QUATERNARY RESEARCH 4, 496–508 (1974)

Shoreline Changes Along the Southeastern Coast of Martha's Vineyard, Massachusetts for the Past 200 Years

J. GORDON OGDEN III[1]

Received February 20, 1973

Shoreline changes since 1776, including two 30-yr periods separated by nearly 100 yr are documented from surveys, topographic maps, harbor charts, and aerial photographs for the southeastern corner of the island of Martha's Vineyard, Massachusetts (41°25′ N, 70°35′ W). From 1776 to 1969, a barrier beach has receded by more than 880 m, an average rate of 4.6 m/yr. A series of four detailed surveys from 1840 to 1886 document consistent shoreline retreat in this area of 3.1 m/yr.

For the period 1938–1969, planimetry from aerial photographs and field observation indicate that more than 28 ha and nearly 3×10^6 m³ of foreland composed of till have washed away. A house, located 200 m from the cliff edge of the foreland in 1938 was only 56 m from the cliff edge in July 1972.

Violent storms were associated with the opening of the bay behind the barrier beach in nearly the same location in 1856, 1886, 1938, and 1954. Easterly migration of the opening results in rapid erosion of the southeastern corner of the island (Wasque Point) and eventual closing of the opening.

Field observation of the 1954 opening indicates that the mechanism of failure of the barrier beach is primarily by storm tide-induced subsidence. Subsequently, strong (up to 1.2 mps) easterly currents cause migration of the opening to the east and closure within 15 yr.

A summary review of evidence for changes in sea level in the past is suggested in partial explanation for the consistent shoreline retreat described in this paper.

INTRODUCTION

Martha's Vineyard is an island of approximately 100 sq miles located in lat. 41°25′ N and long. 70°35′ W. It is the largest of a group of islands south and southwest of Cape Cod, Massachusetts (Fig. 1). These islands and Cape Cod form the northernmost outposts of the Atlantic Coastal Plain which here dips beneath the sea and continues northeastward as George's Bank. The surface of the islands is of glacial drift and date from the retreat of the Wisconsin ice sheet. Material underlying the drift consists of beds of unconsolidated Tertiary sands and clays which outcrops in several localities, and in some instances (Gay Head at the southwestern tip of Martha's Vineyard) thrust up into steeply tilted beds of remarkable beauty caused by various colors in the Cretaceous and Tertiary clays and sands (Kaye, 1964a).

The moraines which form the northwestern coast of Martha's Vineyard have a maximum relief of 91 m. The topgraphy is steep and rolling in contrast to the very flat and gently sloping outwash plain to the east. Soils of the moraine are rocky, thin, and lacking in almost every soil component except sand. Deeper soils are found in the outwash plain with few rocks and little clay. The southern coast is exposed to the Atlantic Ocean and vigorous longshore cur-

[1] Dept. of Biology, Dalhousie University, Halifax, Nova Scotia, Canada.

Copyright © 1974 by University of Washington.
All rights of reproduction in any form reserved.

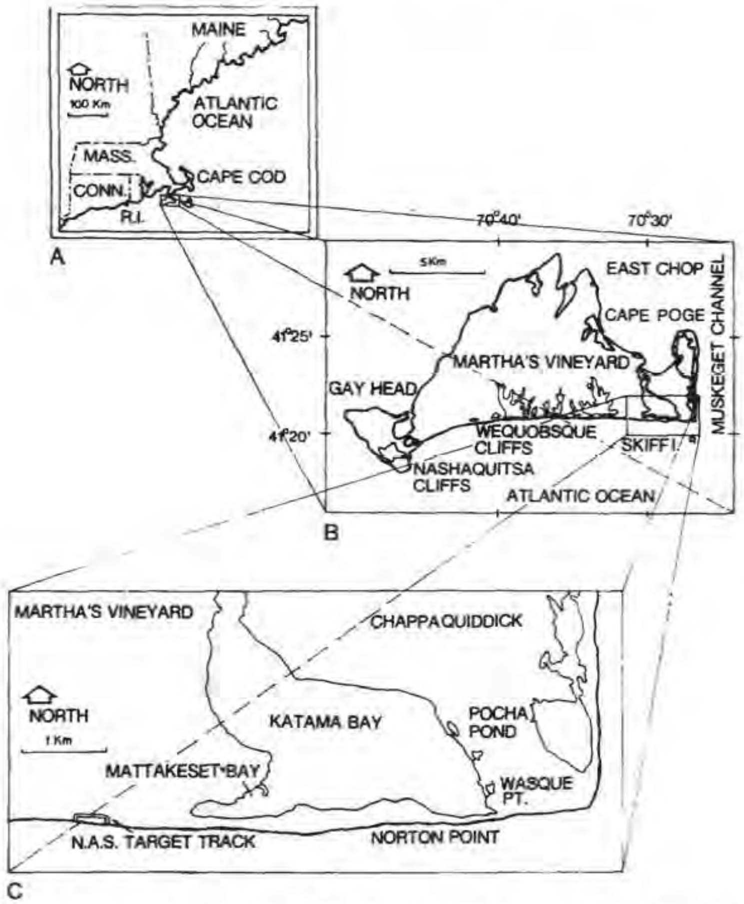


FIG. 1. Regional map of Cape Cod and the Offshore Islands showing location of study area.

rents (velocities to 1.2 mps) have a predominantly easterly set.

The following report outlines the evidence for shoreline changes along the southeastern coast of Martha's Vineyard from 1776 to 1972. The 1776 shoreline was rescaled from Kaye (1973) and based on Des Barres (1777) survey.

Information for 1846–1886 was compiled from the detailed surveys (1:10,000) of Prof. H. L. Whiting (1882, 1887), and Shaler (1888), Woodworth and Wigglesworth (1934), old files of the Vineyard Gazette in Edgartown, Massachusetts, and records found in the archives of the Dukes County Historical Society.

Data for the period 1938–1972 were compiled from aerial photographs, USGS topographic maps (1:24,000) and various coastal charts as well as field observations. Transparencies were prepared from all old charts and aerial photographs available and rescaled to 1:24000 using H. L. Whiting's original coordinates of lat. 41°21'00" N and long. 70°27'00" W to long. 70°31'00" W. Grid ticks are indicated at 1'00" of longitude in the accompanying illustrations.

Shoreline Features—1776

According to Kaye (1973), the Des Barres (1777) map of Martha's Vineyard was surveyed by plane table, and is probably accurate to within 50 m. The shoreline position in 1776 is compared with the 1969 shoreline in Fig. 2, which also shows the 1846 shoreline surveyed by Whiting (1887). Retreat of the Wasque Point foreshore was approximately 880 m in the period 1776–

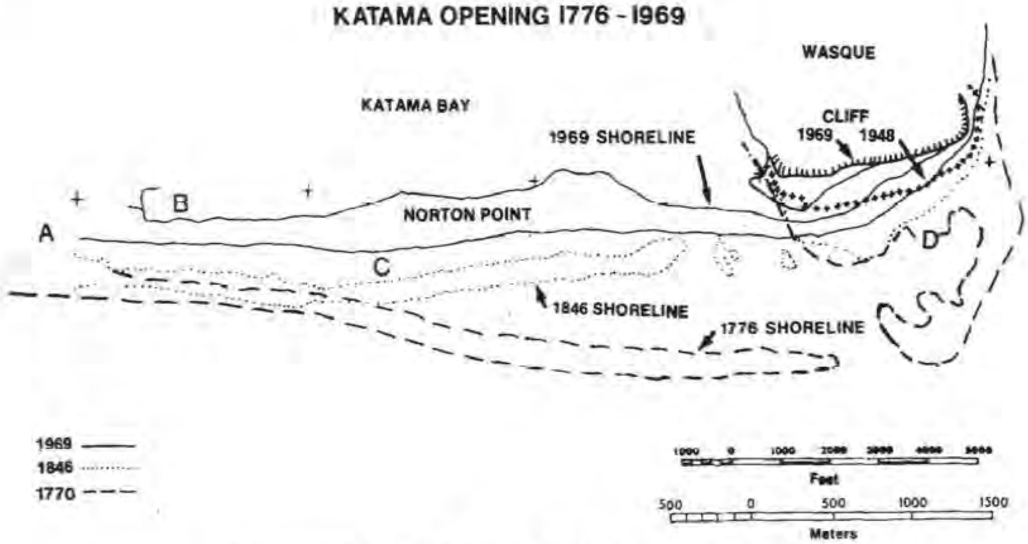


FIG. 2. Comparison of 1776, 1846, and 1969 shoreline at Wasque Point.

1969, for an average rate of retreat of 4.6 m/yr.

The 1776 shoreline indicates an opening at the eastern end of Katama Bay. The relationship of openings into Katama Bay and erosion of Wasque are discussed in a subsequent portion of this paper.

Shoreline Changes in the Period 1846—1877

The amount and rate of coastal weathering was of considerable interest to N. S. Shaler (1888) in his detailed study of the geology of the Vineyard, and he devoted considerable attention to various parts of the island, as did H. L. Whiting (1887). Whiting noted that the central portion of Wequobsque Cliffs (Fig. 1b) lost 67 m during the period 1846–1886, at an average rate of 1.7 m/yr. Shaler notes "perhaps the most rapid gain of the sea on the land where the shore is considerably elevated which has been observed on any part of the New England coast."

Erosion has not, of course, been limited to the southern side of the island. On the eastern side, the cliff face at East Chop (Fig. 1b) retreated 23 m between 1846 and 1871 at a rate of about 1 m/yr. Shaler noted that some 368,000 m^3 of material was removed from this section during the period of measurement. Family photographs and records recall that a tennis court existed on the seaward side of East Chop drive above the old steamer landing.

H. L. Whiting (1887) recorded that the waste of material from Cape Poge (Fig. 1b) was about 130 m during the period 1846–1886, and that the cliff face had approached to within 14 m of the lighthouse foundation and was continuing to wear rapidly. Owing to rapid erosion of the salient at Cape Poge, the lighthouse has been moved several times.

At the time of Whiting's report, he noted that Skiff's Island, southeast of Wasque Point, which for most of the period of his survey had been awash at high tide, had increased to a maximum length of about 365 m in a north–south direction and about 88 m in an east–west direction. The island included about 1.8 hectares and supported "beach weeds and grasses." Banks (1911) in his "History of Martha's Vineyard" records that salt hay was frequently harvested on Skiffs Island and that for a time, sheep were pastured there.

The beach 10 km W of Norton Point re-

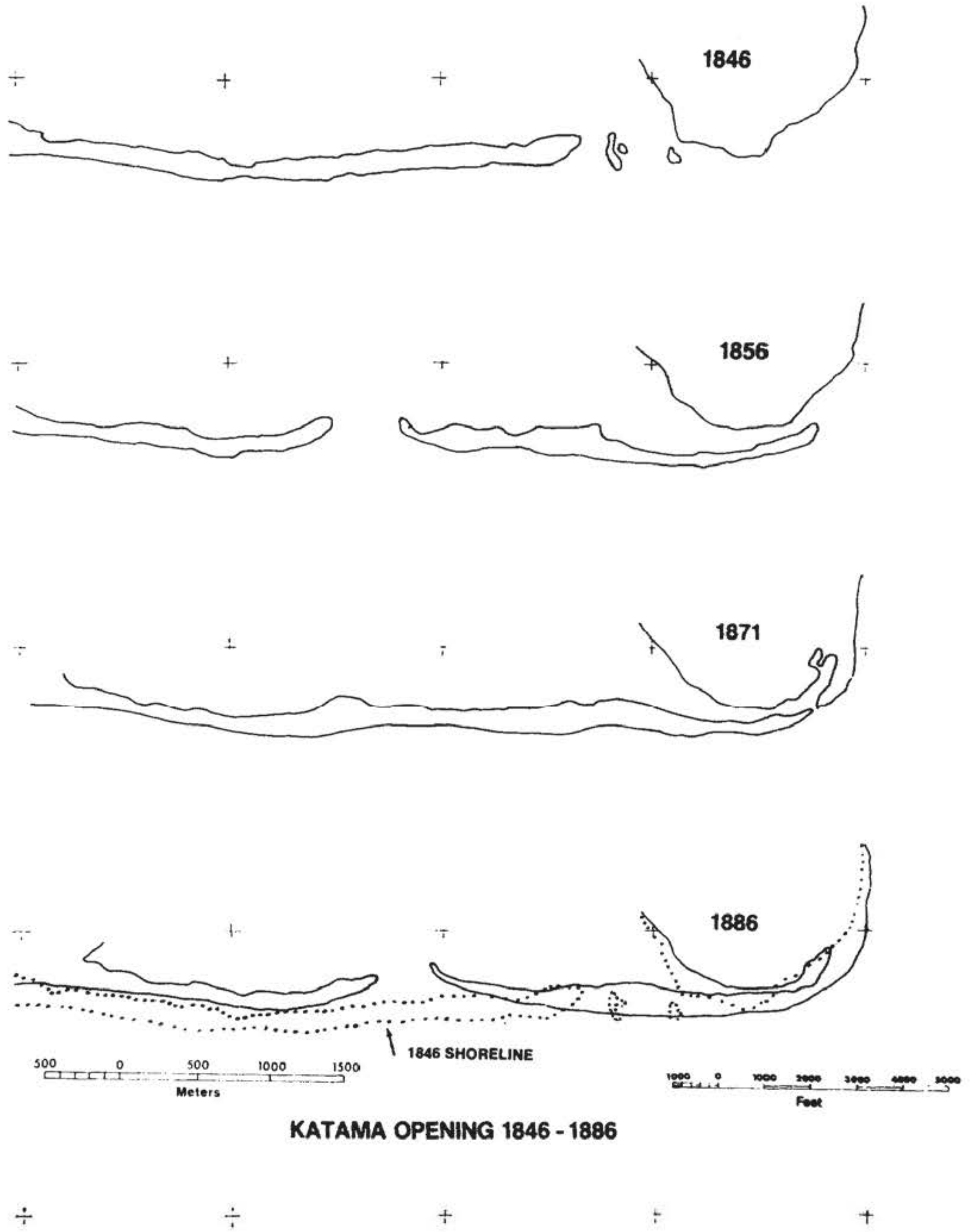


FIG. 3. Shoreline changes 1846–1886 at Wasque Point and Norton Point. From surveys by H. L. Whiting (1887).

ceded a distance of 146 m in the 40-yr period covered by Whiting's survey. Beach retreat at Wasque Point showed a maximum of 117 m.

The 1846 shoreline (Fig. 3) is shown by dotted lines superimposed on the 1886 shoreline and illustrates the general beach retreat mentioned by both Whiting and Shaler. The interval covered by Whiting's survey included two western openings, one of which (1886) Prof. Whiting observed following its formation in a January storm.

Shaler (1887) noted that the western openings generally occur in about the same place near Mattakeset Bay in Katama Bay. The predominant easterly drift of the strong currents along this coast cause the western tip to accrete and the eastern tip to retreat until the opening comes up against the Chappaquiddick shore at Wasque Point.

The present author had the opportunity to witness the 1954 breakthrough at the western end. A comparison of the western openings and migration of the opening is considered elsewhere in this report.

Shoreline Changes in the Period 1938—1972

Aerial photographs from flights in 1938, 1944, 1948, 1951, 1955, 1963, and 1969, together with a topographic map (USGS 7.5′ series, Edgartown, Mass.) and coastal charts (USCGS) provide dramatic evidence of continuing instability of the coastline in this portion of Martha's Vineyard. Aerial photography provides additional detail on coastal features not available from topographic maps (10-ft (3.04 m) contours), or coastal charts.

Shoreline changes from 1938 to 1969 are summarized in Fig. 4, which shows the migration of the opening and overall retreat of the beach during the 31-yr period. A comparison of the shoreline in 1776, 1846, and 1969 is shown as Fig. 2, together with the position of the cliff face at Wasque Point in 1948 and 1969. Because of the detail available from aerial photography, shoreline changes are described below for separate sections of the region (A–D in Fig. 2).

A. Target Track, Naval Air Station, Katama. In the early 1940s visitors to the Island recall a target track (Fig. 1c), parallel to the shore, measuring about 15 m wide and 430 m long with a massive concrete bunker located in the center of the track on the shore side. In 1944, the southern side of the track and the bunker were more than 60 m from the high-tide line.

Measurements from aerial photographs (target track to the shoreline) indicate that the beach has retreated 93 m since 1944, at an average rate of 3.7 m/yr. Similar measurements from 1951 and 1955 air photos indicate that the retreat has been remarkably uniform with rates varying from 3.66 m to 3.81 m/yr. Only about one-half of the track remained back of the beach sand in 1972.

B. Mattakeset Bay. Shoreline retreat in the area of Mattakeset Bay, based on aerial photographs from 1951 through 1969, indicate that the beach has moved back about 85 m, at an average rate of 4.7 m/yr.

C. Norton Point. Because of periodic aggradation of the point when western openings develop into Katama Bay, the shoreline appears deceptively stable. Five measurements at 500-m intervals from the western to eastern terminus of Norton Point show retreat of 67 m, 15 m, 0, 15 m, and 180 m, giving an average retreat of 30.5 during the 18-yr period 1951–1969 or a rate of 1.7 m/yr. Comparison with the 1846 shoreline, however, shows retreat in excess of 300 m during the 123 period, an average rate of 2.5 m/yr. Similarily, the 1776 profile shows a loss of about 600 m, for a rate slightly more than 3 m/yr.

D. Wasque Point. Since 1846, the maximum retreat of the outer beach at Wasque Point is approximately 310 m, an average rate of retreat of 1.7 m/yr. This part of the shoreline periodically progrades when there is a western opening. Each time the opening moves eastward against the cliffs at Wasque Point, however, retreat is exceptionally rapid. As shown in Fig. 2, the salient of Wasque Point has retreated more than any other portion of the shoreline.

E. Wasque Cliff. The retreat of Wasque Cliff is even more dramatic than the retreat of the old target track west of Mattakeset Bay (A in Fig. 2). Reference points on aerial photographs include the cliff face, old roads, a rectangular woodland, and the position of a cottage at Wasque Point. From west to east along the shore, retreat

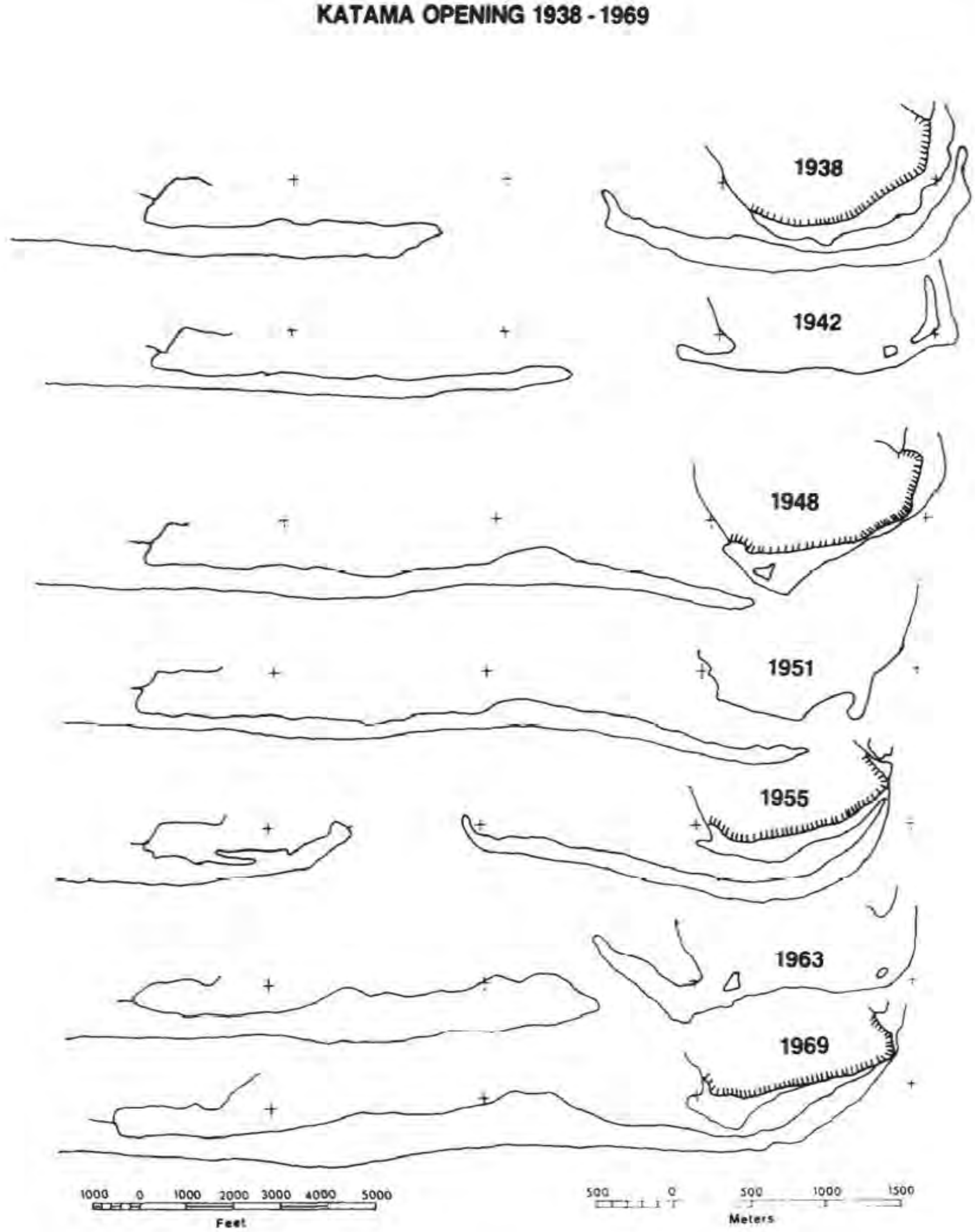
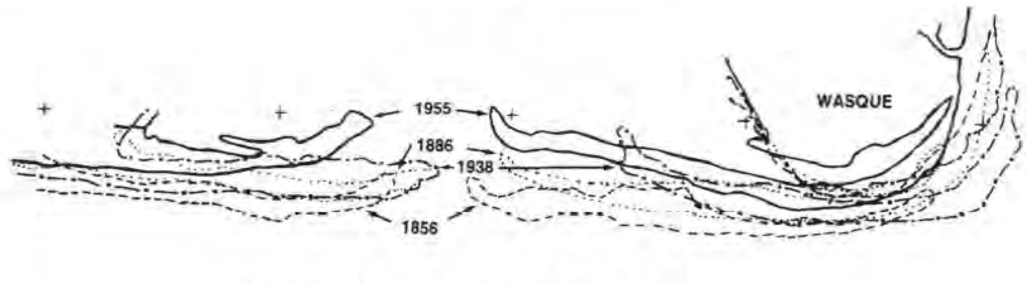


FIG. 4. Shoreline changes at Wasque Point 1938–1969.

since 1948 is measured at 198 m, 230 m, 213 m, 238 m, and 152 m, at approximately 200-m intervals, an average retreat of 206 m. In 1948, the cliff face at the center of the section was less than 2 m high, and tapered both east and west to intersect the beach sand. Landward, ground sloped upward at a uniform grade of 3%. In July 1972, the cliff face was approximately 9 m high for a distance of approximately 1000 m, and tapered sharply to the beach to the east and west. The volume of earth lost to the sea is estimated at more than 3×10^6 m^3 over a 21-yr period (1947–1969), with



WESTERN OPENINGS – KATAMA BAY
1856 - 1955

FIG. 5. Western openings into Katama Bay, 1856–1955. 1938 (—.—.); 1955 (———); 1886 (.....); 1856 (----).

a yearly retreat for this period of nearly 10 m. The cliff does not wear away at a uniform rate, however, as the face is relatively stable until Katama opening sweeps eastward and slices off another large portion of Wasque Point. The rate of cliff retreat here at present is slower than in the period 1948–1955 due to the increased height of the cliffs and the additional volume of earth to be removed with each foot of cliff retreat.

The old cottage at Wasque Point is increasingly threatened by the migration of the cliff face. An aerial photograph taken after the 1938 hurricane showed the house to be 196.5 m from the cliff edge. In 1948, the house was 167.6 m from the 1-m high "cliff" that separated the till of the cliff from beach sand. By 1951, the cliff had been cut back to within 135 m of the house, and in 1955 further retreat had reduced the distance to the cliff face to less than 100 m. In November 1969 the house was within 76 m of the cliff face, and a tape measurement in July 1972 showed the cliff to be within 56 m of the house foundations. The amount of land lost to the sea at this point from 1938 to 1969 is approximately 28 ha, with 20 ha lost since 1948.

F. Skiff's Island. Located about 2 km SE of Wasque Point (Fig. 1b), Skiff's Island is a transitory feature formed infrequently by shifting sands and currents in the offshore area. Historical records (Shaler, 1888) indicate that it was occasionally used for summer pasturage for sheep. The last appearance of the island was in 1938, at which time it was approximately 2 ha in extent with a maximum relief of 9 m, and supported a solid cover of marram grass (*Ammophila breviligulata*) and marsh grass (*Spartina alterniflora*). The island was nearly bisected in the 1938 hurricane and had disappeared by 1942, and has existed since that time as a shoal exposed only at low tide.

WESTERN OPENINGS OF KATAMA DAY AND EASTWARD MIGRATION OF NORTON POINT

Figure 5 shows the positions of western openings to Katama Bay in 1856, 1886, 1938, and 1955. H. L. Whiting witnessed the formation of one opening and reported his observations in his Appendix to Shaler's report. An excerpt from his record follows:

> The new opening through Cotamy [sic] beach (so called) occurred on the night of January 9–10, 1886. After a gale from the ENE, the wind shifted to WSW, still blowing a gale. The "west beach," as the portion west of the new inlet is now called, was quite low before this gale occured, and after the shift of wind the whole beach, in long-shore phase, was a "breaker." A very high tide, one of the highest in this locality since the Minot gale, accompained this storm. The general opinion is that at the time of the high tide of the bay the opening was first made by the out-going or southerly current. As soon as the beach could be visited for observation the opening was already, by estimate, about one hundred yards in width . . . (Shaler, 1888:362.)

The Vineyard Gazette for 15 January 1886 made the following observation regarding the storm which Prof. Whiting witnessed: "One of the results of Saturday's gale was the breaking through of the South Beach near the entrance to Cotamy Bay, the first effectual opening from the harbor directly to the ocean in twenty years." The report goes on to express enthusiasm for the prospect of improving the shellfish beds and shortening the time for vessels to reach the rich fishing grounds southeast of Wasque Point. Shoreline processes were the same then as now, however, and the opening had migrated around Wasque Point and closed again within 15 yr.

There is a striking correspondence in the location of the western openings, each of them located just a little east of Mattakesett Bay. Each opening then migrates easterly by deposition of sand derived from the coast west of Katama (presumably the whole coast from Squibnocket and Nashaquitsa contributes sand to the predominantly easterly current alongshore).

As the opening moves to the Chappaquiddick shore, the sand source for the erosion of the eastern chop of the opening becomes Wasque Point. Over a period of several years (5–7 by observation), the western chop extends around Wasque Point, eventually sealing the outlet to Katama Bay, as at present. During those periods when the barrier beach of Norton Point wraps around Wasque Point, the cliff face is protected and does not retreat as rapidly as when the full force of sea waves dashes against the foot of the cliffs. According to Kaye (1973), little erosion occurs while the toe of the cliff is protected by a sandy foreshore. When this cliff face is exposed, however, losses in excess of 30 cm/day are common.

The growth of the western chop (viz., Norton Point) is due to the excess sand supply moving along the shore. As the point extends around Wasque, the channel leading from Katama Bay southward and eastward becomes attenuated so that it is not longer competent to flush the sand away from the cliffs. When this happens, overshoot of sand from Norton Point seals off the opening and the extended narrow arm of Katama Bay gradually fills in and makes a broad sandy foreshore with coarse sand of remarkably uniform grain size.

Elongation of the channel leading seaward from Katama Bay by the easterly migration of Norton Point causes the tides in Katama Bay to peak at ebb or flood out of phase with the ocean tides. In addition, because the opening of Katama Bay to the north through Edgartown Harbor is long (approx 5.5 km), tidal flushing of Katama Bay becomes weak, to the detriment of profitable shellfish beds in the lower part of the Bay. Periodically, when the eastern opening is closed, and before a new western opening develops naturally, there have been attempts to induce tidal flow by artificial openings. In 1871, General G. K. Warren (Whiting, in Shaler, 1887) cut an opening, which survived only briefly, and was closed prior to migration to the Chappaquiddick shore. The opening in 1886, recounted by Whiting (see above), occurred in very nearly the same place as the opening attempted by General Warren. Since that time, other artificial openings have been made, with equally impermanent results.

The eastern opening of Katama Bay has been closed at least since November 1969, as shown on aerial photographs. Since that time, the outer beach of Norton Point has been driven back against the Wasque shore, gradually filling the pond that formed the eastward arm of Katama Bay.

HURRICANES AND WESTERN OPENINGS INTO KATAMA BAY

There is a clear association between heavy storms and the cutting through of the barrier beach of Norton Point to create western openings into the Bay. The opening of 1886 is documented by Whiting (see above), and the opening in 1938 was caused by a hurricane which caused great damage to many parts of Martha's Vineyard. In the fall of 1954 a succession of major hurricanes swept Martha's Vineyard, producing widespread destruction and loss of both ships and property. The two most violent of these storms (Carol and Edna) were instrumental in effecting the most recent western opening into Katama Bay, as well as creating an opening into Pocha Pond on the NE side of Wasque Point.

Hurricane Edna struck on Tuesday, 31 August 1954, producing widespread flooding in many parts of the Island. Sand dunes, which had grown to a height of more than 6 m along much of South Beach including Norton Point were destroyed, leaving a broad narrow lowland, vulnerable to breaching by storm tides. The author had the unique opportunity of witnessing the breakthrough of the beach during the late afternoon of 31 August 1954. As noted by Whiting for the opening of 1886, the whole beach was "a breaker" with driving onshore winds from the ESE. The crest of the storm tide had passed, and the tide on the ocean side of Norton Point was falling. Flood conditions still prevailed in Katama Bay, however, with the waters of Herring Brook under the bridge near Mattakesett Bay within 30 cm of the road surface. Visibility was sufficient to see that about 1000 m down Norton Point, seas were dashing over the crest of the divide between Katama Bay and the ocean. The waves were not washing into Katama Bay, but were dissipating into the sand well downslope on the Katama side of the beach. Rough estimates of elevation differences at this time record that the height of Katama Bay waters was at least 1.5 m below the crest of the beach divide, and the "average" water level on the ocean side was at least 3 m below the divide. At this time, the beach was about 150–250 m wide. On walking down the Katama side of the beach to observe the action of the waves (field notes indicate no anticipation of a breakthrough at this time), I observed a small "fault cliff" in the sand as I approached the area where the waves were washing furthest toward Katama Bay. A wave had just passed, almost reaching Katama Bay water, and I stepped out onto the "drop block" of sand, a vertical scarp less than 10 cm high extended more than 30 m transversely across the beach. Field notes record a distinct sense of fright as I sank in "quick" sand up to my knees. Recovering solid ground, I stayed near the "cliff" edge and watched as successive waves struck further toward Katama Bay, widening and deepening the "graben" I had originally observed. Within 30 min, a steady succession of waves approached, reached, and extended into Katama Bay. As each wave receded, the level of the beach fell more, until within 1 hr of my arrival at the scene, it became apparent that a new opening was in the making, as waters of Katama Bay were following the recedence of waves from the Atlantic side of the beach. At this point, losing track of both time and the responsibility to keep accurate notes, I observed the waters of Katama Bay follow retreating ocean waves, and effect a complete breach of the beach. A stream, at first no more than 2–4 m wide and not more than 30 cm deep flowed seaward from Katama Bay, but rapidly widened and deepened to produce a sand cliff near where I stood, 2–3 m high and a channel at least 50 m across. As water began to pour seaward from Katama Bay, the effect on the ocean side of the beach was spectacular, to say the least. Where the receding waters of Katama Bay met the storm waves on the ocean side, a maelstrom resulted, with spray being thrown high into the air both alongshore and offshore of the new opening.

Within 2 hr of the first breach of the beach by ocean waves, the new opening was almost 300 m wide, and water was boiling seaward from Katama Bay. The following morning, under clear skies and bright sun, the opening looked as if it had always been there, and the tide was flowing quietly into the Bay from the ocean.

Figure 4 clearly indicates the rate of eastward migration of Norton Point. The

TABLE 1
HISTORICAL RECORD OF OPENINGS INTO KATAMA BAY

Date	Source	W. opening	E. opening	Remarks
1724	Southack (1694 survey)	—	X	Scale makes reliability doubtful
1776	Des Barres map		X	Plane table survey
1795	Benj. Smith, Edgartown town survey	—	X	Shown at extreme E. tip of Wasque
1830	H. Grape, Edgartown town survey	—	X	Shown E. of 1846 opening near Wasque shore
1846	H. L. Whiting, USCGS	—	X	
1856	H. L. Whiting, USCGS	X	X	
1860	Unid. hydrographic chart	X	X	Chart fragment in files Dukes Co. Historical Society
1871	H. L. Whiting, USCGS	—	—	No opening
1873	Dredged eastern opening			Not successful closed before completion
1886	H. L. Whiting, USCGS	X	—	
1887	USGS 15′ topographic	X	X	
1892	Geo. W. Eldridge	X	X	No sources, souvenir map
1897	USACE Edgartown report		X	
1901	Chart no. 45 Edgartown Harbor, Geo. W. Eldridge		X	Gives soundings at M.L.W.
1915	USACE Edgartown report	—	—	No opening
1917	USCGS Chart no. 46 Edgartown Harbor	—	X	
1919	USACE report	—	—	Opening attempted
1921	USACE report	X	—	Dug opening, successful
1924	USACE report	—	X	Migrated to Chappaquiddick shore
1934	USACE report	—	—	No opening
1938	Air photo GSF5-176/178	X	X	Flown Nov. 1938 following hurricane
1942	USGS 15′ topographic map	—	X	Near Wasque shore
1944	Air photo USCGS C-2340	—	X	
1948	Air photo USCGS J-965	—	X	Near Wasque shore
1951	Air photo USCGS J-4714/4730	—	X	
1955	Air photo USGS W-5069/5070	X	—	Also shows opening into Pocha Pond
1958	USCGS chart no. 346	X	—	
1963	USCGS chart no. 261	—	X	
1969	Air photo USGS VCIQ 1-27/29	—	—	
1970	Air photo USDA DPO-111-10/11	—	—	
1972	Field observation (J.G.O. 111)	—	—	
1974	Field observation (J.G.O. III)	—	—	

western tip of the opening (Norton Point proper) moved nearly 2 km eastward in the period 1938–1954, an average rate of approximately 107 m/yr. Rate of migration of the point, and eventual closure of the eastern opening is similar for the 1954 opening in both distance and duration.

Table 1 lists available dates, sources, and seaward openings of Katama Bay. Whiting's 1871 survey indicated that there was no opening of the Bay, although in the fall of that year, General G. K. Warren attempted to create an opening near the site of the previous (1856) opening, and very close to the site of the subsequent (1886) opening.

The data of Figs. 3 and 4, together with the sketchy information available from Table 1, indicate that following a western opening near the mouth of Mattakesett Bay, the point migrates easterly around Wasque Point within 10–15 yr, and results in closing the southern end of Katama Bay. Within a few years (5–10 from the existing records), a new western opening is effected during a severe storm with unusually high tides.

SEA LEVEL RISE AND SHORELINE EROSION AT WASQUE POINT

While storms and prevailing longshore currents are undoubtedly competent to effect the changes outlined in the previous portions of this paper, some attention should be focused on the effect of sea level trends, and their possible role in exacerbating coastal management problems.

Hicks and Crosby (1974) indicate that for periods of record ranging from 16 to 50 yr, there has been an average rise in sea level of 2.6 mm yr^{-1}, based on tide gauge records at five stations from Portmouth, NH, to Newport, RI. Standard errors of the trends reported by Hicks and Crosby (1974) are about $\pm 10\%$ of the reported values. Similarly, Meade and Emery (1971) define a mean annual rise of sea level of .25 cm yr^{-1} for the Gulf of Maine, .35 cm yr^{-1} for the coastal section from Cape Cod to Cape Hatteras, .26 cm yr^{-1} from Cape Hatteras to Key West, and .18 cm yr^{-1} for the Gulf of Mexico. Since river runoff into the coastal zone accounts for only 7% of the annual difference in sea level in the two northern coastal sections, and 13 and 21% in the southern and Gulf of Mexico sections, respectively, these authors conclude that melting glaciers and coastal adjustments associated with isostatic rebound or sediment loading on the continental shelf are dominant mechanisms in sea level variation.

Walcott (1972a, 1972b) shows values of coastal subsidence of 3 mm yr^{-1} for the Cape Code region. Approximately 50% of this value is attributed to an eustatic rise in sea level, the remainder to isostatic deleveling, at least partly in response to increased crustal loading on the continental shelf. These conclusions are in agreement with evidence presented by Grant (1970) who accounts for most, if not all, of the recent crustal subsidence in the Maritime Provinces of Canada by increased crustal loading of water and sediments on the continental shelf.

These views are in conflict with Kaye (1964b) and Kaye and Barghoorn (1964) who demonstrate the stability of barnacle growth limits on coastal rocks and lighthouses by comparing modern and historical photographs during the past century. Additional evidence, based on tide gauge variability, and autocompaction of peat in coastal environments lead Kaye and Barghoorn to infer that sea level has fluctuated within 45 cm of the present sea level for the past 200 yr, a conclusion generally supported by Bloom (1967).

Two relevant radiocarbon dates from Martha's Vineyard also imply a continuing rise in sea level. K. M. Jones (personal communication) recovered a pine stump whose root crown was just exposed at extreme low tide in April 1967 about 6 km west of Katama Bay. A sample from this stump gave an age of 590 ± 90 yr BP (Gx 1-1078). The tree was rooted in gravel, and *in situ*, as pieces of intact bark and clumps of gravel were recovered with a stump. Based on the levels of living and dying pines in coastal environments in other parts of Martha's Vineyard, it is probable that the tree was killed when sea level was approximately 2 m below its present level. In low-lying coastal environments on Martha's Vineyard, such as characterizes the area around this sample, pine trees are not found less than 1.5–2.0 m above mean sea level, and some distance inland (100–300 m).

Similarly, on the northwest coast of Martha's Vineyard, a red maple (*Acer rubrum*) stump was recovered in 1.2 m of water (below M.H.T.) which dated 370 ± 105 yr BP (OWU-334, Ogden and Hay, 1973). This stump was also rooted in mineral soil, which decreases the probability of deleveling by autocompaction as suggested by Kaye and Barghoorn (1964). There are no coastal red maple swamps at present in the vicinity since this species (*A. rubrum*) is quite intolerant of salt. It is not unreasonable to infer that sea levels were at least 1.5 m lower when this tree died. Since the tree is approximately 20 m offshore at the present time, it is also apparent that the shoreline was many meters to the north of its present position.

While the evidence reviewed above is not conclusive, it does indicate that shorelines in the area of Martha'sVineyard have been unstable for more than the past 500 yr, and that in addition to shoreline erosion, rising sea levels have also played a part in the shaping of the shoreline.

SUMMARY AND CONCLUSIONS

Evidence from old surveys, topographic maps, coastal charts, aerial photographs, and field observations document more than 190 yr of shoreline changes in the vicinity of Wasque Point on the southeastern coast of the island of Martha's Vineyard, Massachusetts (41°25′ N, 70°35′ W).

Comparison of the shoreline mapped by Des Barres (1777) in 1776 with the 1969 shoreline indicates a total shoreline retreat of more than 880 m, an average rate of 4.6 m/yr. Detailed surveys during the period 1846–1881 were made by Whiting (1887) and showed a beach retreat of 125 m in 40 yr, an average rate of 3.1 m/yr. During the period 1951–1969, portions of the shoreline showed a consistent retreat ranging from 2.5 m to 4.7 m/yr.

Cliff retreat at Wasque Point is documented from aerial photographs and field observations and shows a total loss of more than 213 m in the period 1948–1969. The average rate of 10 m/yr for this 21-yr period must rank as one of the most vigorous rates of coastal erosion anywhere the sea is attacking a headland of more than 10 m elevation.

Vigorous longshore currents (up to 1.2 mps) have a predominantly easterly set and are competent to remove the sand to the much more vigorous Muskeget Channel waters to the east where currents to 2.2 mps are common. The sands are then dispersed into the shoal waters E of Martha's Vineyard. At infrequent intervals, the confluence of the easterly flowing coastal currents and the predominantly north–south currents of Muskeget Channel produce Skiff's Island. The last recorded appearance of this island was in 1938, when it was reported to have been approximately 2 ha in extent and 9 m high. Within historic times it is reported to have developed sufficient beach grass and salt hay to have pastured sheep. The island was subsequently reduced to a tidal shoal by a series of hurricanes that swept this area between 1938 and 1955.

The development of a western opening into Katama Bay from the sea and subsequent eastern migration around the tip of Wasque Point is documented for 1856, 1886, 1938, and 1955. In each case, the western opening occurred in approximately the same portion of Norton Beach, and the rate of closure is approximately the same in each instance. Based on 1955–1969 aerial photographs, the opening averages 150–500 m in width and requires 10–15 yr to move 3.5 km to close around the promontory of Wasque Point.

There has been no opening into Katama Bay since 1969, and there can be little doubt, on the basis of past experience, that a new opening will occur within a few years somewhere east of the mouth of Mattakesett Bay.

With the exception of occasional transitory openings made by man in the Ponds along the southern shore of Martha's Vineyard, there have been no major construction works anywhere along this coast which would account for the rapid erosion of the shoreline. In view of the evidence available, it would appear that the principal cause for the consistent erosion of this shore may be explained by continuing rise of sea level and vigorous alongshore currents which effectively keep the sand in suspension until they are dispersed in Nantucket Sound or the adjacent coastal shelf.

From the evidence presented, there can be little doubt that additional breaches of the beach will occur in future, and available data indicates that these openings will occur near the western side of Katama Bay, following a major storm coinciding with a high tide. Because the failure of the beach is by sapping, rather than overshoot of storm waves, it seems unlikely that a proposed 3-m high berm parallel to the beaach, as recommended by the U.S. Army Corps of Engineers (USACE, 1969), can successfully prevent the establishment of western openings with Katama Bay.

ACKNOWLEDGMENTS

Without implying any responsibility for the conclusions reported in this study, I wish to acknowledge with sincere thanks the critical and constructive comments of the following individuals who reviewed drafts of this manuscript: K. O. Emery, J. L. Forsyth, J. R. Hails, C. A. Kaye, V. K. Prest, and R. I. Walcott.

REFERENCES

BANKS, C. E. (1911). "The History of Martha's Vineyard, Massachusetts." Vol. 1, General History. Dean Co., Boston, Mass.

BLOOM, A. L. (1967). Pleistocene shorelines: A new test of isostasy. *Geological Society of America Bulletin* **78**, 1477–1494.

DES BARRES, J. F. W. (1774–1781). "Part of Martha's Vineyard and Nantucket Islands and Buzzard Bay, the Elizabeth Islands, Vineyard Sound." *In* "The Atlantic Neptune." London, publ. for the British Navy.

GRANT, D. R. (1970). Recent coastal submergence of the Maritime Provinces, Canada. *Canadian Journal of Earth Science* **7**, 675–689.

KAYE, C. A. (1964a). Outlines of the Pleistocene Geology of Martha's Vineyard, Massachusetts. *U.S. Geological Survey Professional Paper* **501**—C, C139.

——— (1964b). The upper limit of barnacles as an index of sea level change on the New England coast during the past 100 years. *Journal of Geology* **72**, 580–600.

——— (1973). Map showing changes in shoreline of Martha's Vineyard, Massachusetts, during the past 200 years. U.S. Geologic Survey, Miscellaneous Field Studies, Map MF-534.

KAYE, C. A. AND BARGHOORN, E. S. (1964). Late quaternary sealevel change and crustal rise at Boston, Massachusetts, with notes on the autocompaction of peat. *Geological Society of America Bulletin* **75**, 63–80.

OGDEN, J. G. III, AND HAY, R. J. (1973). Ohio Wesleyan University natural radiocarbon measurements V. *Radiocarbon* **15**, 350–366.

SHALER, N. S. (1888). "Geology of Martha's Vineyard." VIIth Annual Report U.S. Geologic Survey, p. 297–363.

USACE, (1969). Edgartown Harbor, Massachusettts Survey Review of Reports, U.S. Army Corps of Engineers, New England Division, Waltham, Mass.

WALCOTT, R. I .(1972). Past sea levels, eustasy, and deformation of the Earth. *Quaternary Research* **2**, 1–14.

——— (1972b). Late quaternary vertical movement in eastern North America: Quantitative evidence of glacial-isostatic rebound. *Reviews of Geophysics and Space Physics* **10**, 849–884.

WHITING, H. L. (1872). "Shoreline retreat at Cotamy Bay." VIIth Ann. Report, Harbor Commissioners, Boston, pp. 106–111.

——— (1887). Recent coastal changes at Martha's Vineyard, Massachusetts. Appendix 9, U.S. Coast and Geodetic Survey. Annual Report.

WOODWORTH, J. B. AND WIGGLESWORTH, E. (1934). "Geography and Geology of the region including Cape Cod, the Elizabeth Islands, Nantucket, Martha's Vineyard, and Block Island." Museum of Comparative Zoology, Harvard, Cambridge, Mass.