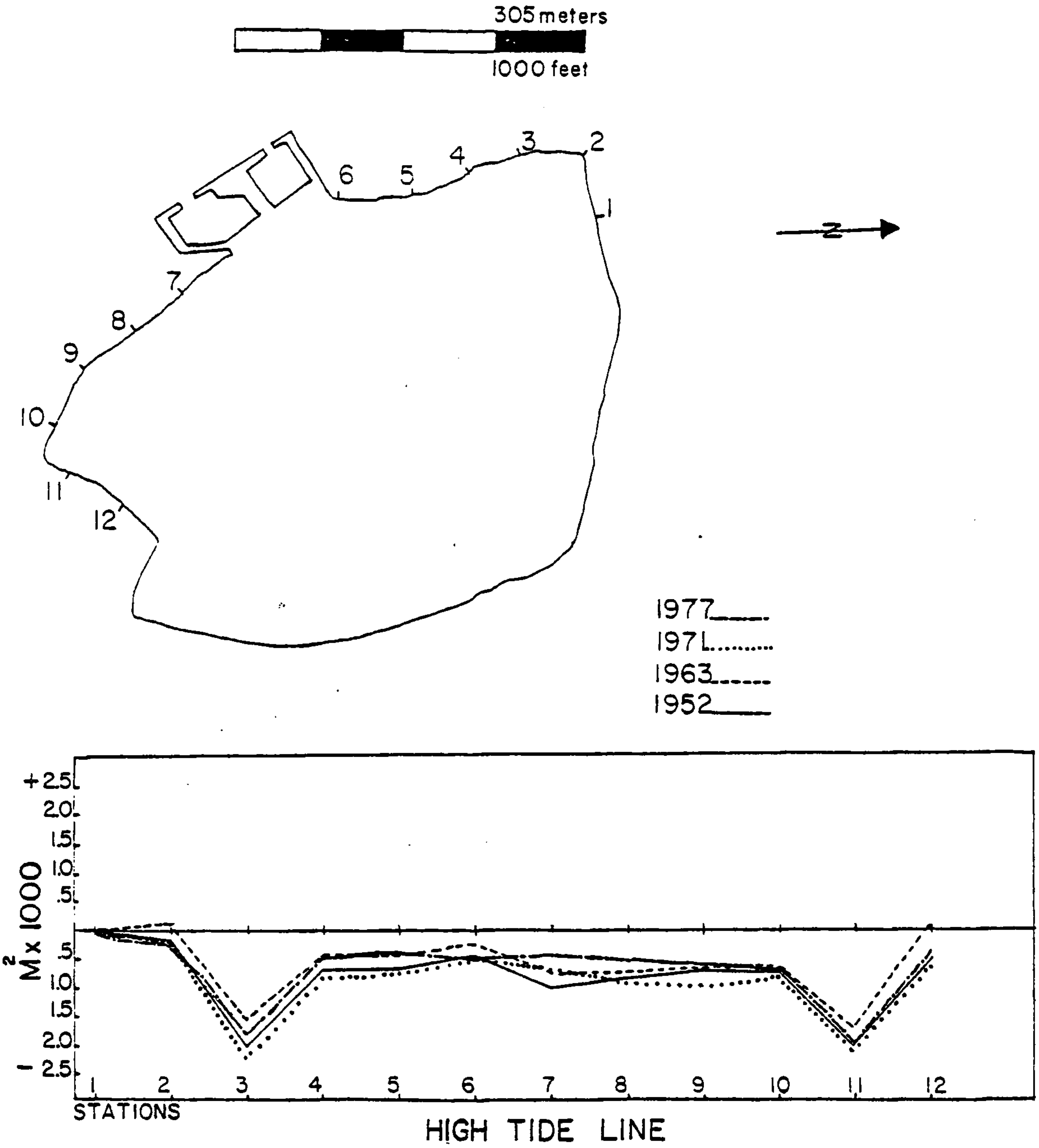
Station 1-2 eroded approximately $143m^2$ from its high tide line between 1938 and 1952. Accretion followed from 1952 to 1963 and the high tide line at stations 1-2 was $112m^2$ greater in areal extent than the 1938 high tide line. The 1971 and 1977 high tide lines were approximately $165m^2$ less than the areal extent of the 1938 high tide line. Stations 2-3 lost $1801m^2$ over the 39 year study period. Stations 3 through 5 were all erosional between 1938 and 1952. Between 1952 and 1963 accretion occurred and the segments were an average of $375m^2$ less than the areal extent of the 1938 high tide line. Erosion returned and by 1977 each segment had lost approximately $300m^2$ from its 1963 high tide line. By 1977 each segment was an average of $425m^2$ less in areal extent than the 1938 high tide line. Stations 6 through 9 were erosional from 1938 to 1952. Accretion followed from 1952 to 1963 and from 1963 to 1971 all the stations experienced erosion again. By 1977 each segment had lost an average $775m^2$ from the areal extent of its high tide line as compared to the 1938 high tide line. Stations 10-11 lost 1,998m^2 over the 39 year study period. Stations 11-12 lost 579m^2 from its high tide line between 1938 and 1952. In 1977 the high tide line at stations 11-12 was 402m^2 less in areal extent than the 1938 high tide line.

Shoreline Development

Overall, Georges Island experienced a net yearly loss of 210m^2 from its high tide line between 1938 and 1977. Over the 39 year study period, the entire high tide line lost 8,255m^2 from its areal extent. Approximately one-half of all the erosion occurred at stations 2-3 and 10-11. Between 1938 and 1977, stations 2-3 and 10-11 lost 1,801m^2 and 1,998m^2 respectively. Because these stations are located at the points of the islands, they are exposed to wave attack from all directions. No accretional areas were present between 1938 and 1977. The only cliff lines present are protected by the stone sea wall.

FIGURE 17

<u>Georges Island</u>: High Tide Line Areal Change


305 meters
1000 feet
N
1
2
3
4
5
6
7
8
9
10
11
12
1977
1971
1963
1952
+2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
− 2.5
M² x 1000
STATIONS
HIGH TIDE LINE

Rainsford Island

Island Geomorphology

Rainsford Island is located southeast of Long Island and west of Gallops Island. The eastern end of the island is composed of drumlin deposits. A stone sea wall occurs between stations 9 and 10. The island is connected in the middle by a stone jetty which is surrounded by sand to cobble-sized beach material. The western half of the island is composed of beach depostis with outcrops of bedrock exposed between stations 1 and 14 and 3-4. The segment length for the island was 100 meters. Segment 13 is 165m long because of the uneven length of the coastline. The scale of the base 1977 aerial photographs is 1:3690.

Shoreline Changes

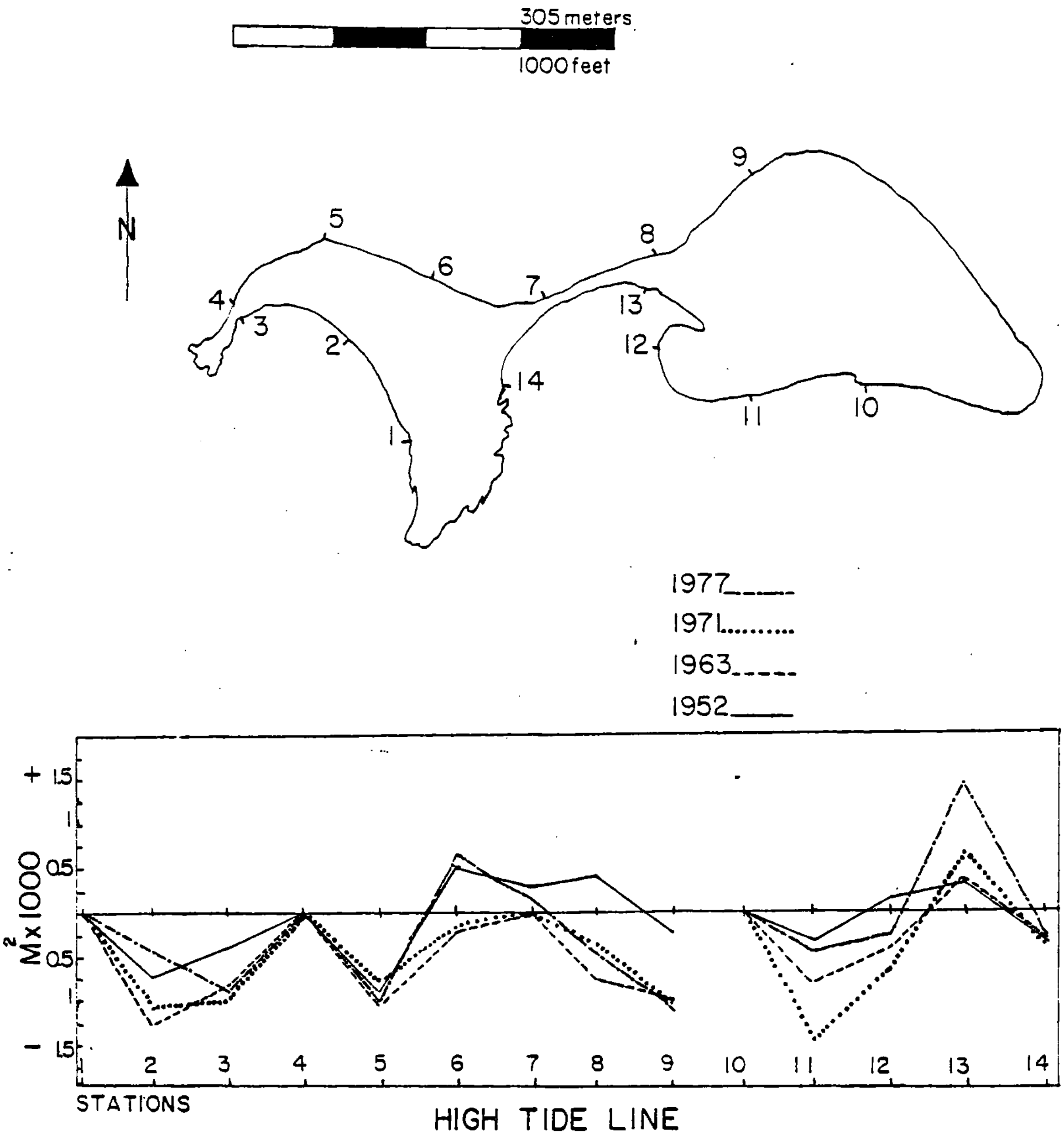
Between 1938 and 1963, stations 1-2 lost 1,269m^2 from the areal extent of its high tide line. Accretion followed and by 1977 the high tide line was 417m^2 less in areal extent than the 1938 high tide line. Stations 2-3 were erosional from 1938 to 1971. Accretion followed and in 1977 the high tide line was 888m^2 less in areal extent than the 1938 high tide line. Station 3-4 was composed of bedrock and had no measurable net change. Station 4-5 experienced net erosion from 1938 to 1977. Stations 5-6 accreted 502m^2 from 1938 to 1952. From 1963 to 1977 station 5-6 was erosional and was 200m^2 less in areal extent than the 1938 high tide line. Accretion returned from 1971 to 1977 with an addition of 671m^2. Station 6-7 remained fairly stable with accretion of 141m^2 from 1938 to 1977. Stations 7-8 and 8-9 experienced net erosion from 1938 to 1977. Erosion occured at station 10-11 and 11-12 from 1938 to 1971. Accretion was the trend from 1971 to 1977. Station 12-13 experienced by far the most accretion on the Island. A gain of 1,469m^2 occured over the period of 1938 to 1977. This cuspate spit of land experienced a net westward accretionary movement over the 39 year study period. It would seem to indicate that the net drift of sediment was to the west in this area. Segment 13 experienced a slight erosional trend of 290m^2 from 1938 to 1977 and maintained that position from 1952 to 1977.

Shoreline Development

Overall, Rainsford Island experienced a net yearly loss in its high tide line of 67m^2 between 1938 and 1977. The cuspate spit, located at stations 11-12 and 12-13, moved westward during the 39 year study period. Stations 11-12 lost 272m^2 from its high tide line areal extent between 1938 and 1977. Stations 12-13 accreted 1,469m^2 to its high tide line areal extent between 1938 and 1977. Stations 5 through 7 accreted 1,265m^2 between 1938 and 1977. The northern half of the island is sheltered from wave attack from the northeast and northwest by other islands. The cliff line located at the eastern end was protected by a stone sea wall and showed no detectable change.

FIGURE 18

Rainsford Island: High Tide Line Areal Change


305 meters
1000 feet
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1977
1971
1963
1952
+ 1.5
1
0.5
0.5
1
- 1.5
$M^2 \times 1000$
STATIONS
HIGH TIDE LINE

Thomsons Island

Island Geomorphology

Thompsons Island is located southeast of South Boston and southwest of Spectacle Island. The northern half is composed of drumlin deposits. The southern half is composed of stratified deposits of sand, gravel and minor sections of till. LaForge (1932) called the southern end of Thompsons Island a recessional moraine deposit. Drumlin till cliffs are present on the northwestern end of the Island between stations 9 and 15. Recessional moraine cliffs occur at the southeastern end of the Island at stations 17-18 and 18-19. The Island was divided where a pier occurs at station 1 (Southern Thompsons Island) and station 19 (Northern Thompsons Island). Four series of aerial photographs were available for use. The 1971 series of aerial photographs did not cover Thompsons Island. The segment length for the island was 150m. The scale of the base 1977 aerial photograph was 1:8986.

Northern Thompsons Island - Shoreline Changes

The high tide line at stations 1-2 lost 5,286m^2 from its aerial extent between 1938 and 1963. Erosion followed and by 1977 the high tide line was 4,226m^2 less in areal extent than the 1938 high tide line. Stations 2-3 was entirely erosional, losing 2,392m^2 over the 39 year period. Stations 3-4 and 4-5 were both accretional, gaining approximately 1,500m^2 from 1938 to 1952. Stations 3-4 and 4-5 then experienced erosion from 1952 to 1963. The high tide line at station 3-4 was approximately in the same postiton as the 1938 high tide line in 1963 and 1977. In 1963, stations 4-5 were 1,000m^2

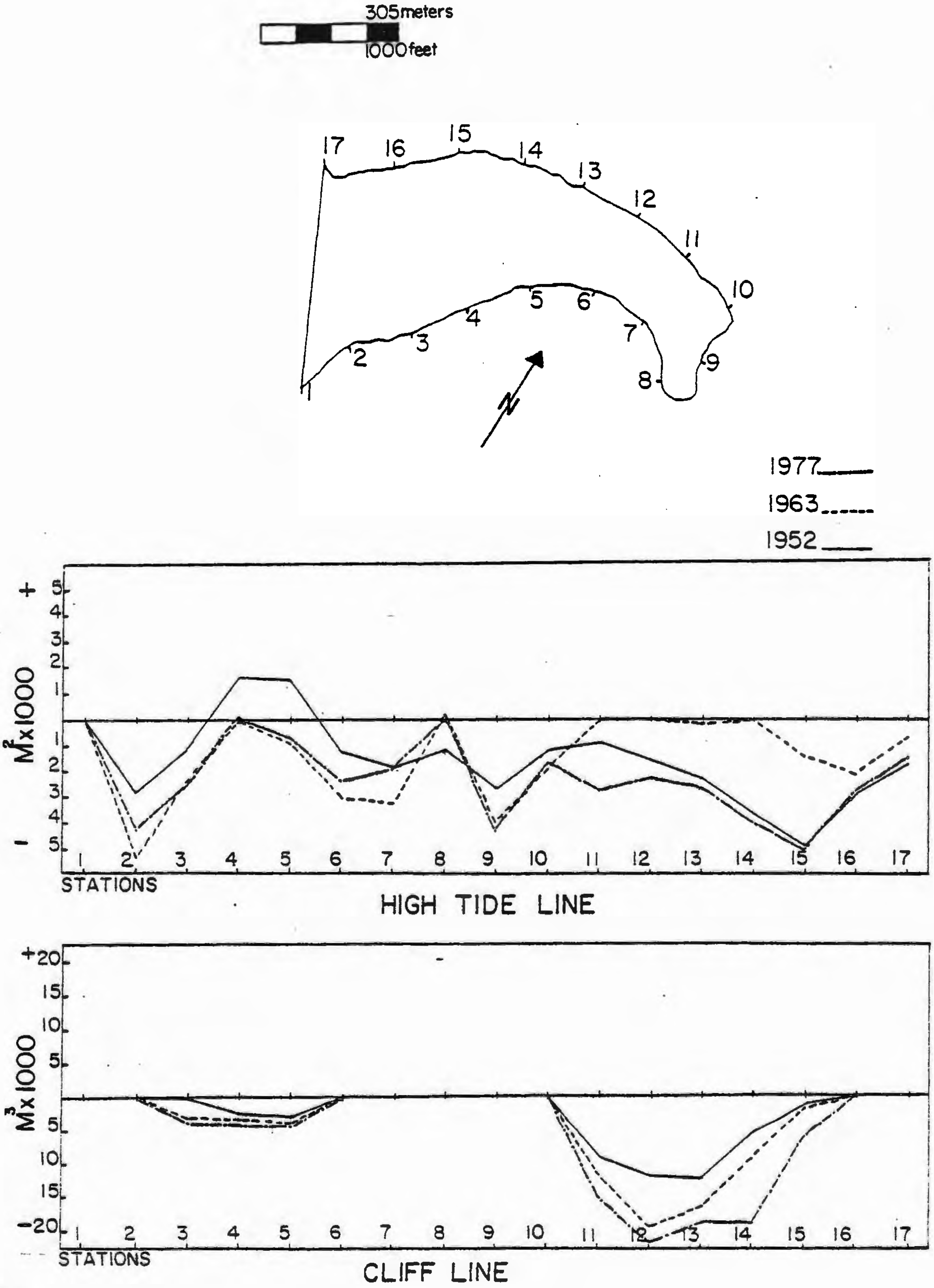
less in areal extent than the 1938 high tide line. In the 1977 the high tide line added about 200m^2 to its 1963 areal extent. Stations 5-6 and 6-7 were both erosinal, losing an average of 3,1000m^2 between 1938 and 1963. Accretion followed and by 1977 both stations were approximately 2,100m^2 less in areal extent than the 1938 high tide line. The high tide line at stations 7-8 lost 1,192m^2 in its areal extent between 1938 and 1952. Accretion followed and in 1963 and 1977 the high tide line was approximately 100m^2 greater in areal extent than the 1938 high tide line. Stations 8-9 were erosional throughout the study period, losing 4,352m^2 from its high tide line by 1977. After losing 1,215m^2 from 1938 to 1952, stations 9-10 remained fairly stable. In 1977, the high tide line was 1,742m^2 less in areal extent than the 1938 high tide line. Stations 10 through 12 all experienced arosion from 1938 to 1952. The stations lost an average of 1,650m^2. From 1952 to 1963 the stations gained back area lost and approximated the 1938 high tide line. From 1963 to 1977, erosion occured and the stations lost an average of 2,600m^2 from their high tide line areal extent.

The cliff lines at stations 2 through 4 exhibited similar erosion rates. Over the 39 year study period thy lost an average 1225m^2 (4000m^3) in their areal extent. When this loss in areal extent is spread out over the 150m segment length, it calculates out to be a 0.2m/yr. retreat of the cliff line. The cliff lines at stations 5-6 and 6-7 showed no detectable change in their extent. The cliff lines at stations 10-12 eroded an average of 3,348m^2 (18,000m^3) in areal extent between 1938 and 1977 or at an average rate of 85m^2/yr. The cliff lines at stations 13 and 14 also experienced erosion but at a more moderate rate. From 1938 to 1977, the cliffs lost an average 1,538m^2 (12,000m^3) each. The average rate of erosion was 39m^2/yr. for each segment.

The high tide lines at stations 13 through 16 all experienced erosion from 1938 to 1952. In 1963 accretion followed and all the stations recorded advances in their high tide lines. Erosion again returned between 1963 and 1977. Stations 13-14 and 14-15 showed the most erosion. Each segment was approximately 3,500m^2 less in areal extent than the 1938 high tide line. Stations15-16 and 16-17 were approximately 2,100m^2 less in areal extent than the 1938 high tide line.

FIGURE 19

Northern Thompsons Island: High Tide Line Areal Change
and
Cliff Line Volumetric Change


305meters
1000feet
1977
1963
1952
M²x1000
STATIONS
HIGH TIDE LINE
M³x1000
STATIONS
CLIFF LINE

Southern Thompsons Island

Shoreline and Cliff Line Changes

Stations 1 through 5 experienced erosion from 1938 to 1952, with an average loss of 812m^2. The 1963 high tide line in contrast, accreted an average of 996m^2 from the 1938 high tide line. The 1977 high tide line in turn eroded 768m^2, on the average, from the 1938 high tide line. Stations 6-7 eroded 3,987m^2 over the 39 year period. Stations 7-8 were erosional, losing 2,846m^2 from 1938 to 1952. This station reversed and the 1977 high tide line was almost equal to the areal extent of the 1938 high tide line. Until the 1977 photographs, the shallow embayment present at stations 8-9 was closed to Boston Harbor. The area was accreting until a channel opened to Boston Harbor in the late 1960's. Stations 9-10 lost 957m^2 from 1938 to 1952. The high tide line accreted from 1952 to 1977, where it was 526m^2 less than the areal extent of the 1938 line. Stations 10-11 and 11-12 were slightly erosional from 1938 to 1952 and accreted during 1952 to 1963 to the approximate 1938 high tide line. From 1963 to 1977, stations 10-11 lost 1,821m^2 and stations 11-12 lost 974m^2.

The spit, shown by the line AA' (Figure 21) grew almost 100 meters to the southeast between 1938 and 1977. The net overall change for the 39 year study period is 14m^2/yr. of accretion. This was not a constant change though. Accretion of 458m^2 to the spit between 1938 and 1952 was followed by the erosion of 1,201m^2 from the spit between 1952 and 1963. 1,291m^2 was added to the spit's areal extent between the years of 1963 and 1977.

FIGURE 20

Southern Thompsons Island, Cliff Slump

Stations 12-13 and 13-14 were erosional from 1938 to 1952. Both station's high tide lines accreted between the years of 1952 and 1963. Between the years of 1963 and 1977, stations 12-13 lost 613m^2 and stations 13-14 lost 112m^2. The spit located at station 14 lost 8,452m^2 between 1938 and 1952. Between 1952 and 1977, slightly more than 1,000m^2 were lost from the spit. Stations 15-16 and 16-17 were accretional from 1938 to 1952. They lost area during the time interval of 1952 to 1963. Accretion returned in 1963 to 1971, with an average accretion of 314m^2. Stations 17-18 and 18-19 were both accretional from 1938 to 1952, gaining approximately 1,500m^2 for each segment. This trend reversed and the average areal extent for the 1963 high tide line was 1,050m^2 less than the areal extent for the 1938 high tide line. Between 1963 and 1977, stations 17-18 accreted slightly and stations 18-19 eroded slightly.

The high tide line at stations 19-20 remained stable between 1938 and 1952. Erosion followed during 1952 to 1963 and the segment lost 2,709m^2. The 1963 to 1977 time interval was accretional and the segment was 325m^2 less than the areal extent of the 1938 high tide line. Stations 20-21 lost 3,676m^2 between 1938 to 1952. This erosional trend continued between 1952 and 1963 and the segment lost an additional 1,000m^2 from the high tide line. Between 1963 and 1977, accretion followed and the segment was 2,492m^2 less in areal extent than the 1938 high tide line.

Glacial cliffs were present at stations 17-18 and 18-19. Between 1938 and 1977, the cliff line lost 268m^2/yr. The rate of cliff material eroded varied from 173m^3/yr. to 746m^2/yr. Slumping of the cliff line on the eastern shore of Southern Thompsons Island, caused by the blizzard of 1978, can be seen in Figure 20.

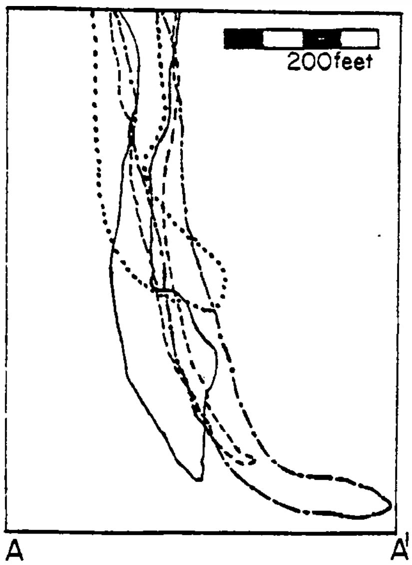
Shoreline and Cliff Line Development

Overall, Thompsons Island experienced a net yearly erosion of $835m^2$/yr. from the areal extent of its high tide line between 1938 and 1977. In 1977 no station on Northern Thompsons Island had a high tide line whose areal extent exceeded the 1938 high tide line areal extent. Stations 10 through 15 lost 16,907m^2 from their high tide line between 1938 and 1977. The cliff line located between stations 10-15 eroded 13,570m^2 from its areal extent between 1938 and 1977. Stations 10 through 15 were subject to wave attack with a maximum fetch of 3 miles.

Stations 14-15 experienced the greatest erosion at Southern Thompsons Island by losing 9,969m^2 from its high tide line areal extent between 1938 and 1977. Station 16-17 experienced the most accretion at Southern Thompsons Island, gaining 87m^2 in areal extent to its high tide line between 1938 and 1977. The cliff line present at stations 17-18 and 18-19 lost 2,283m^2 between 1938 and 1977.

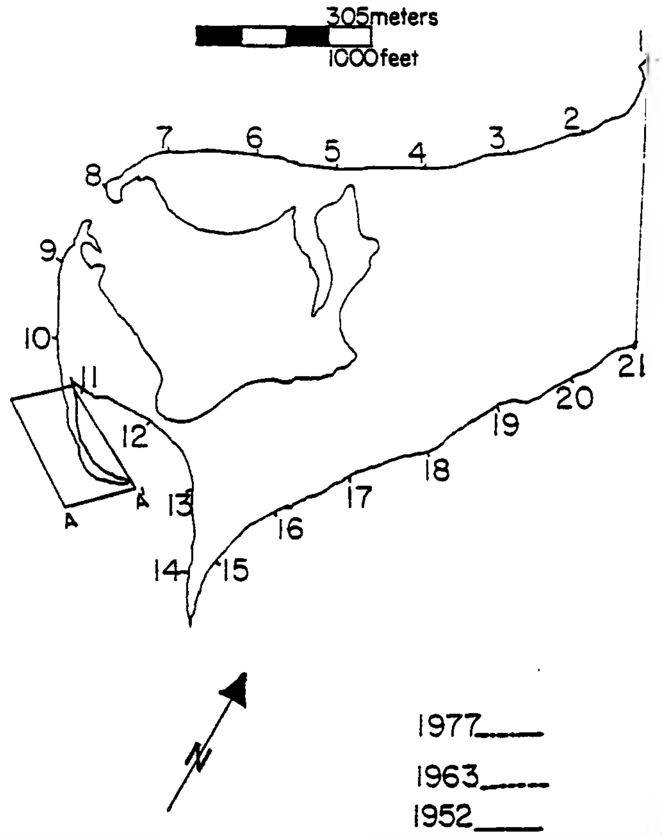
FIGURE 21

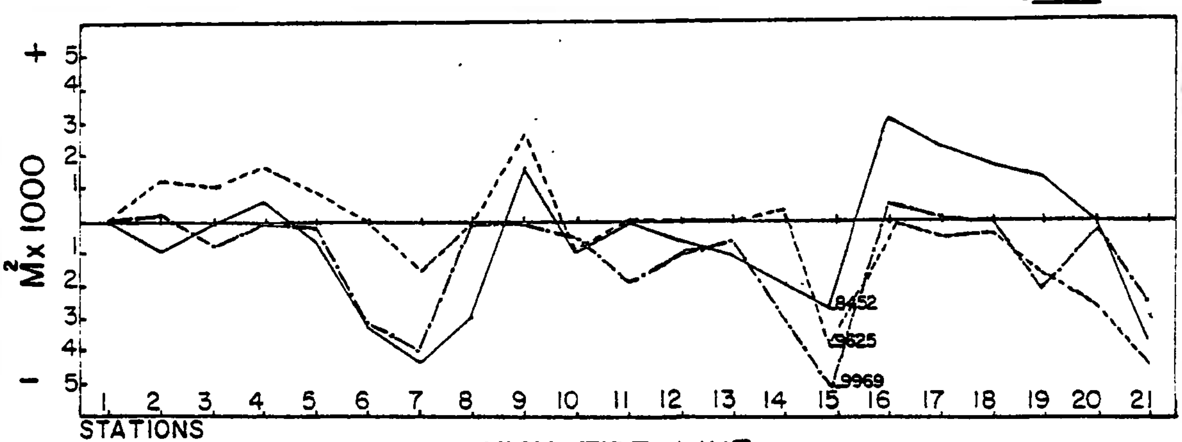
Southern Thompsons Island: High Tide Line Areal Change
and
Cliff Line Volumetric Change



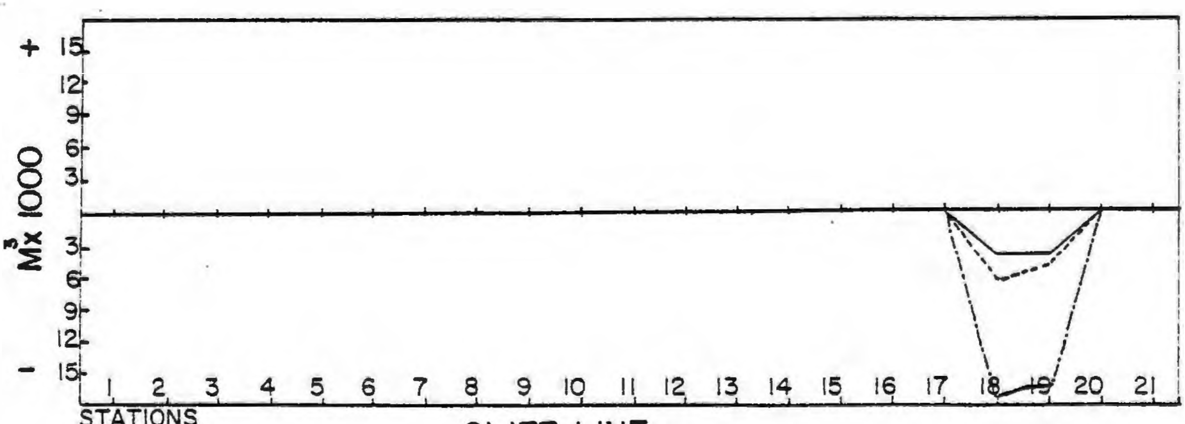
AREA OF SPIT IN M^2

1938	1952	1963	1977
2576	3034	1833	3124





HIGH TIDE LINE



CLIFF LINE

Long Island

Island Geomorphology

Long Island is located east of Spectacle Island and west of Gallops Island and Rainsford Island. The northern end of Long Island is a drumlin deposit surrounded by a stone sea wall between stations 1 and 12. Alluvial deposits occur south of the drumlin. Another drumlin deposit occurs just south of the alluvial deposits at stations 4-5, 5 to pier, 6-7 and 7-8. A pier is located at the end of station 5. Middle Long Island is composed entirely of drumlin deposits. Drumlin till cliffs are present along the entire shoreline. Southern Long Island is composed of drumlin and beach deposits. Beach deposits occur at stations 3-4, 5-8, and 12-14. The rest of the stations are composed of drumlin till deposits. A bridge at stations 1 and 18 connects Southern Long Island with the mainland. The Island was covered by all five series of aerial photographs. The segment length for the Island was 150m. On Southern Long Island, station 9 to the match line is 200m in length, on Middle Long Island station 6 to the match line is 95m in length and on Northern Long Island, station 5 to the pier is 85m in length due to the irregular distance around the shoreline. The scale of the base 1977 aerial photographs ranged from 1:5330 to 1:5643.

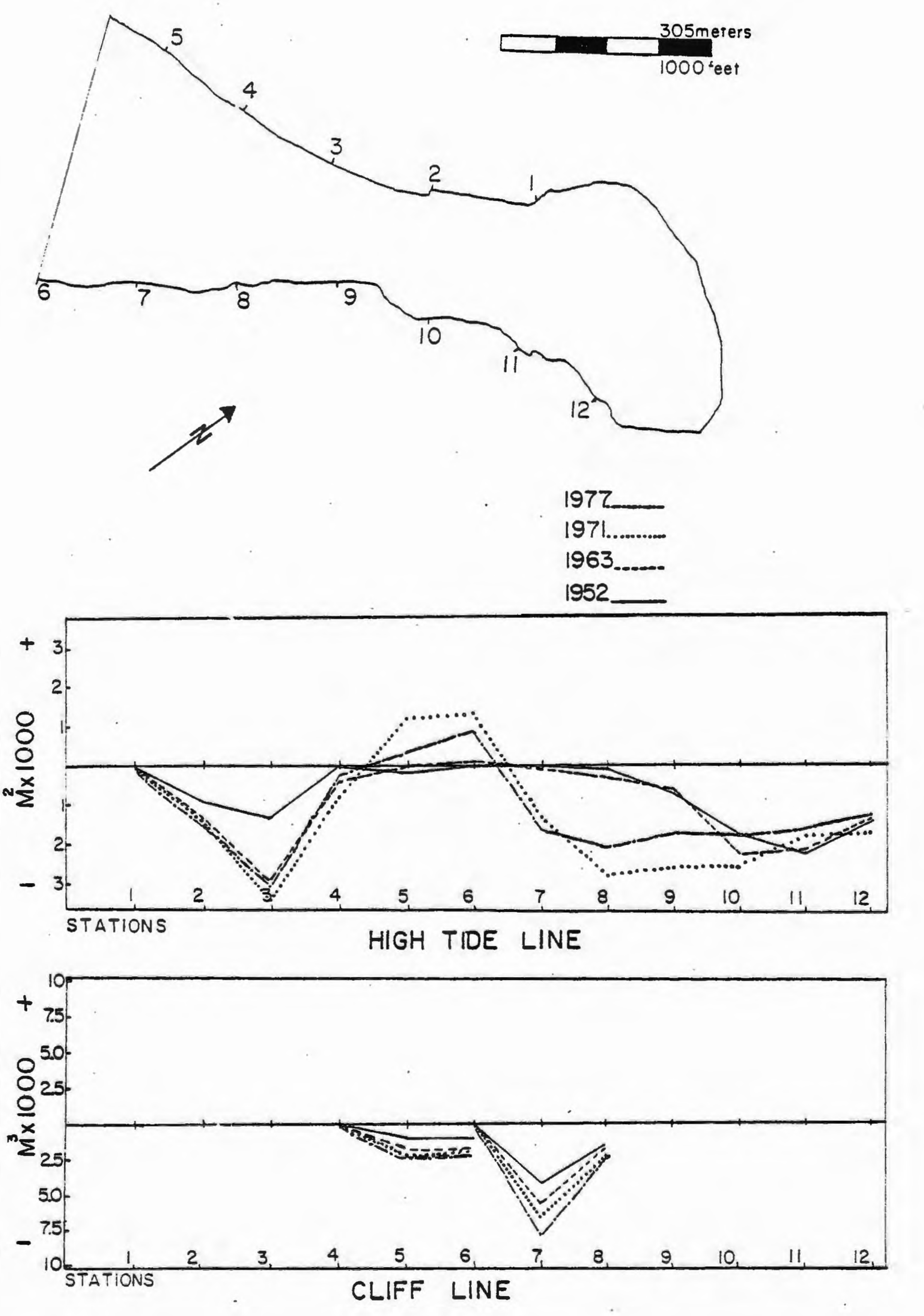
Northern Long Island Shoreline and Cliff Line Changes

Stations 1-2 were erosional throughout the study period. In 1977 the high tide line was 1,496m^2 less than the areal extent of the 1938 high tide line. Stations 2-3 lost 3,121m^2 from its high tide line over the 39 year period. At stations 3-4 no change was recorded between 1938 and 1952. By 1971 the high tide line had lost 841m^2 from its areal extent. Accretion followed and in 1977 the high tide line was 294m^2 less than the areal extent of the 1938 high tide line. Stations 4-5 lost 189m^2 from its high tide line between 1938 and 1952. Accretion followed and by 1971 the high tide line was 1,220m^2 greater in areal extent than the 1938 high tide line. Erosion returned and in 1977 the high tide line was 395m^2 greater than the 1938 high tide line areal extent. Stations 5-6 recorded no change in its high tide line between 1938 and 1952. Accretion followed and by 1977 the high tide line was 879m^2 greater in areal extent than the 1938 high tide line. Stations 6-7 were erosional throughout the study period. In 1977, the areal extent of the high tide line was 1,683m^2 less than the 1938 extent. Stations 7-8 eroded until 1971, when the high tide line had lost 2,819m^2. In 1977 the high tide line was 2,104m^2 less in areal extent than the 1938 high tide line. The high tide line at stations 8-9 and 9-10 experienced erosion until 1971, when they had lost an average 2,625m^2 in areal extent. Accretion followed and both were approximately 1,750m^2 less in areal extent than the 1938 high tide line. Stations 10-11 lost 2,314m^2 from its high tide line between 1938 and 1952. Accretion followed and by 1977 the segment was 1,641m^2 less in areal extent than the 1938 high tide line. The high tide line at stations 11-12 remained approximately the same between 1952 and 1977. The station lost 1,472m^2 between 1938 and 1952.

The cliff line at stations 4-5 and 5-6 lost an average of 1,310m (2300m^3) between 1938 and 1977. Stations 6-7 and 7-8 experienced a similar amount of erosion as stations 4 and 5, losing an average 1321m^2 (4500m^3) between 1938 and 1977.

FIGURE 22

Northern Long Island: High Tide Line Areal Change
and
Cliff Line Volumetric Change


305meters
1000 feet
1 2 3 4 5 6 7 8 9 10 11 12
N
1977
1971
1963
1952
M² x 1000
+ 3 2 1 1 2 - 3
STATIONS
HIGH TIDE LINE
M³ x 1000
10 + 7.5 5.0 2.5 2.5 5.0 - 7.5 10
STATIONS
CLIFF LINE

Middle Long Island

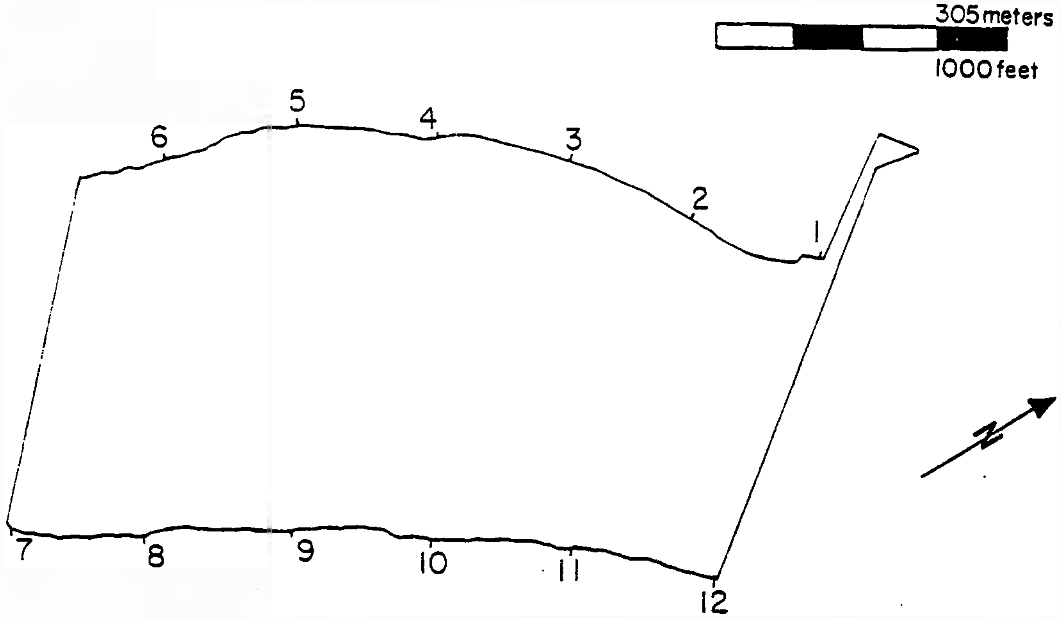
Shoreline and Cliff Line Changes

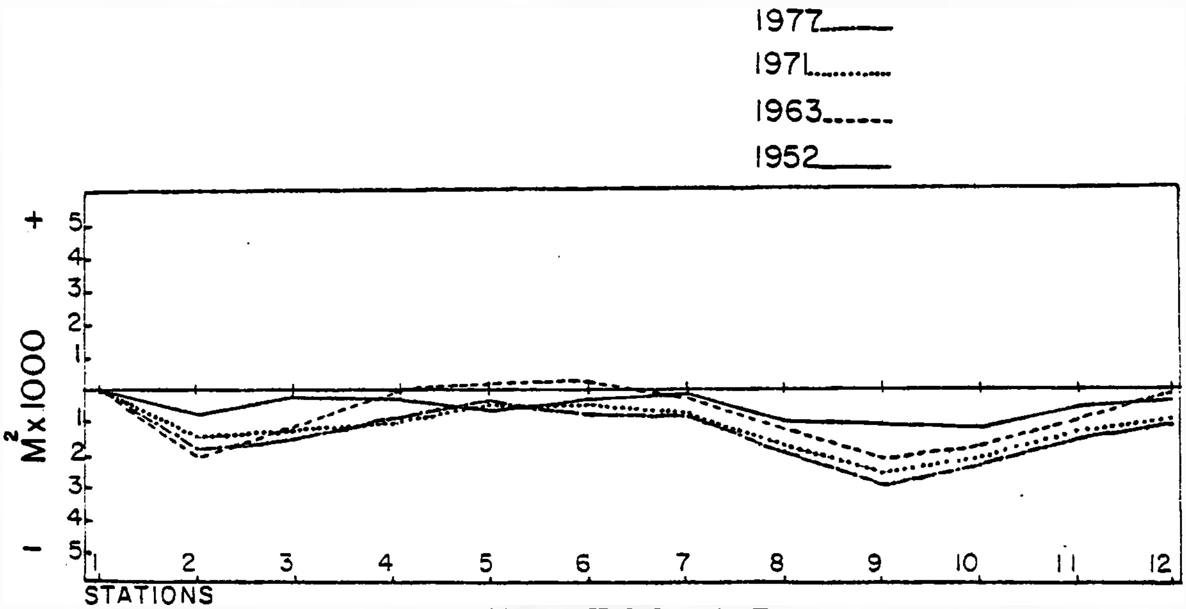
The high tide line at stations 1-2 lost 2,034m^2 from its areal extent between 1938 and 1963. Accretion followed and in 1971 the high tide line accreted 492m^2 from the 1963 high tide line. In 1977, the high tide line was 1,772m^2 less in areal extent than the 1938 high tide line. Stations 2-3 lost 1,486m^2 less in areal extent than the 1938 high tide line. Stations 2-3 lost 1,486m^2 from its high tide line extent between 1938 and 1977. Stations 3-4 experienced erosion during the time periods of 1938 to 1952 and 1963 to 1971 and accreted during the time periods of 1952 to 1963 and 1971 to 1977. In 1977 the high tide line was 884m^2 less in areal extent than the 1938 high tide line. Stations 4-5 had a similar history of erosion and accretion as stations 3-4. In 1977 the high tide line was 421m^2 less in areal extent than the 1938 high tide line. At stations 5-6, the high tide line eroded 304m^2 between 1938 and 1952. Accretion followed and in 1963 the high tide line was 191m^2 greater in areal extent than the 1938 high tide line. The high tide line eroded in 1971 and 1977 and was 762m^2 less in areal extent than the 1938 high tide line. Stations 6 through 11 all experienced erosion of their high tide lines between the years of 1938 to 1952, 1952 to 1963, 1963 to 1971 and 1971 to 1977. The area of maximum erosion occurred at stations 7 through 9 where an average 2,325m^2 was lost between 1938 and 1977. Stations 6-7 and 7-8 had an average 1348m^2 eroded from their high tide lines between 1938 and 1977. The high tide lines of stations 10-11 and 11-12 eroded an average 1334m^2 between 1938 and 1977.

The cliff line at stations 1 through 7 eroded at a similar rate. Between 1938 and 1977 the cliff lines lost an average of 482m^2 (2,000m^3) in areal extent. The average rate of loss was 12m^2/yr. per segment. The cliff line at stations 6 lost only 45m^2 (109m^3) from its areal extent between 1938 and 1977. The cliff line at stations 8 through 11 also experienced similar erosion rates. Between 1938 and 1977 each segment lost an average of 2039m^2 (12,500m^3) in areal extent from the cliff line. The average rate of loss was 52m^2/yr. per segment.

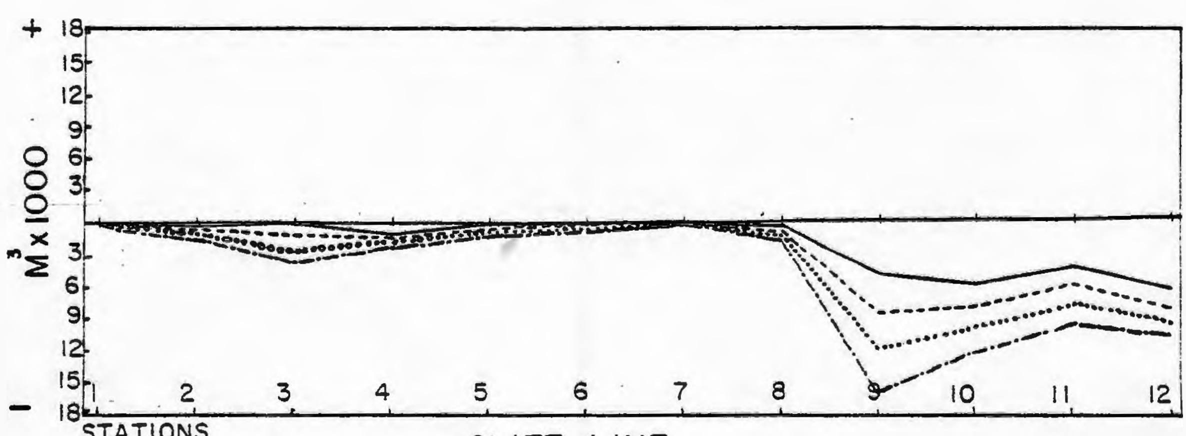
FIGURE 23

Middle Long Island: High Tide Line Areal Changes
and
Cliff Line Volumetric Changes





HIGH TIDE LINE



CLIFF LINE

Southern Long Island

Shoreline and Cliff Line Changes

Stations 1-2 and 2-3 were both erosional between 1938 and 1977. The high tide line at station 1-2 lost 3,932m^2 in areal extent from the 1938 high tide line. Stations 2-3 lost 1,667m^2 over the 39 year period. Stations 3-4 accreted 237m^2 to its areal extent between 1938 and 1952. Erosion followed and by 1977 the high tide line was 279m^2 less in areal extent than the 1938 high tide line. Stations 4-5 accreted 214m^2 to its areal extent between 1938 and 1952. Erosion occurred between 1952 and 1971. Accretion followed and by 1977 the high tide line was 1,453m^2 less in areal extent than the 1938 high tide line. The high tide line at stations 5-6 accreted between 1938 and1971. The segment then experienced erosion and by 1977 the high tide line was 383m^2 greater in areal extent than the 1938 high tide line. Stations 6-7 and 7-8 were both accretional between 1938 and1977. The high tide line at stations 6-7 accreted 3,591m^2 and station 7-8 accreted 2,137m^2. Stations 8-9 and 9-10 were both accretional between 1938 and 1971. Both stations experienced erosions between 1971 and 1977. In 1977, the high tide line at station 8-9 was 825m^2 less in areal extent than the 1938 high tide line. By 1977, the high tide line at station 9 to the match line was 1,347m^2 less in areal extent than the 1938 high tide line by 1977.

The cliff line at stations 1-2 retreated 1215m^2 (9,234m^3) in areal extent between 1938 and 1977. The cliff line at stations 2-3 and 4-5 retreated 762m^2 (2614m^3) and 525m^2 (1575m^3) respectively over the same time span. The average rate of retreat was 21m^2 yr. for each segment. The cliff line between stations 10-11 and 11-12 lost an average of 800m^2 (2500m^3) in areal extent between 1938 and 1977. Station 16-17 and 17-18 experienced erosion and the cliff line retreated at an average rate of 875m^2/yr. (5000m^3) per segment between 1938 and 1977.

The high tide line at stations 10-11 and 11-12 were erosional between 1938 and 1977, being slightly accretional from 1952 to 1971. In 1977, the high tide line of both stations were an average of 2,600m^2 less in areal extent than the 1938 high tide line. In 1963, the high tide line at station 12-13 was 3,719m^2 less than the 1938 high tide line areal extent. Accretion followed and by 1977 the high tide line was 1,069m^2 greater areal extent than the 1963 high tide line. Stations 13-14 and 14-15 both lost approximately 3,000m^2 between 1938 and 1963. Between 1963 and 1977 both stations accreted and in 1977 the high tide lines were an average of 1,880m^2 less in areal extent than the 1938 high tide line. Station 15-16 lost 2,308m^2 from its high tide line between 1938 and 1977. Between 1938 and 1952, stations 16-17 lost 3,400m^2 from its high tide line areal extent. The high tide line remained approximately at the same extent from 1952 to 1977. Stations 17-18 lost 4,416m^2 from its high tide line between 1938 and 1977.

Shoreline and Cliff Line Development

Overall, Long Island experienced a net yearly erosion of 461m^2/yr. from the areal extent of its high tide line between 1938 and 1977. At Northern Long Island, two areas of major accretion to the high tide occurred between 1938 and 1977. Stations 4-5 and 5 to the pier accreted between 1952 and 1971. Erosion followed, but by 1977 the high tide line between stations 4 and the pier located at the end of Station 5, was 1,276m^2 greater in areal extent than the 1938 high tide line. The pier appears to have caused the depostion of sediment on its northeast side by interfering with a dominant southwest littorial transpot direction.

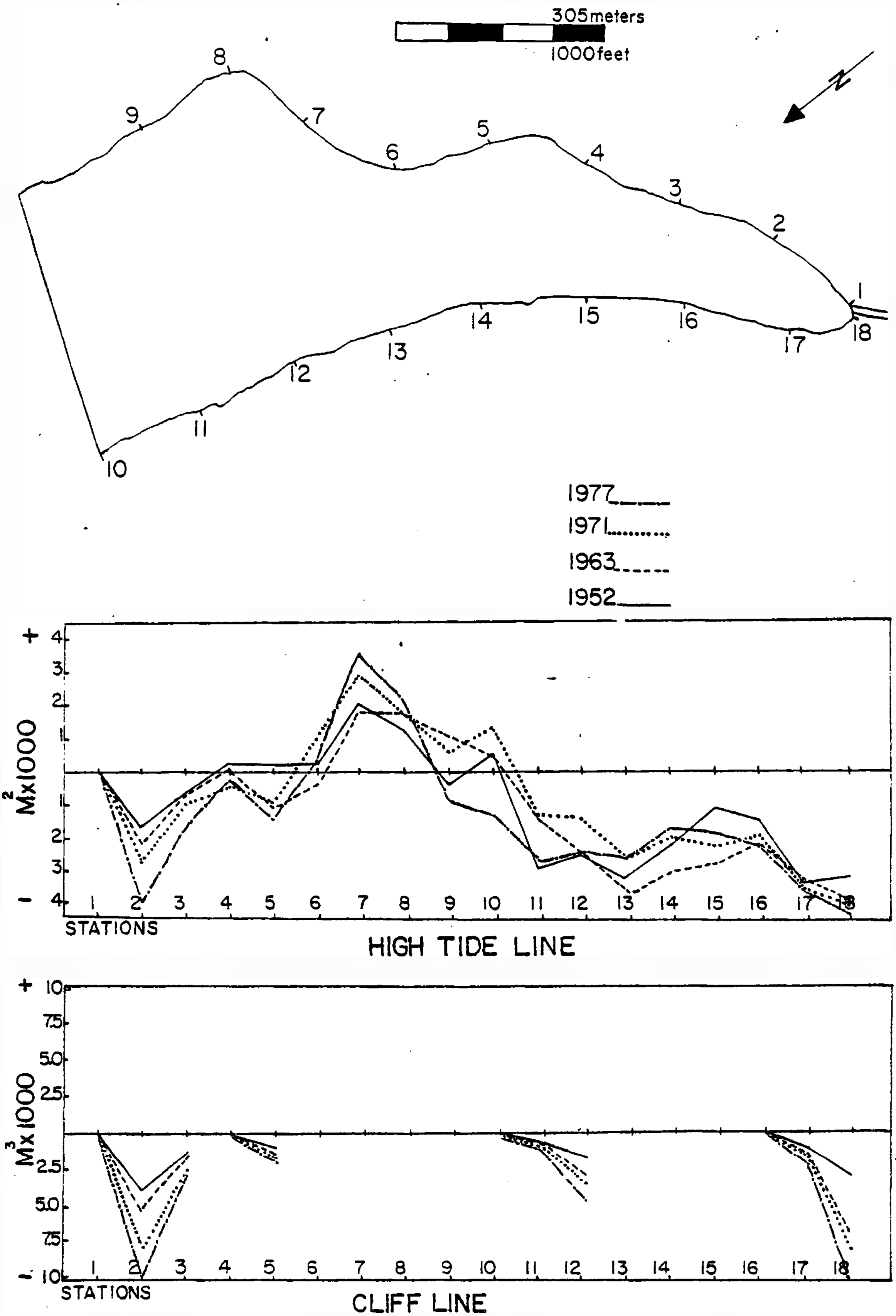
The maximum cliff erosion occurred at Middle Long Island between stations 8 and 12. 8,399m^2 was lost from the areal extent of the clif line between 1938 and 1977. The high tide line between stations 8 and 12 retreated at a similar rate, losing 7, 737m^2 from its areal extent between 1938 and 1977. The maximum fetch for wave attack on western Long Island is 3 miles. The larger fetch and greater exposure to the open sea may be the reason why the maximum cliff erosion occured on Eastern Long Island. Southern Long Island experienced the most erosion and accretion to its high tide line areal extent between 1938 and 1977. The embayed area between stations 5 through 8 accreted 6,111m^2 to its high tide line areal extent. Because this areas, wave attack is not as destructive as in adjacent areas, allowing for the accretion of sediment. Stations 1-2 and 16-to 18 were erosional between 1938 and 1977 losing 3932m^2 and 8049m^2 respectively.

FIGURE 24

<u>Southern Long Island:</u> High Tide Line Areal Change

and

Cliff Line Volumetric Changes


305meters
1000feet
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
1977
1971
1963
1952
+
-
4
3
2
1
1
2
3
4
M^2x1000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
STATIONS
HIGH TIDE LINE
+
-
10
7.5
5.0
2.5
2.5
5.0
7.5
10
M^3x1000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
STATIONS
CLIFF LINE

Shoreline Budget

A sediment budget is important in the geomorphic analysis of coastal areas. Not all the material that is eroded from the shoreline and cliff line is redeposited in the near-shore zone. The formation of coastal landforms will be partially dependent upon the amount and type of sediment eroded and where it is redeposited. This is important in planning potential uses for the coastal zone.

Coastal geologists have long recognized that movement of sand and especially larger-sized material is somewhat restrictive and non-integrated along rocky and embayed coastal areas. Portions of the Harbor Islands are directly exposed to the ocean while other parts are embayed and protected areas. Within the embayed and protected areas, sand and pebble transport during times of high wave energy may be considerable when one considers the small length of some of the Harbor Islands.

Results of sand budget and sedimentology studies of moderate to high energy sandy coasts by Pierce (1969) and Stapor (1971, 1974) indicate a significant reduction in the effective distance over which longshore transport operates. Depending upon the wave energy, accretion and erosion in these sandy areas was somewhat balanced. Reversals in the direction of net longshore transport, permanent sediment sinks, and significant sediment sources serve to compartment any coast. Wave energy, coastal and offshore geology, offshore bathymetry, tidal range, and climatic conditions are perhaps the most important of the factors which interact to create a compartmentalization of the coast. One would assume that in this area where the sediment source is drumlin till deposits, only limited movement of the larger-sized material occurs and comparatively rapid movement of the smaller-sized material. Comparison of the percentages of sediment size in the drumlin till cliffs should indicate what sizes were transported and what sizes were not.

Glacial Sediment Analysis

A sediment analysis of the drumlin till was performed to determine the amount and distribution of material available for erosion and deposition. Crosby (1890) analyzed 16 sediment samples from 12 different drumlins of the Boston area. Two Harbor Islands, Long Island and Nut Island, were among the 12 drumlins sampled. The average of these two islands was computed at the end of Table 1. The average percentage of sediment size corresponds very well with the average drumlin sediment size percentage. Nut Island is located one-half mile southwest of southern end of Peddocks Island. A single sample from any one drumlin may not be representative of the average sediment composition. Glacial erosion in the Boston basin was very variable in its effectiveness and a given glaciation event did not entirely remove the deposits from earlier ice sheets. Incorporated within the drumlin may be deposits from earlier ice advances or retreats. Layering or stratified deposits have been found in freshly exposed drumlins (Kaye, 1976). These deposits consist of thin, sandy, silty and even gravelly layers, interbedded with till. While some exposures of drumlin till show only a few of these beds of sorted sediments, others show many. For this reason the average of Crosby's 16 samples was used as a representative sediment sample of the drumlin till composition.

Table I *

		Gravel	Sand	Flour	Clay
1.	Mount Hope	26.53	21.33	42.13	10.01
2.	Skinner Hill	24.66	20.66	48.31	6.84
3.	Parker Hill	28.80	16.90	42.10	11.00
4.	Parker Hill	14.41	20.09	50.18	14.69
5.	East Boston	29.10	13.70	47.76	10.14
6.	East Boston	27.90	14.70	41.81	14.69
7.	Milton Hill	26.25	18.80	50.12	5.68
8.	Convent Hill	24.50	17.82	46.39	11.16
9.	Convent Hill	24.41	19.13	43.03	13.46
10.	Mt Bowdoin	26.46	17.04	43.55	12.92
11.	Mt. Bowdoin	23.93	20.54	40.18	15.18
12.	Ten Farm Hill	25.30	24.93	36.57	13.44
13.	Green Hill	23.20	17.28	43.90	15.27
14.	Long Island	16.72	36.94	38.03	8.22
15.	Nut Island	20.73	11.09	52.49	15.69
16.	Corey Hill	35.48	21.28	35.23	8.41
	Average Drumlin	24.90	19.51	43.86	11.67
	Two Island Average	18.75	24.01	45.26	11.95

* Adapted from Crosby (1890)

In Crosby's method of analysis, all stones more than 2 inches in diameter were excluded. He concluded that stones and boulders more than 2 inches in diameter rarely form more than 5 to 10% of the till. The samples he analyzed varied from 8 to 16 pounds in weight. Six sieve sizes in all were used. The sieve sizes were 4, 6, 12, 20, 40, and 60. These sieve sizes correspond to the phi (ø) range of -2.25 ø to + 2.0 ø; (5mm to .25mm). For sediment smaller than + 2.0 ø, decantation was used to determine the percentages present. From - 7.5 ø to + 2.25 ø was considered to be the range of the s n -sized sediment, + 2.25 ø to 5 ø was considered to be the range of silk-sized sediment, and sediment smaller than 5 ø was considered to be clay-sized.

It can be seen from Figure 25 that after the larger stones are excluded, that the drumlins are composed of about 25% gravel, about 20% sand, 40 to 45% of extremely fine sand or rock flour and less than 12% clay. Two samples of till from Grape Island till were analyzed. The samples were found to contain 11% gravel, 17% sand, 42% fine sand to medium silt and 30% fine silt and clay.

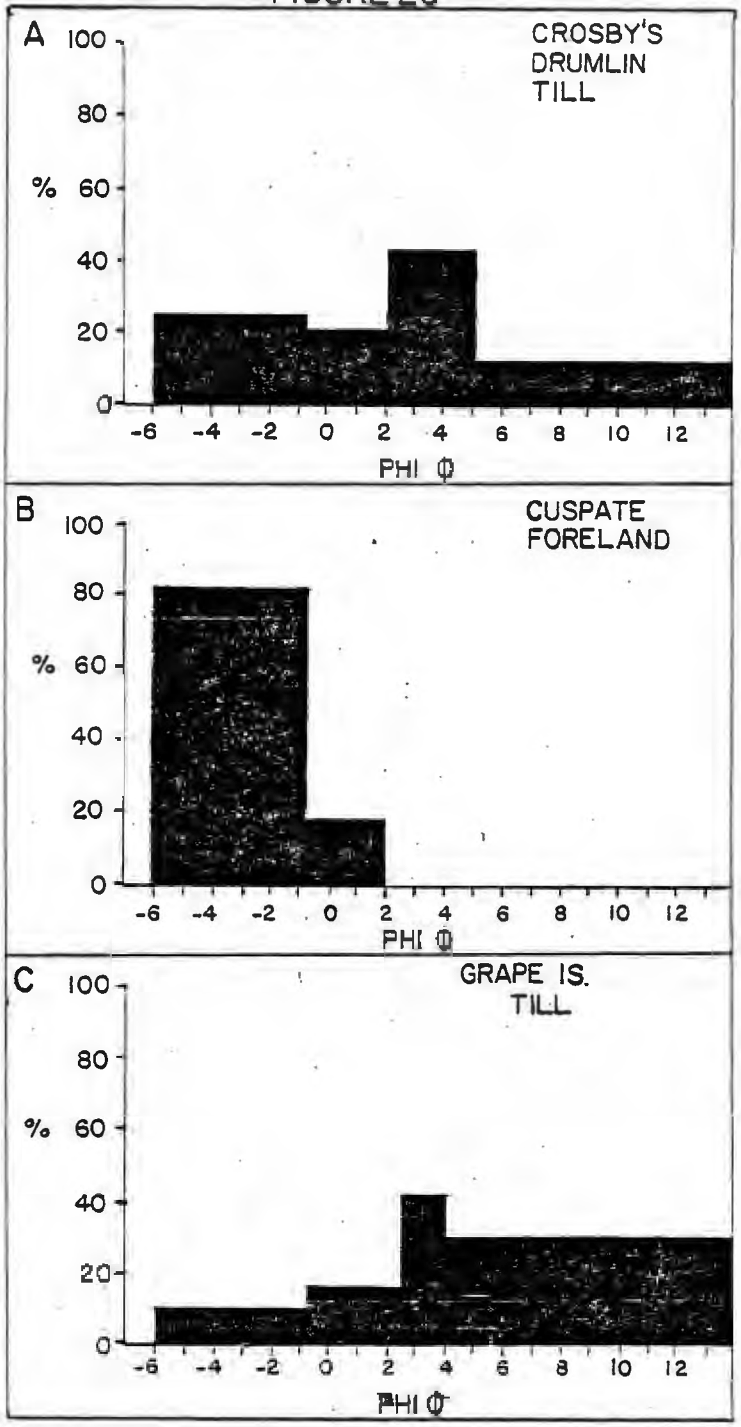
Shoreline Sediment Analysis

Ten samples of a cuspate foreland located at the southeastern end of Grape Island were obtained during summer field work. Dr. Richard Jones of Boston State College, analyzed the samples by dry sieving. The percentage of certain sediment sizes present or not present in the cuspate foreland would give an indication of what sediment size was being transported and which sizes were not. The cuspate foreland was found to contain 81% gravel, 17% sand and 1% silt to clay-sized sediment.

FIGURE 25

Histogram: Crosby's Till, Cuspate Foreland
and
Grape Island Till

FIGURE 25


A
CROSBY'S
DRUMLIN
TILL
%
100
80
60
40
20
0
-6 -4 -2 0 2 4 6 8 10 12
PHI Φ
B
CUSPATE
FORELAND
%
100
80
60
40
20
0
-6 -4 -2 0 2 4 6 8 10 12
PHI Φ
C
GRAPE IS.
TILL
%
100
80
60
40
20
0
-6 -4 -2 0 2 4 6 8 10 12
PHI Φ

Sediment Budget Analysis

Using the Coastal Engineering Research Center's 1973 estimate of the volume of beach lost ($0.76m^3$) per areal loss of beach ($0.09m^2$) one can derive a value of $8.44m^3$ sediment loss per $1m^2$ areal units of beach erosion. This figure, $8.44m^3$, was multiplied by the areal loss or accretion of the shoreline for each Island in m^2. The volume of accretion to the shoreline was compared to the volume of material eroded from the cliff line and its high tide line along an island's shoreline. Cliff heights were measured during summer field work and these values were used to compute the volume of the cliff material eroded. From these calculations the following values for the Islands over the entire study period can be computed:

Total Cliff Erosion (1938-1977)	:	$306,510m^3$
Total Shoreline Erosion (1938-1977)	:	$1,727,710m^3$ +
Total Volume Loss from Harbor Islands (1938-1977)	:	$2,042,876m^3$
Total Accretion of Shoreline (1938-1977)		$\frac{363,599m^3}{2.042,876m^3} \times 100 = 18\%$

According to these calculations 18% of the sediment that was eroded from the high tide line and cliff line between 1938 and 1977 is now present as accretion of the shoreline. From Table II it can be seen that there is a wide variance in the sediment budget among the Harbor Islands. Factors such as wave exposure, sea walls and sediment between islands probably does not exist and each island is a closed system.

TABLE II

	Shoreline Erosion	Cliff Line Erosion	Shoreline Accretion	%Retained
1. Lovells Island	234,421	-	85,674	36.5%
2. Gallops Island	51,467	-	9,216	17.9%
3. Spectacle Island	217,903m^3	72,421m^3	176,547m^3	60.8%
4. Great Brewster Island	37,375	24,512	3,511	5.6%
5. Georges Island	69,672	-	0	0%
6. Rainsford Island	41,136	-	18,795	45.6%
7. Thompson Island	557,605	104,323	7,511	1.1%
8. Long Island	517,818	105,314	62,345	10.0%
TOTAL	1,727,757	306,570	363,599	17.8%

18% of the total volume of matter eroded is redeposited along the shoreline.

Using the percentage of sediment size present in an average sediment sample of drumlin till and comparing it to the percentage of sediment size present in the cuspate foreland, one can determine the approximate sediment size and volume of material that has been eroded or accreted. Figure 25 is a histogram for the drumlin till and the cuspate foreland. If one uses the sediment size percentage of the accretional shorelines in the Harbor Islands, one can calculate the individual amount of gravel, sand and silt and clay accreted. The percentages of gravel, sand, silt and clay were multiplied by the total volume of accretionary shoreline to obtain the following percentage and volume of material: of the 363,599m^3 of sediment accreted to the high tide line, 294,519m^2 would be composed of gravel, 61,812m^3 of sand, 7,273m^3 of rock-flour and a negligible amount of clay sized particles. The cliff line could only supply a percentage of its volume because only 1% of the silt and clay and part of the sand and gravel would remain at the shoreline after erosion took place. Only 20% to 25% of the total volume of material eroded would remain for later potential accretion. The cliff line erosion could supply 70,000m^3 of the 363,599m^3 accreted to the shoreline. The eroded shoreline, being composed of the same material as the accretionary areas could supply all of the necessary volume for the accretionary shorelines. A total of 1,797,757m^3 (1,727,757m^3 from shoreline erosion and 70,000m^3 from cliff line erosion) would be available to supply the accretionary shorelines.

Total Shoreline Accretion ÷ Total Volume of material available to supply shorelines of accretion

$$363{,}599m^3 \div 1{,}727{,}752 = 20\%$$

Approximately 20% of the total volume of material available to supply the shoreline of accretion is accreted. Overall 80% is lost offshore to various sediment sinks.

	Gravel-sized	Sand-sized	silt-sized	Clay-sized
Volume Eroded that is Available for Accretion	1,339,479m^3	293,717m^3	Less than 1%	Less than 1%
Volume Accreted	294,519m^3	61,812m^3	Less than 1%	Less than 1%
Per Cent Redeposited	21%	21%		

A total of 21% of the sand and gravel eroded from the cliff line and shoreline is redeposited. Silt and clay-sized sediment that is lost from the erosion of the cliffs and shoreline is either transported to the numerous dredged channels or is lost to the nearshore bottom. Approximately 80% of the gravel and sand eroded from the cliff line and high tide line is lost to channels or the nearshore bottom.

Conclusions

Between 1938 and 1977, the Boston Harbor Islands experienced a net erosion of approxiamately 1,727,575m^3. During the same time period the high tide line retreated at an average rate of .20m/yr. The cliff line eroded 306,510m^3 between 1938 and 1977. The average rate of retreat of the cliff line was .19m/yr.

The total volume of sediment that was eroded between 1938 and 1977 from the high tide line and cliff line was 2,034,327m^3. The high tide line accreted 363,510m^3 between 1938 and 1977. This accretion can account for 18% of the sediment eroded from the high tide line and cliff line.

The drumlin till, which is the shoreline's main sediment supply, is mainly composed of silt with lesser amounts of gravel, sand and clay. Areas of accretion are mainly composed of gravel and sand sized sediment. It would seem that sediment smaller than +2.0 phi (Ø) is not redeposited at the shoreline after erosion initially occurs. Waves from cyclic storms and storm associated currents that cause erosion of the cliff line have the initial velocity necessary to suspend silt and clay sized sediment. Landshore currents probably transport the silt to clay sized sediment beyond an Island's extent because of the short length of the Islands. Sand and gravel sized sediment are transported alongshore but tend to remain along the shoreline due to a decrease in the energy of the longshore current at an Island's end. Approximately 80% of the sand and gravel eroded from the shoreline and cliff line is lost to offshore areas.

The general direction of the longshore drift is to the south throughout the islands. All the major areas of accretion were located at the southern extent of individual Islands. This would seem to indicate that the dominant wind direction that causes the longshore drift is from the north or northeastern direction.

A retreat of the cliff line was usually followed by a retreat of the shoreline. Because of deep, dredged channels and the distance between Islands; exchange of sediment between Islands was considered to be small or non-existent.

APPENDIX

Table I

Georges Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1	-143	+112	-162	-173
2	-2018	-1566	-2257	-1801
3	-708	-433	-811	-478
4	-691	-442	-747	-421
5	-440	-249	-541	-463
6	-996	-765	-727	-402
7	-842	-727	-919	-527
8	-713	-671	-996	-653
9	-734	-689	-823	-727
10	-1930	-1754	-2115	-1998
11	-579	+89	-632	-402

Gallops Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1	-680	-550	-97	-502
2	-1717	-2528	-1863	-1944
3	-2544	-3305	-4301	-3451
4	-810	-453	-1183	-178
5	-761	-664	-1079	-23
6	-499	+259	-632	+23
7	-162	+372	+716	+1069

Rainsford Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1	-707	-1296	-1070	-417
2	-399	-816	-979	-888
3	0	0	0	0
4	-889	-1051	-780	-1015
5	+507	-216	-162	+671
6	+289	-38	0	+141
7	+417	-780	-362	-453
8	-220	-997	-1033	-1102
10	-297	-816	-1469	-453

Table I

Georges Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1.	-143	+112	-162	-173
2.	-2018	-1566	-2257	-1801
3.	-708	-433	-811	-478
4.	-691	-442	-747	-421
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7.	-842	-727	-919	-527
8.	-713	-671	-996	-653
9.	-734	-689	-823	-727
10.	-1930	-1754	-2115	-1998
11.	-579	+89	-632	-402

Gallops Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1.	-680	-550	-97	-502
2.	-1717	-2528	-1863	-1944
3.	-2544	-3305	-4301	-3451
4.	-810	-453	-1183	-178
5.	-761	-664	-1079	-23
6.	-499	+259	-632	+23
7.	-162	+372	+716	+1069

Rainsford Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1.	-707	-1296	-1070	-417
2.	-399	-816	-979	-888
3.	0	0	0	0
4.	-889	-1051	-780	-1015
5.	+507	-216	-162	+671
6.	+289	-38	0	+141
7.	+417	-780	-362	-453
8.	-220	-997	-1033	-1102
9.	-297	-816	-1469	-453

10	+163	-418	-671	-272
11	+321	+380	+653	+1469
12	-290	-290	-380	-274

Lovells Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1	-4191	-3509	-5605	-5688
2	-2628	-5109	-8207	-7770
3	-4569	-9633	-11426	-11583
4	-437	+349	-1513	-1104
5	-1891	+292	-641	+1106
6	-1979	-640	-1629	-612
7	-1775	0	-442	-57
8	-611	-87	-291	0
9	-117	+1833	+1484	+2444
10	+175	+2299	+2765	+2561
11	0	-223	0	-473
12	+320	+1160	+582	+482
13	+523	+2794	+2590	+3085
14	+233	+524	+29	+61

Spectacle Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1977
1	-785	+216	+3083
2	-1017	-2057	-2438
3	+957	-89	-533
4	+3547	+6872	+9125
5	-879	-838	-1829
6	+457	-73	+206
7	+190	+230	+847
8	+4303	+3986	+4248
9	+2171	+1586	+614
10	-824	-1523	-2691
11	-1905	-1157	-2400
12	-2019	-1296	-2651
13	-1318	-1143	-1638
14	-785	-304	-1696
15	-800	-305	-1690
16	-953	-1219	-1676
17	-266	-1398	-1542
18	-228	-1311	-1615
19	-952	-1102	-2629
20	-914	+304	-790

21	+1209	+2476	+2795

Cliff Line Segments

	1938-1952	1938-1963	1938-1977
1-5	-	-	-
6	-489	-522	-838
7	-1420	-1472	-1562
8	+4496	+4663	+4305
9	+2288	+800	+389
10	-1181	-1592	-3238
11	-305	-346	-385
12	-202	-381	-495
13	-228	-1113	-1409
14	-872	-1095	-1149
15	-1386	-1522	-1752
16	-1532	-1634	-1676
17	-763	-1181	-1867
18	-712	-1523	-1601
19-21	-	-	-

Northern Thompson's Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1977
1	-2817	-5286	-4226
2	-1208	-2284	-2392
3	+1653	-88	+23
4	+1489	-975	-784
5	-1300	-3042	-2392
6	-1842	-3422	-1976
7	-1192	+202	+23
8	-2709	-3989	-4352
9	-1215	-1981	-1742
10	-912	0	-2798
11	-1608	0	-2275
12	-2384	-188	-2732
13	-3684	-41	-4009
14	-4926	-1417	-5093
15	-2911	-2175	-2812
16	-1791	-758	-1508

Cliff Line Segments

	1938-1952	1938-1963	1938-1977
1	-	-	-
2	-45	-653	-866

	1938-1952	1938-1963	1938-1977
3	-758	-1100	-1372
4	-975	-1308	-1440
10	-1972	-2600	-3342
11	-2058	-3212	-3610
12	-2212	-2717	-3101
13	-750	-1255	-2509
14	-195	-310	-1017

Southern Thompsons Island, Total Shoreline Changes (m^2)

1	-2817	-5286	-4226
2	-1208	-2284	-2392
3	+1653	-88	+23
4	+1489	-975	-748
5	-1300	-3042	-2392
6	-1842	-3242	-1976
7	-1192	+202	+23
8	-709	-3989	-4352
9	-1215	-1981	-1742
10	-912	0	-2798
11	1608	0	-2275
12	-2384	-188	-2732
13	-3684	-41	-4009
14	-4926	-1417	-5093
15	-2991	-2175	-2812
16	-1791	-758	-1508
17	-205	-325	-890
18	-325	-433	-1393

Great Brewster Island, Total Shoreline Changes (m^2)

High Tide Line Segments

	1938-1952	1938-1963	1938-1971	1938-1977
1	-255	-979	-1046	-1101
2	-1492	-1375	-1472	-1258
3	-1414	-939	-794	-1027
4	-794	-290	-232	-465
5	-329	+251	-379	+155
6	-59	0	+174	+166
7	-196	-445	+106	+145
8	-23	-949	-445	-620

Cliff Line Segments

6	102	-123	-179	-212
7	-113	-212	-347	-465
8	-214	-288	-319	-523

Northern Long Island, Total Shoreline Changes (m^2)

High Tide Line Segments

1	-825	-1346	-1392	-1496
2	-1304	-2988	-3453	-3121
3	0	-412	-841	-294
4	-189	0	+1220	+395
5	0	+84	+1352	+879
6	-23	-120	-1291	-1683
7	-89	-336	-2819	-2104
8	-732	-673	-2651	-1725
9	-1609	-2272	-2609	-1767
10	-2314	-2223	-1835	-1641
11	-1472	-1430	-1725	-1304

Cliff Line Segments

4	-394	-925	-1209	-1430
5	-505	-841	-1022	-1178
6	-710	-943	-1095	-1304
7	-757	-923	-1214	-1346

Middle Long Island, Total Shoreline Changes (m^2)

1	-838	-2034	-1542	-1772
2	-115	-1105	-1181	-1186
3	-210	-48	-1029	-884
4	-686	+66	-566	-421
5	-304	+191	-457	-762
6	-65	-210	-724	-724
7	-1029	-1253	-1661	-1905

	1938-1952	1938-1963	1938-1971	1938-1977
8	-1105	-2134	-2592	-2821
9	-1143	-1715	-2021	-2249
10	-571	-876	-1334	-1524
11	-381	-152	-914	-1143

Cliff Line Segment

1	-137	-212	-356	-553
2	-23	-189	-433	-609
3	-228	-333	-419	-623
4	-122	-251	-303	-411
5	-23	-102	-176	-212
6	0	0	0	0
7	-202	-412	-532	-705
8	-686	-1181	-1624	-2173
9	-1105	-1524	-1902	-2363
10	-876	-1143	-1540	-1829
11	-1258	-1572	-1811	-2034

Southern Long Island, Total Shoreline Change (m^2)

High Tide Line Segments

1	-1674	-2180	-2750	-3932
2	-641	-683	-983	-1667
3	+237	+82	-483	-279
4	+214	-1111	-940	-1543
5	+255	-342	+1027	+383
6	+2051	+1796	+2906	+3591
7	+1271	+1752	+1748	+2137
8	-342	+1025	+612	-825
9	+541	+434	+1367	-1347
10	-2906	-1453	-1367	-2707
11	-2564	-2522	-1496	-2479
12	-3248	-3719	-2650	-2650
13	-2223	-3781	-2009	-1709
14	-1112	-2821	-2308	-1880
15	-1496	-2223	-2009	-2308
16	-3405	-3312	-3550	-3633
17	-3206	-3961	-4088	-4416

Cliff Line Segments

2	-341	-427	-598	-726
4	-299	-417	-481	-525
10	-265	-292	-348	-397
11	-441	-755	-912	-1192
16	-299	-384	-448	-556
17	-377	-854	-983	-1196

TIMES A.M.	Dates of Photographs	Tides Time / Tidal Stage
11:56	8-18-52	9:44/8.3-3:37/0.5'
11:30	8-24-52	1:03/9.5-7:15/0.3'
1:00	8-26-52	2:24/8.9'-8:34/0.7'
11:30	8-20-52	11:02/8.9'-4:53/22'
1:30	5-3-63	01:70/1.2'-07:25/8.81
9:30	4-24-71	10:12/10.6'
8:37	5-7-71	9:06-/8.6
11:42	4-14-77	04:20/0.4'-10:34/9.6
1:05	12-5-38	03:37/8.6-10:06/0.6

CLIFF HEIGHTS

ISLAND	Station	Height
Great Brewster	6	27.4m
	7	19.8m
	8	4.6m
Long Island (Northern)	4	1.8m
	5	1.8m
	6	5.5m
	7	1.8m
Long Island (Middle)	1	2.4m
	2	6.1m
	3	3.6m
	4	2.4m
	5	2.4m
	6	2.4m
	7	2.4m
	8	7.6m
	9	5.5m
	10	5.5m
	11	5.5m
Long Island (Southern)	2	3.6m
	4	3.0m
	10	2.4m
	11	3.6m
	16	3.6m
	17	7.6

ISLAND	Station	Height
Spectacle	6	2.43m
	7	5.48m
	8	1.5m
	9	5.55m
	10	5.5m
	11	5.5m
	12	5.5m
	13	5.5m
	14	5.5m
	15	5.5m
	16	5.5m
	17	5.5m
	18	3.0m
Thompsons (Southern)	17	6.1m
	18	3.6m
Thompsons (Northern)	2	4.6m
	3	3.0
	4	3.0
	10	4.6
	11	6.1
	12	6.1
	13	7.6
	14	6.1

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