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RECENT EVOLUTION OF AN ACTIVE BARRIER BEACH COMPLEX: POPPONESSET BEACH, CAPE COD, MASSACHUSETTS

by

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TECHNICAL REPORT

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Approved for Distribution: ______________________
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SUMMARY

1. Popponesset Spit and beach features near the mouth of Cotuit Bay have experienced active changes over the past two centuries. These changes have included growth and attrition of Popponesset Spit as well as its landward migration, loss of a small island near Cotuit Bay and opening and closing of breachways.

2. The length of Popponesset Spit has changed nearly 1.5 km (0.93 miles) during the past century, including; a) a growth phase from about 1850 to 1954, and, b) an attrition phase following 1954.

3. While neither growth nor attrition appear to have resulted from human activities, the exact causes remain conjectural. Growth of the spit appears to have been closely associated with lengthening of the inlet, by means of a process by which material removed from the inlet became deposited on the end of the spit. Attrition (which affected the N.E. limb only) appears to be associated with a process of landward sand movement following the breach event in 1954, eliminating most of the barrier beach and the inlet channel immediately behind it.

4. The S.W. limb, Popponesset Spit as it exists at present, has not experienced appreciable net change in length since 1954.

5. Landward migration of Popponesset Spit has amounted to about 55 to 140 meters (60 to 153 yards) since 1938 (1.3 to 3.5 m/yr or 4.3 to 11.5 ft/yr) accompanied by a slight counterclockwise rotation of its orientation. The migration includes a long term trend as well as conspicuous displacements associated with major storms.

6. Despite this migration, the average width of Popponesset Spit has not changed dramatically, judging from historical maps and photos.

7. Breaches in the spit over the past 200 years have occurred principally near Popponesset Island, Little Thatch Island and west of Big Thatch Island. Since 1961 overwash events have occurred at these sites but stable inlets have not resulted.

8. Because of dredging in the bay and landward migration of the beach, the Popponesset Island site appears increasingly prone to breaching. A breach at this site may become a permanent inlet and result in numerous management consequences.

9. Longshore drift could not be estimated accurately, but appears from more than one line of evidence to be less than previous studies imply. Cliff retreat S.W. of Popponesset, which is too small to resolve with the methods used in this study, is therefore less than about 0.23 m/yr (0.75 ft/yr). This could supply a maximum of about 3,000 m^3/yr (4,000 cubic yards) to the beach, of which an unknown portion would be delivered to Popponesset Spit. The actual amount could also be much less.

10. The direction of net littoral drift as suggested by several geomorphological indicators probably involves convergence toward the mouth of Cotuit Bay. Seasonal variations in longshore transport direction are evident.

11. Dredging in Popponesset Bay and the Cotuit Bay-North Bay-West Bay complex since 1916 has involved an estimated 650,000 m^3 (850,000 cubic yards). At least 60,000 m^3 (78,000 cubic yards) was placed on Dead Neck (Barnstable) and an unknown portion of 107,000 m^3 (140,000 cubic yards) was placed on Popponesset Spit. Thus, dredging may play a significant role in the sand budget of the study area.

12. The quantitative role of the sand wave field offshore from Popponesset Spit in terms of interactions with the spit and longshore transport of sand could not be assessed from historical maps and photos and remains a topic for ongoing studies.

13. Groin fields do not appear to have a large effect on beach dynamics over the study area although their small scale effects may be conspicuous locally.

MANAGEMENT IMPLICATIONS

1. Based on historical trends, Popponesset Spit is not likely to experience dramatic attrition, either in length or width, in the immediate future. Portions of the beach most susceptible to attrition are those portions lying adjacent to deep channels, of which most have already been lost.

2. There is no reason to suspect landward migration of the spit to end in the immediate future, although the rate may decrease as the spit moves into the mouth of the bay. This process will cause continuing loss of shellfish beds in Popponesset Bay and further reduce the size of the Bay.

3. Overtopping of the spit by storm waves will probably continue to occur in the near future. The recently completed beachgrass enhansement project may temporarily diminish the frequency of overwash.

4. The site most subject to breaching is that near Popponesset Island where dredging in the bay brings navigation channels close behind the beach, and where thinning of the barrier beach is already evident. Once opened, an inlet here could become permanent and may result in closing of the present entrance near Meadow Point.

5. A permanent inlet near Popponesset Island may have certain advantages (e.g., for navigation) but would result in new management problems for adjacent property owners on Popponesset Island, including exposure of the shoreline to erosion and storm damage. It would also change the pattern of access by pedestrians to the spit. Aspects of these management questions could be addressed before the event of a breach and a contingency plan formulated.

6. Past management recommendations based on the assumption that strong longshore drift existed here can be reevaluated. If ongoing studies confirm the conclusion that littoral drift is small, projects such as beach nourishment may prove feasible for this area (if permitted by regulations).

7. Future dredging projects on the scale of those in Popponesset Bay 1916, 1935 or 1961 should be carefully planned to take best advantage of channel and spoil placement, both of which can have significant effects on the sand budget here.

INTRODUCTION

The Problem

Popponesset Spit, the barrier beach sheltering Popponesset Bay on Cape Cod, Massachusetts (Figs. 1 and 2), has experienced large changes in its location and shape over the past thirty years (Fig. 3). Concern by the public over loss of this barrier beach and the associated recreational and wildlife resources, as well as its storm-protection function, resulted in a number of studies involving local, state and federal officials. The purpose of these studies was to identify causes and future trends (Benoit and Donahoe, 1979) and to identify engineering solutions to this instability (U.S. Army Corps of Engineers, 1972; Camp, Dresser and McKee, 1981). For various reasons, these studies were incomplete and stated some conclusions which were generally misleading or incorrect. The purpose of the present study was to provide a thorough reexamination of the geological problem at Popponesset Spit, to dispel the misconceptions and to more rigorously document the large-scale changes. The impetus for our concern over the beach was a desire to contribute to an effective, rational management and utilization strategy for this coastal region.

An analysis of historical charts and vertical aerial photographs was combined with a review of the literature and discussions with local residents to assess the modes and rates of beach changes at Popponesset. The perspective provided by this analysis was then evaluated in light of a preliminary synthesis of dominant physical mechanisms which act to modify the beach at this location (winds, waves, tides, and storm surge). Specific tasks which were accomplished by the historical study include:

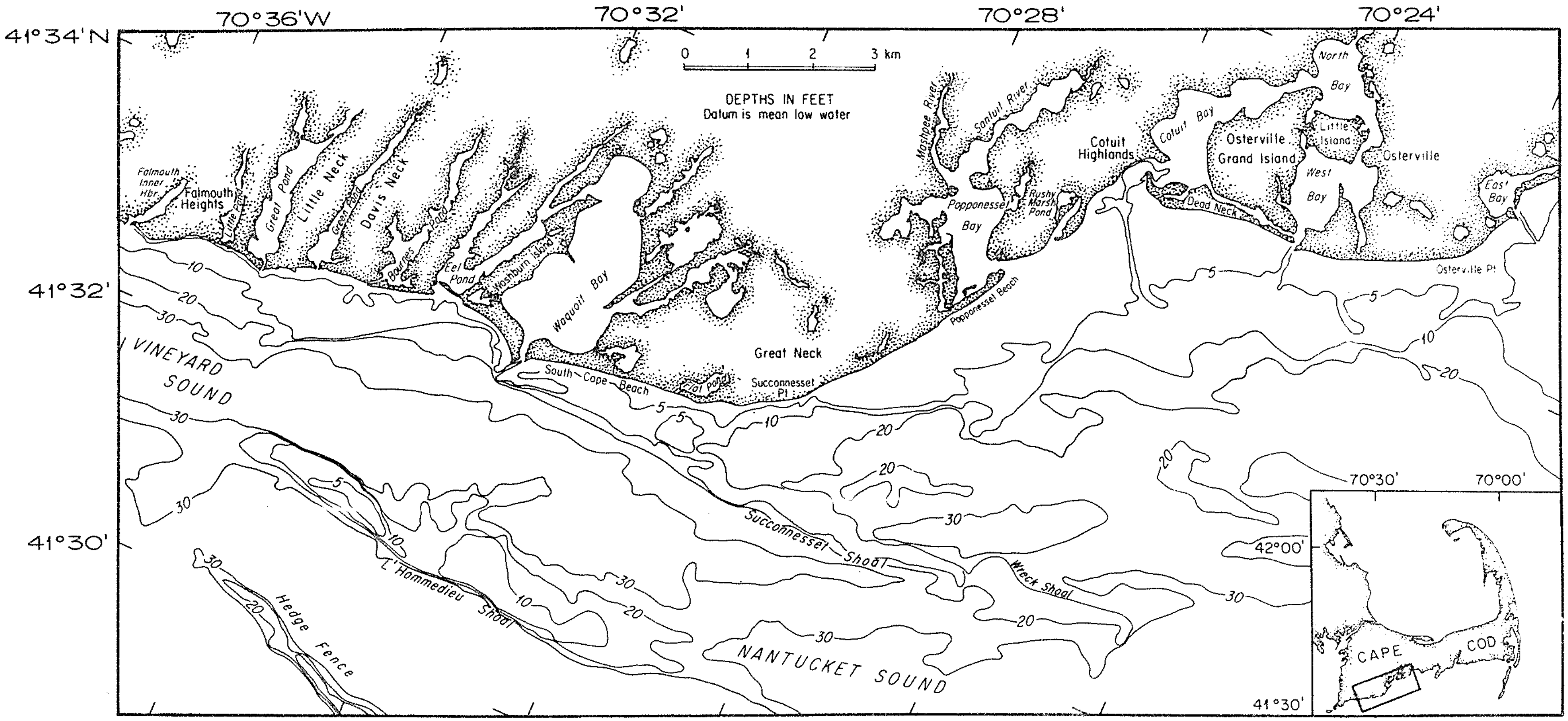

Figure 1. The Popponesset barrier beach setting. Cape Cod, Massachusetts.

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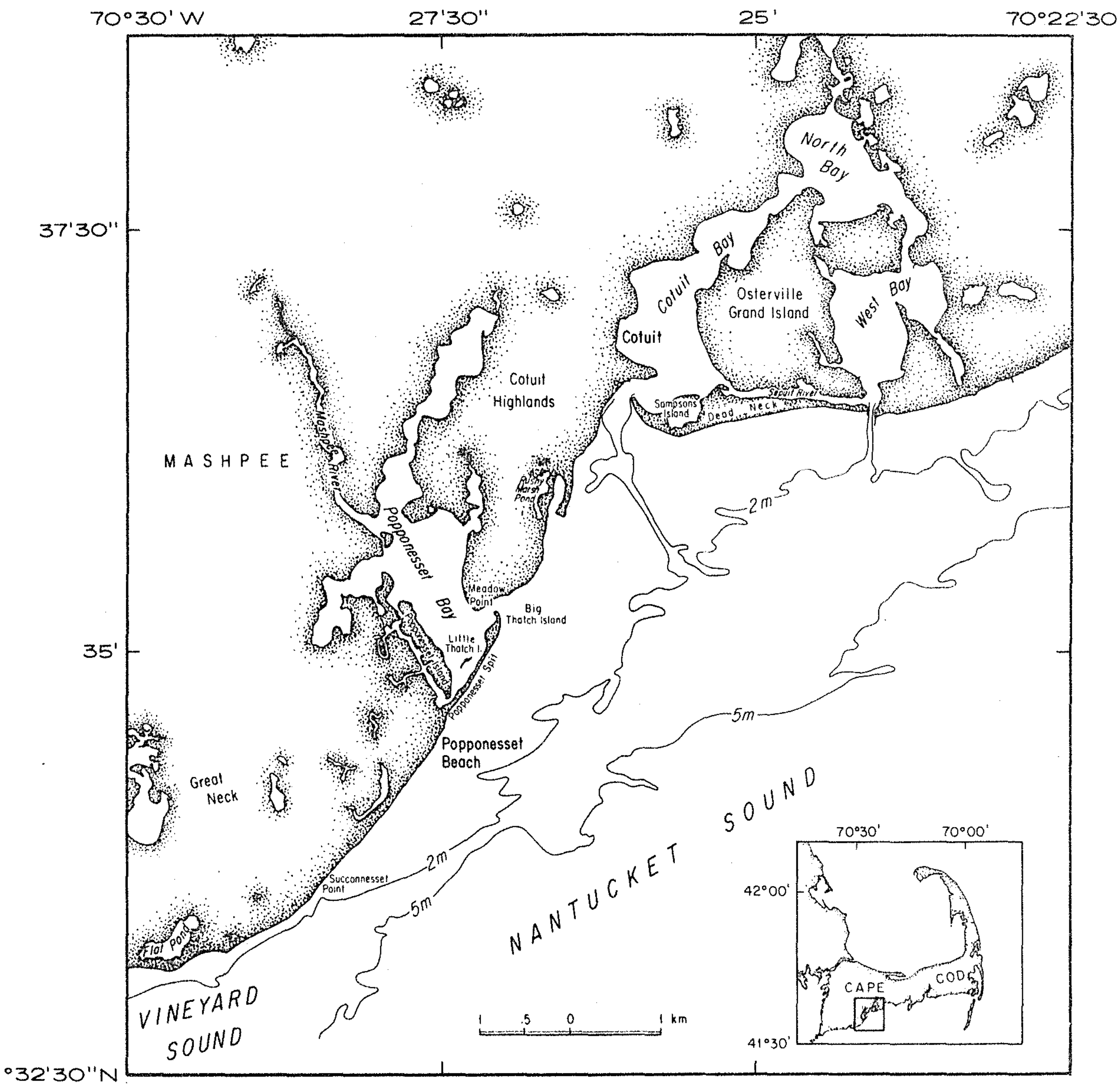

Figure 2. The Popponesset Spit study area, indicating geographical nameplaces.

Figure 3. Net shoreline changes at Popponesset Spit, 1938-1981, based on outlines of vertical aerial photographs (source: see Appendices 2 & 3).

1) Quantification of recent shoreline changes (since 1938) using high quality, vertical aerial photographs.

2) Qualitative assessment of historical shoreline changes extending from 1670 to 1979 using historical charts.

3) Preliminary assessment of the dominant physical mechanisms (waves, winds, tides and storm surge) responsible for sediment transport in the Popponesset region.

4) Delineation of the Popponesset littoral cell (the geographic limits of the region which actively exchanges sediment with the primary study area).

The results of this study provide a number of hypotheses which will be tested through an oceanographic monitoring program within the Popponesset Beach littoral cell. This second phase of the study, to begin in the near future, will consist of a field program designed to monitor the dominant physical forcing at Popponesset and coincidently measure the resultant changes in the beach and nearshore sediments.

Geological and Coastal Setting

The shoreline in the study area extends approximately from Waquoit Bay on the west to Osterville Point on the east. It borders both Vineyard Sound in the west and Nantucket Sound east of Succonnesset Point (figure 1). This general study area encompasses the specific site of interest - Popponesset Spit (figure 2) - as well as the neighboring potential sources and sinks of sediment affecting the spit. In the offshore direction, the study area is bounded by the seaward side of Succonnesset Shoals in water depths of 10 m. These shoals nearly intersect the beach near the Waquoit jetties, and may represent a conduit for sediment transport from the nearshore to deeper water.

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Low sea-cliffs (less than 15 m) composed of poorly consolidated glacial sediment extend from Succonnesset Point to Popponesset Bay, and from Meadow Point to Cotuit Highlands. The rest of the coast is composed of low-lying barrier beaches with variable dune development. There are three major barrier beaches in the overall study area: the Waquoit-Dead Neck barrier beach, Popponesset barrier beach, and the Osterville-Dead Neck barrier beach.

That the geology of Cape Cod is dominated by Pleistocene glaciation has been known for nearly a century. Several popular articles summarize this information (e.g., Chamberlain, 1964; Strahler, 1966) but it should be noted that our understanding of the dynamics of deposition of the sediments by ice in this area is still incomplete (Oldale and O'Hara, in prep.). Most of the sediments in the study area represent outwash material from the Cape Cod Bay glacial lobe, and form part of the Mashpee Pitted Plain Deposits (Oldale, 1976). These sediments are composed primarily of angular-to-subround, gravelly sands forming an outwash fan. The region surrounding Great Neck, however, including its coastal bluffs and Popponesset Island (Fig. 2), is composed of older ice-contact material. This feature appears to be correlative with other scattered ice-contact deposits from Falmouth Heights eastward to Great Hill in Chatham, and may represent a recessional still-stand of the glacier. The sediments in the ice-contact deposits are composed of angular-to-subrounded gravelly sand with scattered boulders (generally coarser than Mashpee Pitted Plain Deposits). As the glaciers receded and sea level rose in response, coastal glacial sediments were reworked to form barrier beaches such as Popponesset Spit, beaches buffering the seacliffs, and other features and bedforms.

The direction of littoral drift around Cape Cod has been surmised from the orientation of prominent barrier spits (e.g., Provincetown hook, Monomoy, Popponesset Spit) by Woodworth & Wigglesworth (1934), Strahler (1966), Brownlow (1979), and others. While large scale generalizations of this kind have usually proven correct, local conditions may result in a contrary behavior. For example, in recent decades littoral drift at Nauset Beach in Wellfleet (Massachusetts) has occurred in the direction opposite to spit growth (Aubrey et al., in prep.). A casual observer would erroneously guess the longshore transportation direction, based on geomorphological evidence alone. The orientation of Bourne Pond inlet, on the south shore of Cape Cod, is another example of this contradiction.

Geomorphology and the Sediment Budget

The present analysis of Popponesset Spit included two related parts. The first involved definition of recognizable coastal geomorphological features and their change over time. Specifically we examined sand spit elongation/attrition; onshore spit migration; barrier beach width; development of breaches; and offshore sand wave migration. Secondly, this and other information was used to outline the framework of a sediment budget for the study area, the elements of which describe the sources and sinks of sand for a beach and its nearshore zone , as well as the pathways and rates of the movement (see Fig. 18). In this regard we considered the role of human activities such as construction of shoreline protection measures and dredging and spoil disposal.

The geographic limits of the region within which sediment exchange is related defines the littoral cell for a particular coastal locality. Beach stability at any point in the cell can be affected by changes in any element of the sand budget elsewhere in the littoral cell, a lesson learned at great expense in past decades through man's attempt to modify or stabilize beaches. For any specific location in the littoral cell, a sediment budget can be formulated. Taken together, the elements of the budget will show whether there is net erosion or accretion over a particular time period. Unfortunately, it is difficult to estimate many of the terms in a sediment budget, directly or indirectly. In this study, therefore, an attempt was made only to place upper and lower limits on these quantities.

Tides and Winds

Sediments in Nantucket and Vineyard Sounds are subject to the forcing of tides and winds. Although the astronomical tide range in the study area is low (mean range is about 0.7 m), the currents associated with them reach up to 0.8 m/sec (Fig. 4). The tidal flow is especially fast through narrow constrictions, such as tidal inlets. The occurrence of large tidal currents in a region of low tidal range results from the complex interference patterns between tidal disturbances propagating through the interconnecting coastal water bodies here (see Redfield, 1980). Although based on few measurements, tidal currents in the study area appear sufficiently strong to move large quantities of unconsolidated sediment and to produce well defined bedforms. As indicated in Figure 4, very few current measurements have been made in the study area.

Winds have three primary effects on sediment motion on beaches and in the shallow nearshore region. The action of strong winds causes the sea surface to re-adjust, producing the familiar wind-driven shelf response and subsequent variation in sea surface elevation from point to point. For strong winds this effect, known as storm surge, can result in a higher than normal sea level

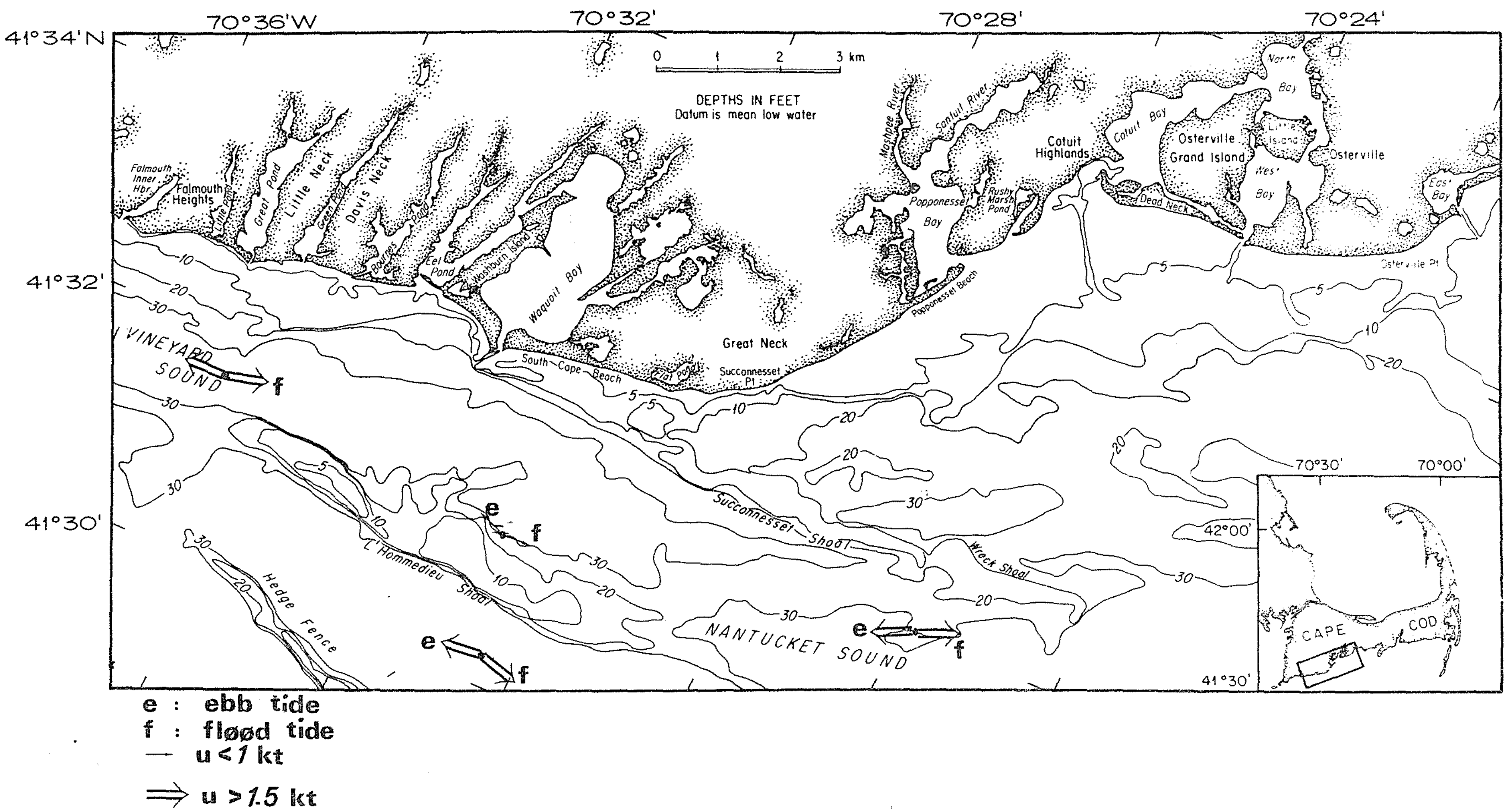

Figure 4. Tidal currents in the Popponesset Spit study area (from Haight, 1938 and Bumpus et al., 1971).

against the coast. Along the south shore of Cape Cod, maximum historical storm surges have reached a height of 3 m above mean sea level in the storms of September 1944 and August, 1954 (Weigel, 1964). The effect of an elevated water level is to bring wave activity to bear on portions of the barrier beach and coastal bluff normally removed from these processes: the result is accelerated erosion and increased incidence of overwash and breaching of barrier beaches.

The second effect of winds is the creation of waves on the ocean surface. These wind waves propagate shoreward and eventually break along the beach. Because of the geometry of Nantucket and Martha's Vineyard, and the intervening shoals, waves coming from south of the islands are mostly blocked and do not propagate into Vineyard or Nantucket Sounds. Consequently, most wave energy impinging on Popponesset Beach is probably locally generated by winds blowing across Nantucket and Vineyard Sounds. Unfortunately, no direct wave measurements showing wave height, period and direction are available for the study area at present. The only available estimates are constructed from wind information, an approach that can give highly variable results, depending upon the specific assumptions and method used. Indirect estimates of wave conditions are not sufficient for accurate predictions of rates of littoral drift.

The third effect of wind, the direct transport of sand by wind on exposed beaches, can account for transport of substantial amounts of material. In this case a wind rose can help in assessing the direct impact of wind on a barrier beach in a particular region. Because of the proximity of several airports, copnsiderable wind data are available for this region.

Management History

It is appropriate to review the background surrounding public and private efforts to preserve or modify this barrier beach because discussion associated with these efforts has influenced popular concepts, polarized public attitudes regarding beach processes here and have affected the management decision-making process. As suggested above, one objective of this report is to address the validity of (and where appropriate to correct) these public perceptions. Some documentation of efforts to preserve or modify the spit resides in files in the Mashpee Town Hall, upon which the following discussion is partly based. Additional information on attitudes and perceptions was obtained from U.S. Army Corps of Engineers (1972), Camp, Dresser and McKee (1981), Benoit and Donahoe (1979) and from a special public meeting we convened for this purpose (see Appendix 6).

Although it is not widely known, navigation channels were dredged in Popponesset Bay in about 1916 and again in 1936 from near the present inlet location toward the north end of Popponesset Island (Fig. 2; see Appendix 4). The earlier dredging project evidently also included an area in the former inlet channel near Rushy Marsh Pond (see Fig. 6 -1916 and Appendix 1). Little justification of or documentation for these projects has been located at either the U.S. Army Corps of Engineers or the Massachusetts Division of Waterways, the agencies which are responsible for permitting dredging projects in Massachussetts. Nevertheless, the dredging indicates interest in management of Popponesset Bay began at an early date, despite the low level of development on this part of Cape Cod.

In later years, public concern for the management of the Popponesset Beach shoreline appears to focus on four events that occurred during the 1950s:

rapid development of waterfront homes adjacent to the beach; construction of the first groins at Popponesset Beach, southwest of Popponesset barrier spit; modifications resulting directly from the 1954 hurricane; and, loss of about half of the barrier spit during subsequent years. As mentioned earlier, the U.S. Army Corps of Engineers (1972), Benoit and Donahoe (1979) and Camp, Dresser and McKee (1981) attribute loss of the barrier spit primarily to downdrift starvation resulting from interruption of littoral drift by the Popponesset Beach groin fields. Others attribute loss of the beach to direct storm damage.

A third large dredging project in Popponesset Bay which occurred in 1961 is better known than earlier ones because of its recency and a highly publicized related controversey (involving alleged irregularities in the dredging and spoil disposal permitting process). The outcome of the 1961 dredging was a navigation channel running the length of Popponesset Creek and then northeastward from its southern end toward Big Thatch Island. Spoils were disposed of on Popponesset Spit near Big Thatch Island and along the shores of Popponesset Island. These and other dredging activities are discussed in more detail elsewhere (see Appendix 4). At our public meeting, the opinion was expressed that loss of Popponesset Spit resulted from this dredging project.

In 1962, Mashpee Selectmen sent a letter to several state and federal agency heads and state and federal representatives regarding the possibility of damage to shellfish beds from destruction or overwash of the barrier beach by storms (Mills, 1962). This letter led to a meeting at the Massachusetts Division of Waterways, involving the U.S. Army Corps of Engineers and the Mashpee Selectmen, to discuss improvements to Popponesset Bay. Evidently, because of potential conflicts between shellfishing and navigation as well as the magnitude of costs involved, the selectmen decided to seek other means of improving the shellfish resource (Hyzer, 1962).

In 1965 a bill was introduced into the State Senate (Senate Bill #165) proposing shoreline protection schemes in the area southwest of Popponesset Spit. Letters from private citizens in support of this bill attest to the belief that the shoreline was rapidly eroding in that area (e.g., MacRae, 1965; O'Neil, 1965) despite the presence of the groins constructed during the previous decade. As discussed later, historical vertical photographs do not support this belief.

During 1965, selectmen and town committees from Mashpee and Barnstable maintained interest in improving the navigation channel connecting Popponesset Bay with Vineyard Sound. Meetings were convened involving residents from both towns to consider alternatives and make recommendations to the U.S. Army Corps of Engineers (Sheehan, 1965; U.S. Army Corps of Engineers, 1965; Lord, 1965). Two alternative proposals emerged, both of which involved large-scale engineering projects, with plans for navigation channels and mooring basins and rip-rapped shorefront facing Nantucket Sound. The ensuing feasibility study of these recommendations and cost-benefit analysis resulted in a report recommending "no action" (U.S. Army Corps of Engineers, 1972). This recommendation was evidently challenged but an appendix considering new information and a smaller scale project reiterated the same conclusion. For the next several years a private group ("The Popponesset Spit Project") coordinated efforts on behalf of the many public and private groups interested in preserving the integrity of the spit (Sloane, 1976) although the specific outcome of these efforts is not clear.

The most recent activities regarding Popponesset Beach management are an outcome of the severe winter "Blizzard of '78" on February 6-8, 1978. Town officials applied for assistance through the Federal Disaster Assistance Administration's Massachusetts Disaster Recovery Team (DRT), created in response to that storm. A Damage Survey Report indicates damage to 46 acres of the spit and loss of 33,000 cubic yards of material to the area behind the beach (Federal Disaster Assistance Administration, 1978). Prolific communications between the town and state agencies led to and followed adoption of the project by DRT, and to a study by the consulting firm of Camp Dresser & McKee (1981) which documents some of these communications. The main purpose of the report was to evaluate the town's proposal to remove 33,000 cubic yards of sediment from the 1961 navigation channel landward of the barrier beach and use it to rebuild the spit to pre-blizzard condition. On the basis of a draft version of this report DRT concluded the proposed project was neither feasible nor legal within the framework of Massachusetts' regulations surrounding use of dredge spoils for beach fill. Instead, a smaller project involving beachgrass planting and fertilization was conducted with the objective of stabilizing the spit. Neither the study leading to this project nor the project itself was regarded as satisfactory by town officials. The failure of the draft report to provide convincing analyses or management recommendations led to continued efforts by the Mashpee Selectmen to solicit professional advice. The study leading to the present report resulted from discussions among the authors and the Selectmen, and was publicly endorsed at a Mashpee Town Financial Meeting.

Popular perceptions of the problem at Popponesset Beach can be summarized as follows: a) Popponesset Beach has been rapidly eroding (shortening) since the mid 1950s; b) the barrier spit was formerly much wider and through attrition over the past few decades has become increasingly more prone to overwash and breaching; and, c) the initial cause of the attrition is a groin field constructed near the southwest end of the spit during the 1950s. In addition, modifications to the spit from nearby dredging and spoil disposal operations have been suspected as accelerating erosion. As discussed below, we now believe all of these generalizations to be either incorrect or misleading.

MATERIALS AND METHODS

Charts and Maps

Approximately 92 charts and maps, dating from 1670 to 1979, were studied to document trends in shoreline changes (Appendix 1; Fig. 5). For our purposes, the charts and maps can be divided into three groups: early maps (1670-1857); U.S. government charts (1857-1938); and maps and charts after 1938. Early maps were generally small scale, reproduced by hand and were often prepared for political or economic purposes rather than for navigation. Some of them do not rigorously represent sand features along the shoreline or other features of interest to this study. For example, the 1795 Lewis map of Massachusetts was evidently copied many times through 1836 (without acknowledgement) for use as a base map for political and economic purposes. This and other early maps do not always accurately record the date of the actual survey or special purposes influencing the accuracy of the mapped features. Therefore, while valuable for perspective, interpretation of these maps required special caution. Maps and charts prepared and printed by government agencies became available in 1857. These are generally based on better defined survey techniques than the earlier ones. Especially useful are the Coastal Survey charts (1860-1920), although irregularities in updating this series mandates careful interpretation. A chart dated 1910, for instance, might actually represent portions of a survey from 1870. An apparently related series of charts by Walker (1892-1915) also provides good perspective regarding shoreline changes at the study area, although both of these series are at a relatively small scale (1:80:000). An especially valuable map produced for the towns (with a

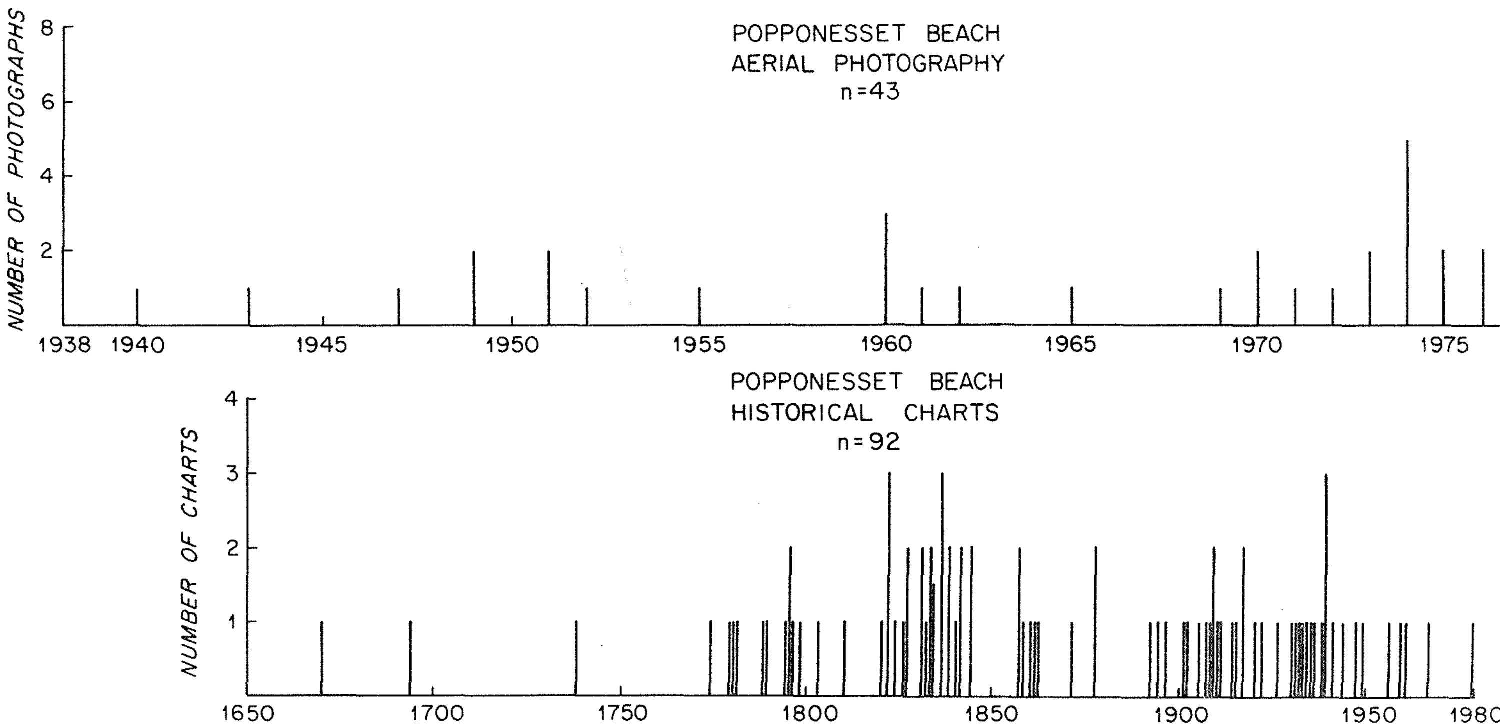

Figure 5. Vertical aerial photographs, charts and maps depicting the Popponesset Spit study area (see also Appendices 1-3).

ca. 1:5000 scale) is the 1894 plan of the Mashpee/Barnstable town line. This map was intended primarily to locate stone monuments defining the town boundary, but also gives detailed bathymetric information behind Popponesset Spit and in the bay. The third category of maps and charts, those prepared after 1938, were less useful to this study than the vertical aerial photographs that became available beginning that year, except for bathymetric information, for which valuable information is also available on recent plans for dredging projects (see Appendix 4).

Vertical Aerial Photography

Aerial photographs (Appendices 2 and 3) are available from 1938 through the present. The distribution of these photographs over time (Fig. 5) provides good coverage of the Popponesset Beach area, with the single exception of the period 1955-1960. In this study, vertical aerial photographs were used to quantify shoreline changes and movement of offshore shoals. The inevitable variability in camera and image quality as well as photograph scale necessarily resulted in some scatter in the results. Measurements were taken relative to a baseline (parallel to Popponesset Spit) established between well defined, permanent features identified on each set of aerial photographs (see Fig. 10). All other measurements were referenced to the known separation between two points on this baseline, yielding a consistent technique for determining scale for all photo sets. Because of the equipment used and the widely diverse scales in the photographs, maximum resolution of coastal features was 10 m, even though some photo sets afforded better resolution. Since some photos did not cover the entire study area, there are some small time gaps in the analysis.

Dredging and Coastal Structures Records

Records of dredging and coastal construction activities were obtained from the U.S. Army Corps of Engineers and the Massachusetts Division of Waterways, which are reponsible for permitting these activities (Appendices 4 and 5). This information was collected in conjunction with the analysis of charts and photos to determine the relationship, if any, between shoreline changes and human activities. These dredging and construction records, though incomplete, form the basis for estimating the importance of man's activities in the Popponesset region.

RESULTS AND DISCUSSION

Coastal Geomorphology

Sand spit elongation / attrition

Key stages in the beach evolution of the Popponesset Spit area are illustrated in Figs. 6-9, to which much of the following discussion refers. By far the most visible of changes in Popponesset Spit over the last thirty years is the change in spit length. As mentioned earlier, the attrition of Popponesset Beach is well known and has been a source of public alarm. Until now, however, it has evidently not been realized that early historical charts show Popponesset Spit approximately the same length as it is now, extending only across the mouth of Popponesset Bay from Great Neck to Meadow Point (about 1.3 kilometers; see Fig. 6 -1789, -1831). The earliest of many charts showing Popponesset Spit at this length in clear detail was the Desbarres chart (1779); charts before 1779 did not have sufficient detail to identify Popponesset Spit with confidence. Popponesset Spit appeared to remain stable in length (with one exception) through 1844. The 1810 chart by Lewis (along with exact copies by Carey in 1822 and Lucas and Fielding in 1826) showed no spit across Popponesset Bay, but these charts are discounted because they show the shoreline only schematically, without details of barrier beaches, while many other maps spanning the same period clearly document the existence of the spit.

The first major change in spit configuration is depicted on an 1857 U.S. Coast and Geodetic Survey (USC&GS) chart and an 1857 chart by Bache which showed the spit elongating towards the northeast (see also Fig. 6 -1860), extending past Meadow Point. Charts and aerial photographs indicate this trend continued through 1954, when the spit extended past Rushy Marsh Pond.

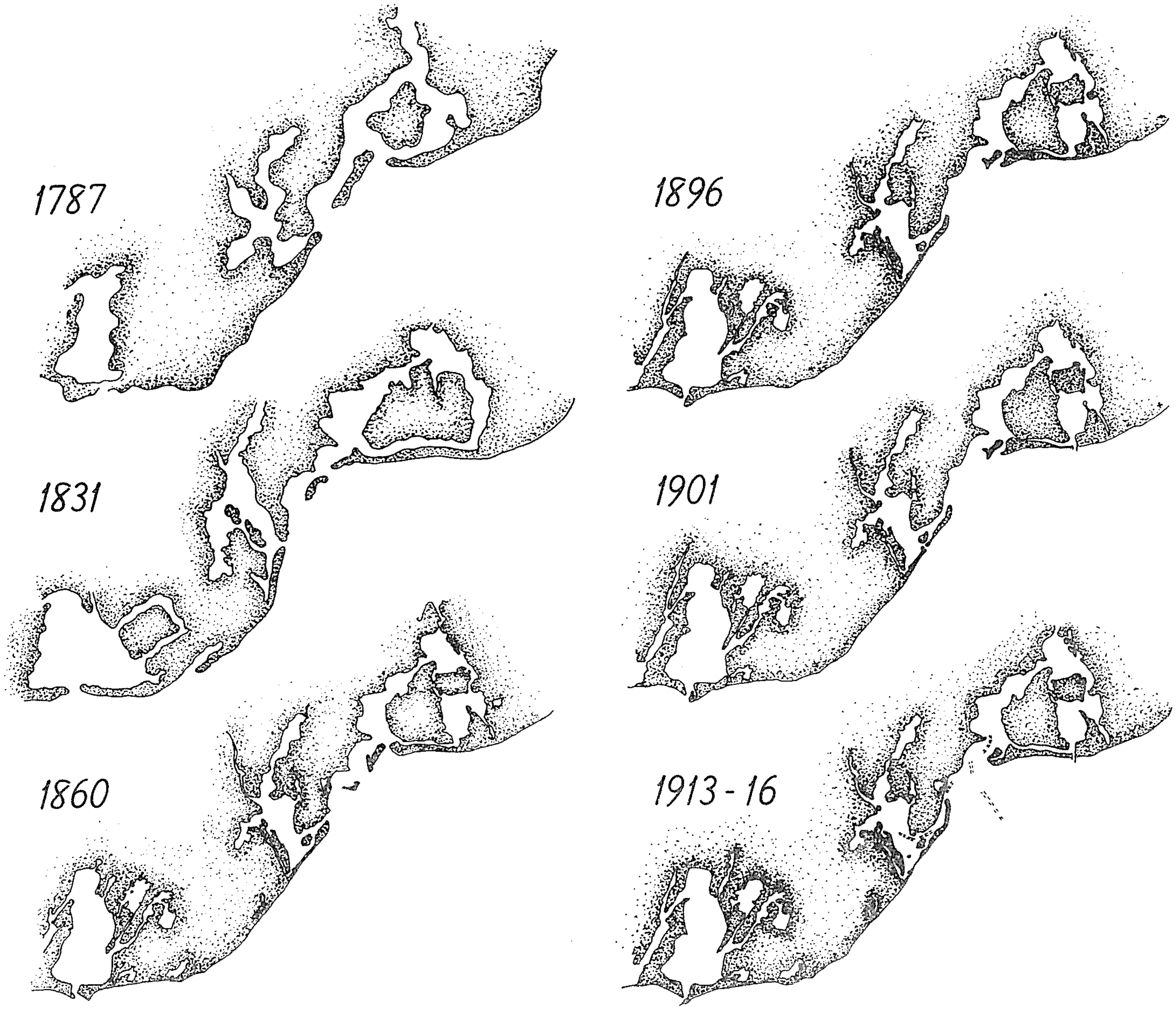

Figure 6. Outlines of selected historical charts and maps illustrating stages of shoreline evolution in the Popponesset Spit study area, 1789-1916 (sources: see Appendix 1).

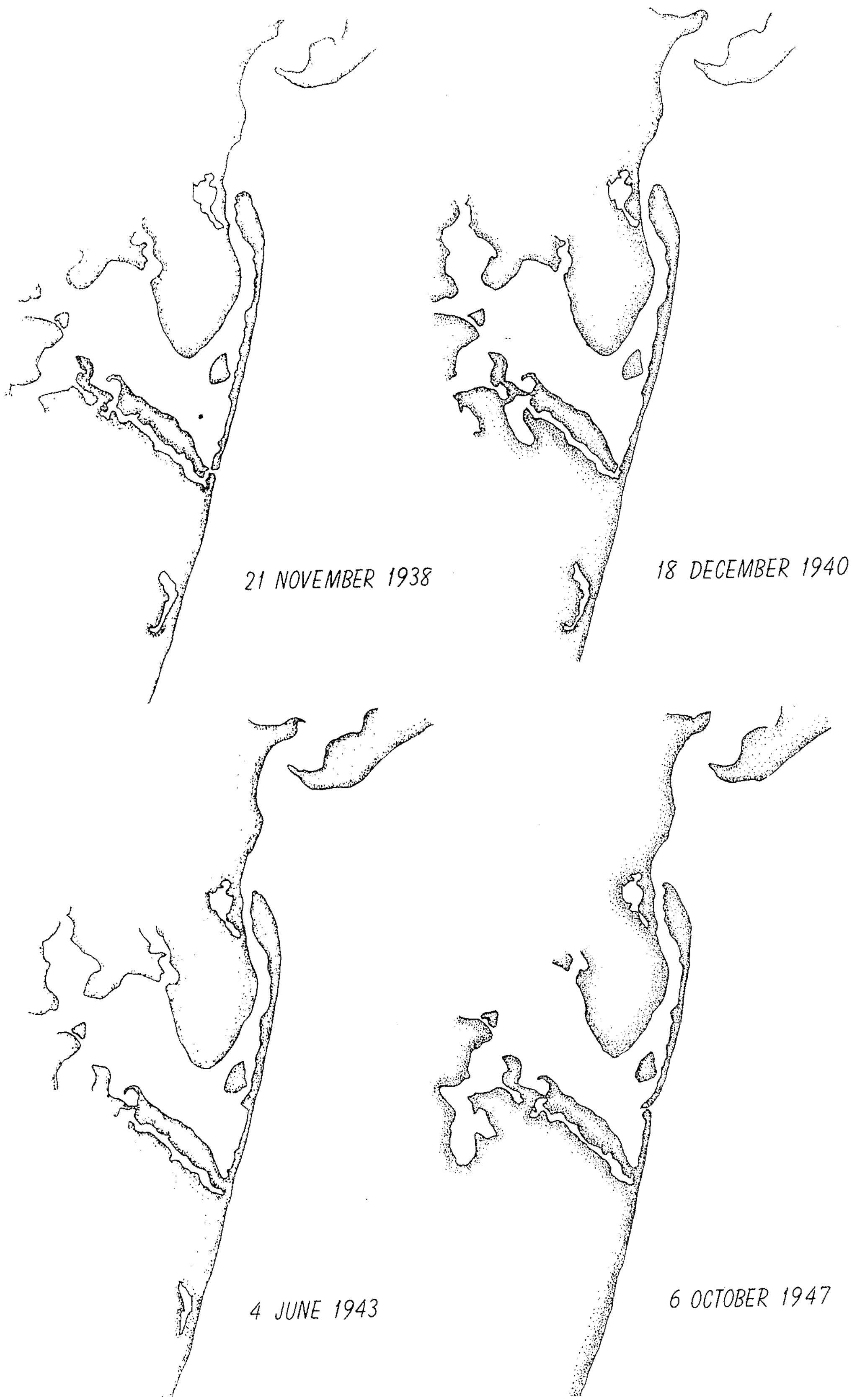

Figure 7. Outlines of selected vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit study area, 1938-1947 (sources: see Appendices 2 & 3).

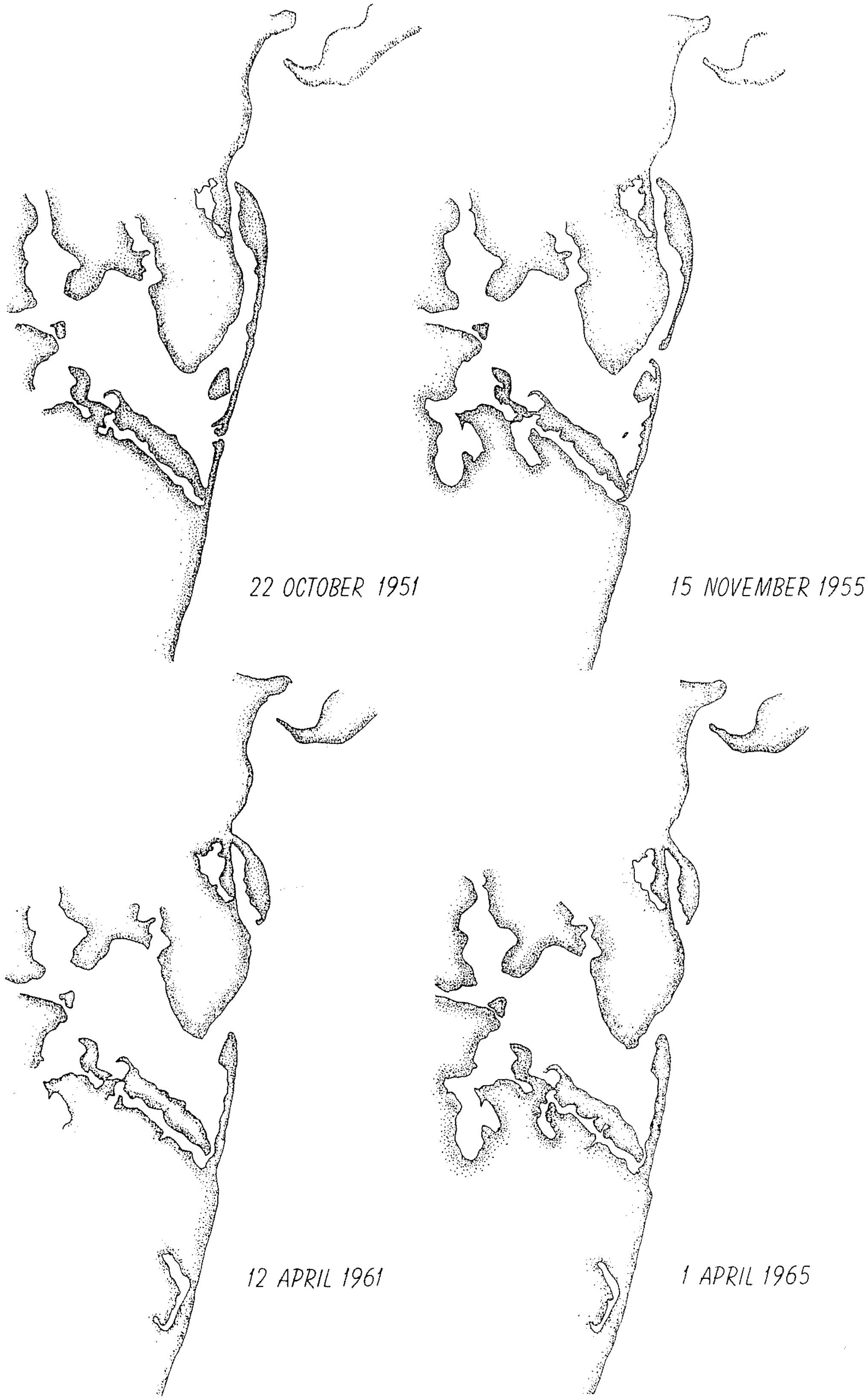

Figure 8. Outlines of selected vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit study area, 1951-1965 (sources: see Appendices 2 & 3).

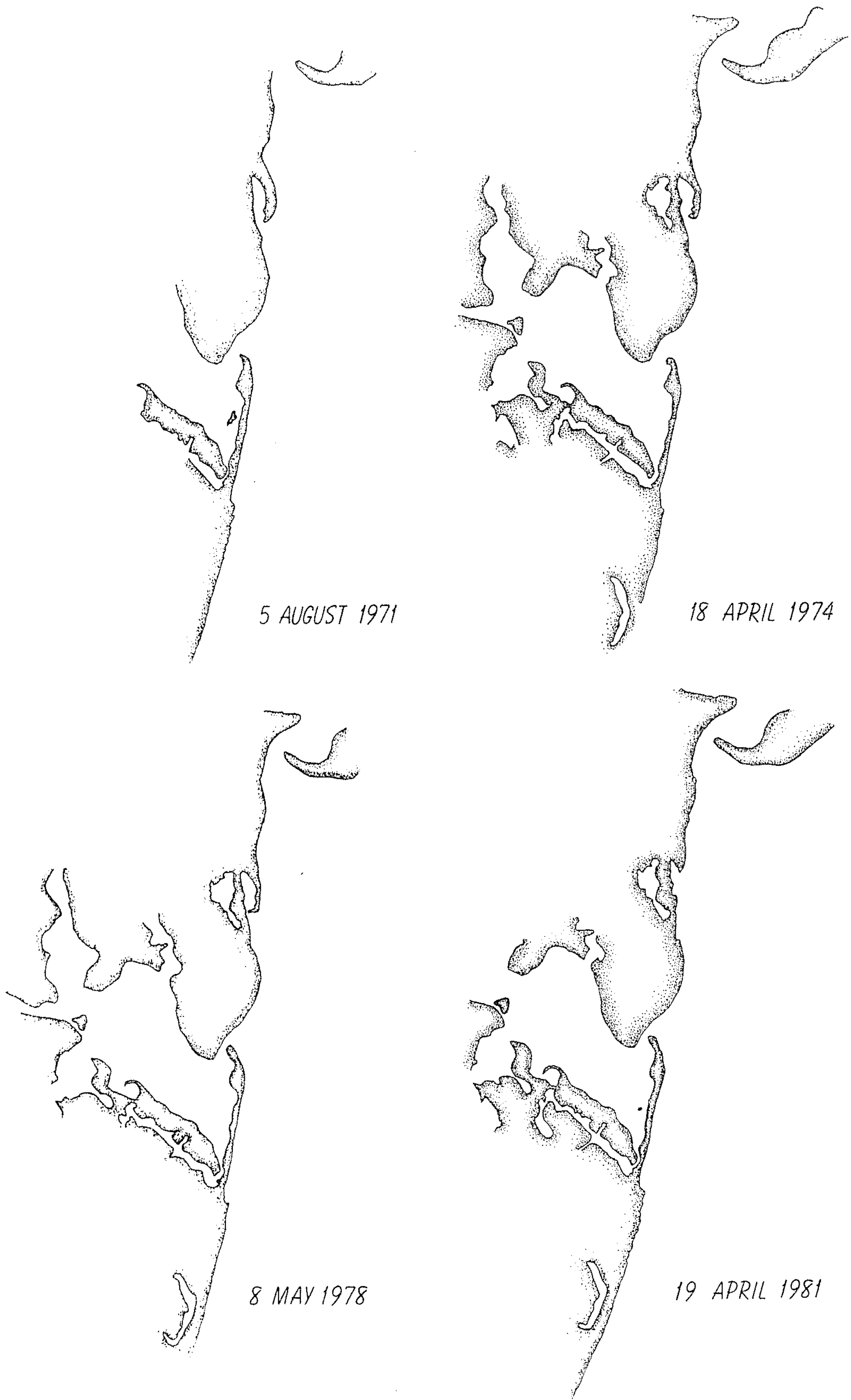

Figure 9. Outlines of selected vertical aerial photographs illustrating stages of shoreline evolution in the Popponesset Spit study area, 1971-1981 (sources: see Appendices 2 & 3).

At its maximum development in 1954, the spit length was approximately 2.8 km long. Early stages of the elongation process are clearly depicted on the Coast and Geodetic Survey series from 1860 through 1917 at a scale of 1:80,000. From 1900 to 1954 the spit grew in a northeasterly direction approximately 1 km (Figs. 7 and 8). Despite the fact that the period of spit development continued to recent years, the early stage of its evolution was neglected by previous studies, and was not mentioned at our public hearing or in discussions with residents of the area. This aspect of the barrier spit evolution is substantially documented by map evidence and opens a new perspective on beach dynamics questions at Popponesset Beach.

In 1954, a series of three hurricanes (Carol, Edna and Hazel) created a breach on the northeast side of Big Thatch Island, effectively separating the barrier spit into two approximately equal limbs; a northeast (N.E.) limb and a southwest (S.W.) limb. The breach occurred near the base of the main inlet channel (Fig. 8, -1955) and provided a very short alternative channel for water exchange between the bay and Nantucket Sound, bypassing the much longer pre-existing inlet channel (nearly 1 km long). The new breachway quickly became the prime conduit for tidal exchange between the two bodies of water. The establishment of this new breachway marked the initiation of the destruction of the N.E. limb of the barrier. Attrition of this part of the beach was rapid at first and slowed over the years (Fig. 11) and is nearly complete at present. The process of attrition primarily involves erosion of sediment from the S.W. end of the beach and its deposition in the former inlet channel behind the beach, which had depths up to 4m (1894 chart, Appendix 1). In 1981, the remnant N.E. limb of the spit still protected a relatively deep body of water, a relict of the former inlet channel (Fig. 9). This process

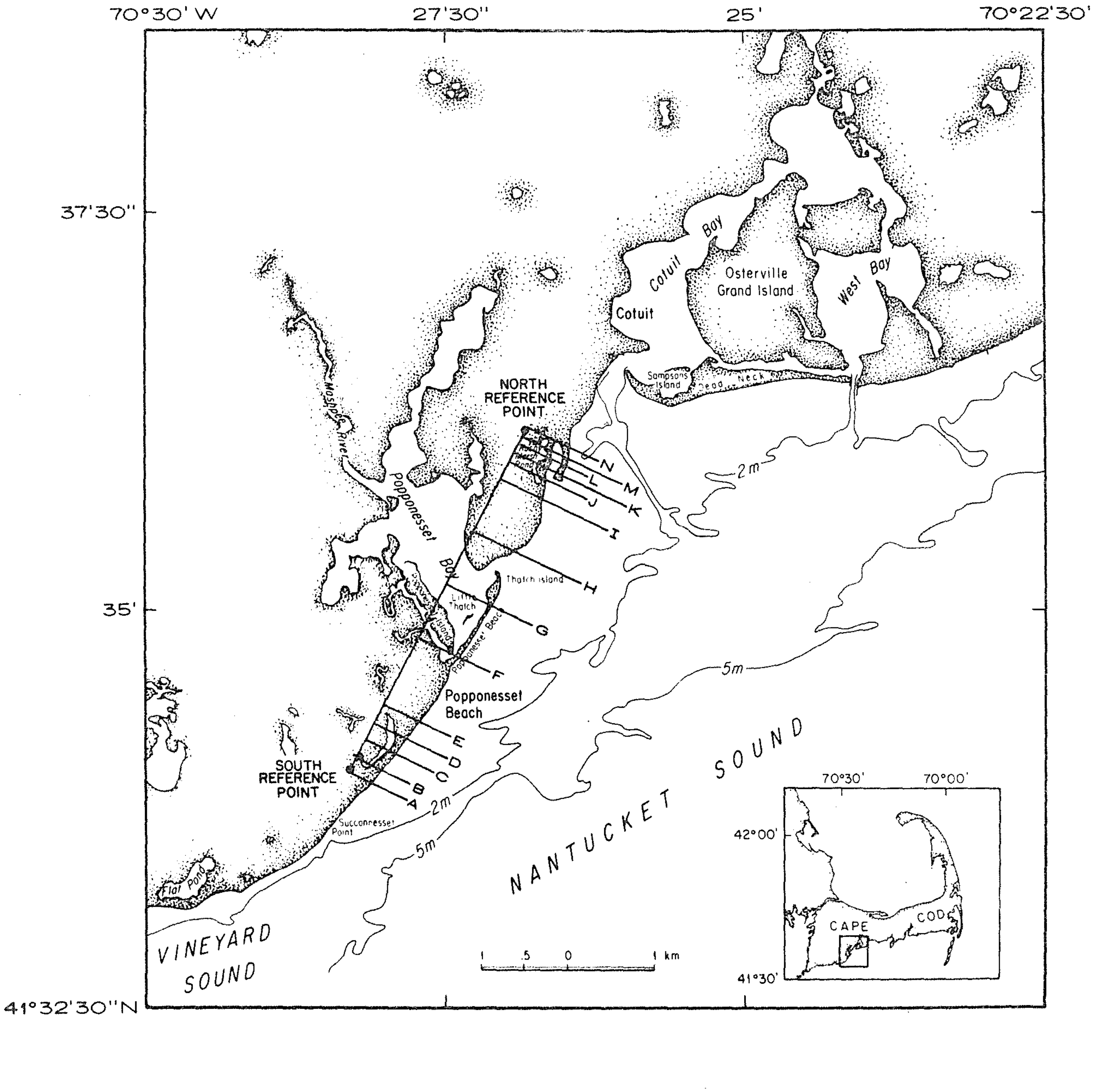

Figure 10. Reference line and perpendicular station lines used for shoreline measurements on vertical aerial photographs for the Popponesset Spit study area. The north and south reference points were well defined points readily visible on all photographs used.

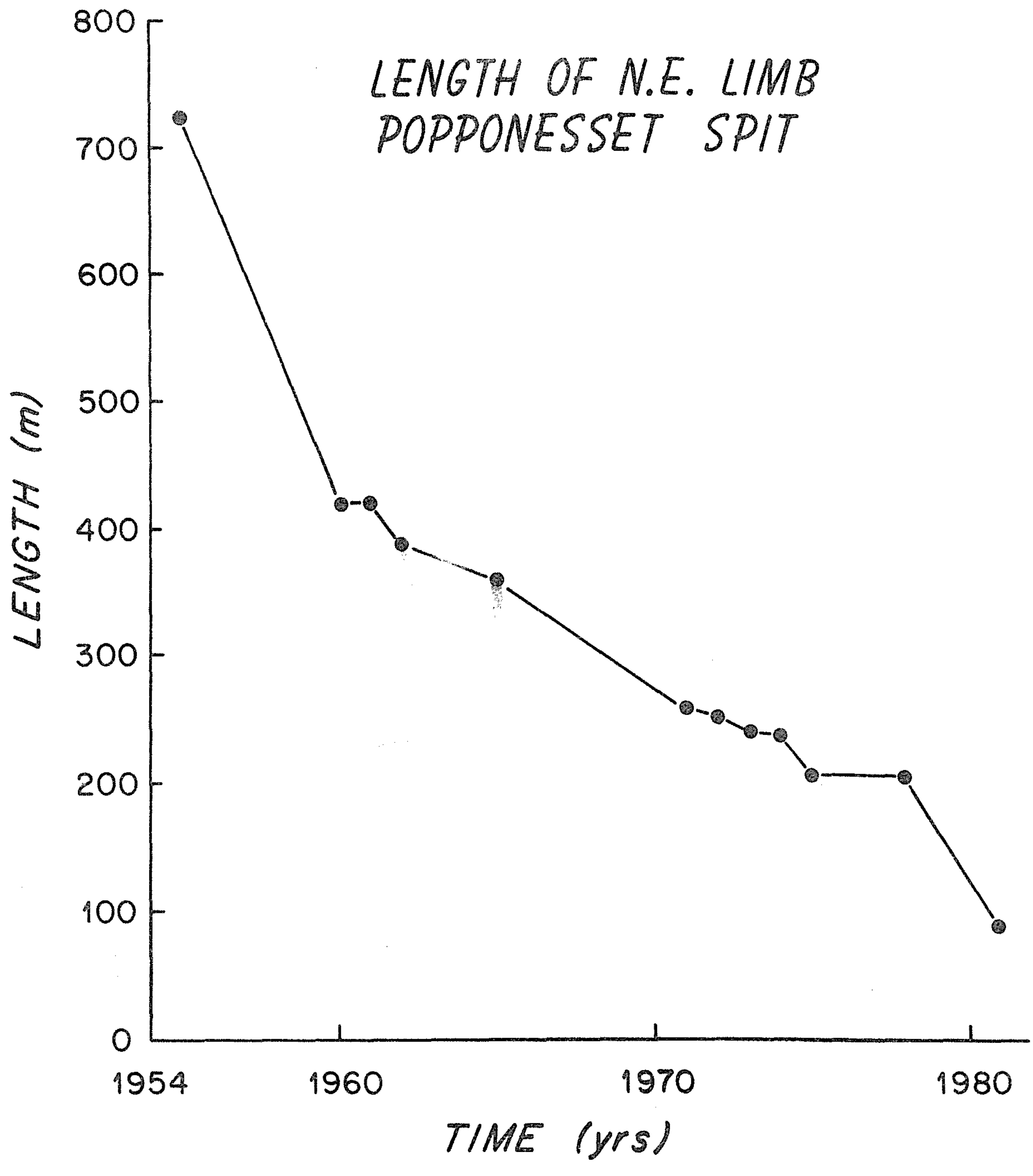

Figure 11. Changes in length of the N.E. limb of Popponesset Spit along the reference line (see fig. 10) over the period of attrition, 1954-present.

had the effect of shortening this limb of the beach from the southwest end, proceeding in a northeastward direction; as a result, some other studies have interpreted the attrition as evidence of intense littoral drift toward the northeast. Alternatively, because of the the shape of the north spit since 1970 (the fact that it is similar in appearance to a southwest growing spit) one might interpret the longshore drift as being in the opposite direction. The actual movement of sand has been principally in a landward direction - to the northwest. At its northeastern extremity, where the spit was widest, landward sand movement has not only closed the former mouth of the inlet near Cotuit Bay, but has produced a subaerial attachment of this end of the beach to the mainland near Rushy Marsh Pond and effectively ended attrition at this end. Attrition of the N.E. limb does not appear to have been controlled by major storm events, but rather has occurred at a fairly regular rate since 1961.

The S.W. limb of the barrier beach, which lacks an appreciable sediment sink immediately behind it, has not experienced comparable attrition. Since the breach of 1954, the length of the south spit has fluctuated a little up to 1978 (Fig. 12). This fluctuation probably mirrors both man-made (e.g. 1961 dredge spoil disposal) and natural processes (such as the gradual elongation and reorientation of the spit towards the shore at Meadow Point).

Another long-term trend in shoreline development along the Popponesset area is the gradual loss of material (probably salt marsh peat and dredge spoils) at Meadow Point (Fig. 13). Since 1938, Meadow Point has eroded towards the north a distance of about 60 m. Most of the erosion occurred during two periods of time (1938-1942 and 1964-1978), followed by long periods of relatively little change. These periods do not coincide with any known

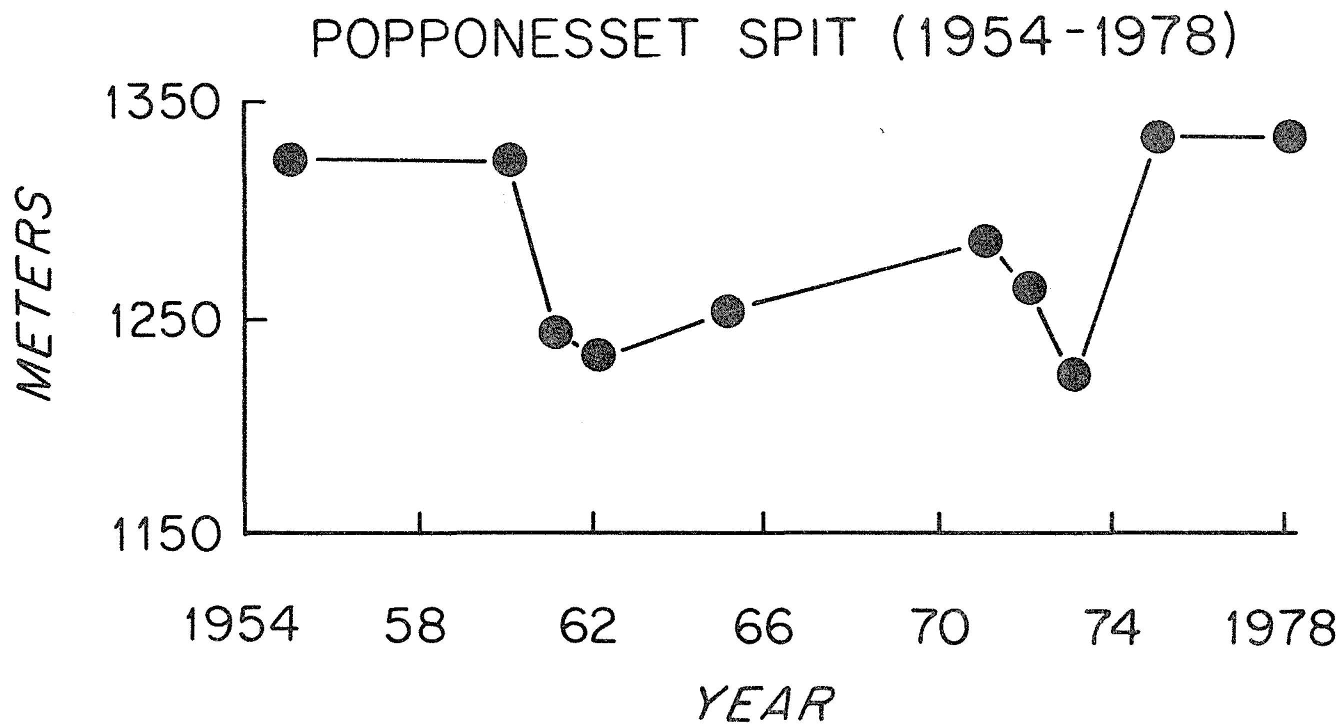

Figure 12. Changes in the length of the S.W. limb of Popponesset Spit, 1954-1978, based on the position of the tip projected onto the reference line (see fig. 10).

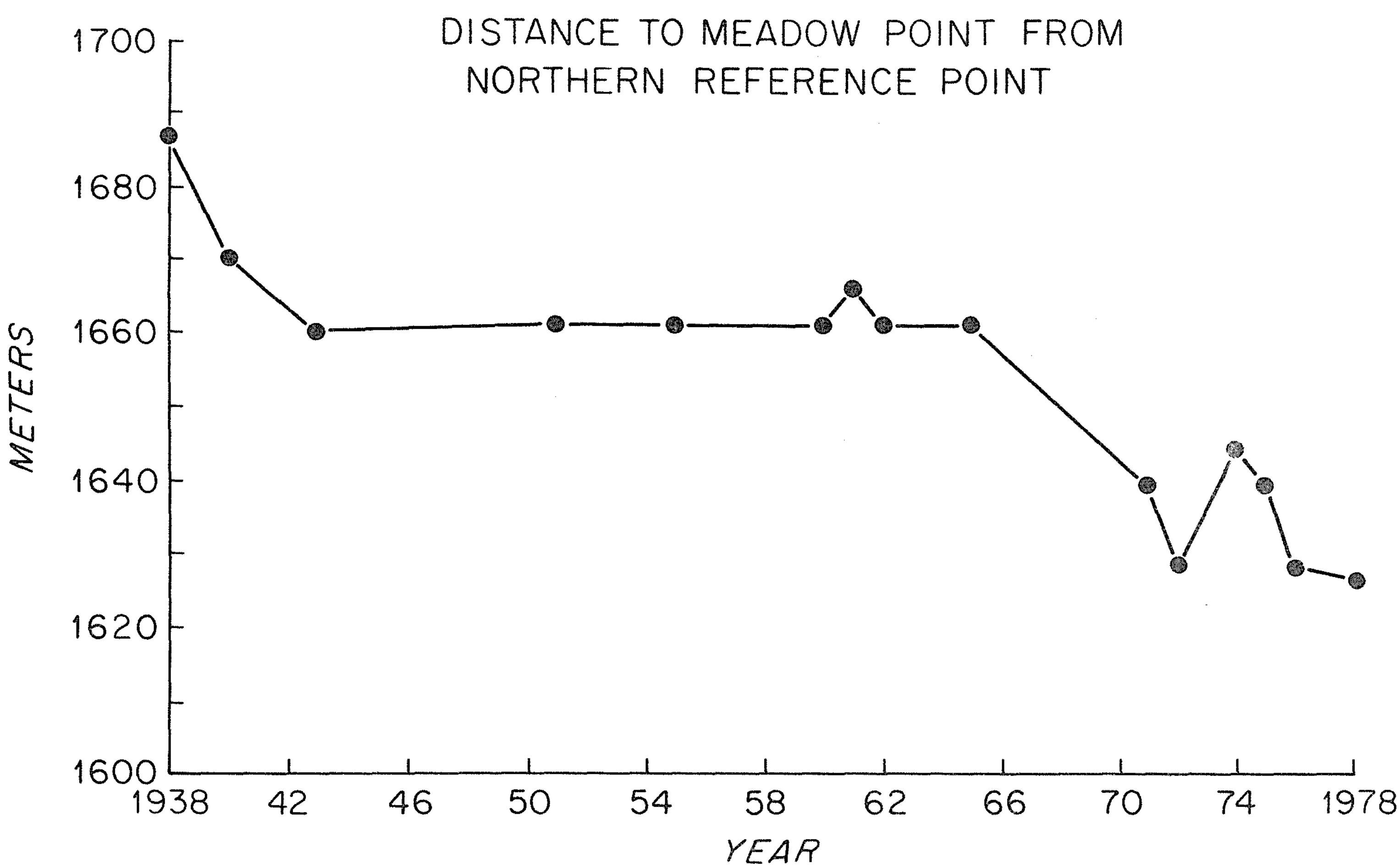

Figure 13. Changes in the length of Meadow Point along the reference line (see fig. 10), 1938-1978.

human activities which might have accelerated erosion and are probably associated with natural migration or reorientation of the adjacent inlet channel. For example, the erosional period between 1964 and 1978 correlates with a reorientation of Popponesset Spit, which is expected to affect the inlet geometry.

Onshore spit migration

Photographic records since 1938 provide detailed information on shoreward migration of the barrier spit (e.g., see Figs. 7-9). These data indicate onshore migration has not been uniform either in time or location along the spit (Fig. 14). At Station G, near Big Thatch Island, the total shoreward migration from 1938 to 1978 has been about 140 meters (460 ft), a rate of about 3.5 m/yr (12 ft/yr). However, these overall figures conceal important information regarding the mechanism of movement. From 1938 to 1955, the rate was about 1.7 m/yr (5.6 ft/yr) and from 1960 to 1975 it slowed to about 1.2 m/yr (4 ft/yr). Between these periods, immediately following 1955, there was a displacement of the beach at this station amounting to about 65 meters, (210 ft) which we presume represents an adjustment resulting from the hurricanes of 1954, such as to the formation of a temporary breach near this location. Coalescence of the barrier beach with Big Thatch Island is associated with this storm event (cf. Fig 8, -1951 and -1955). A similar displacement of about 30 meters (98 ft) appears to have resulted from the blizzard of 1978. Thus more than half of the shoreward migration at Station G appears to be associated with major storms, a quantity added to the more regular onshore movement averaging about 1.5 m/yr (5 ft/yr) at this station.

The effect of the 1954 hurricane at Station F, near Popponesset Island is even more distinct. At this station regular shoreward migration has been

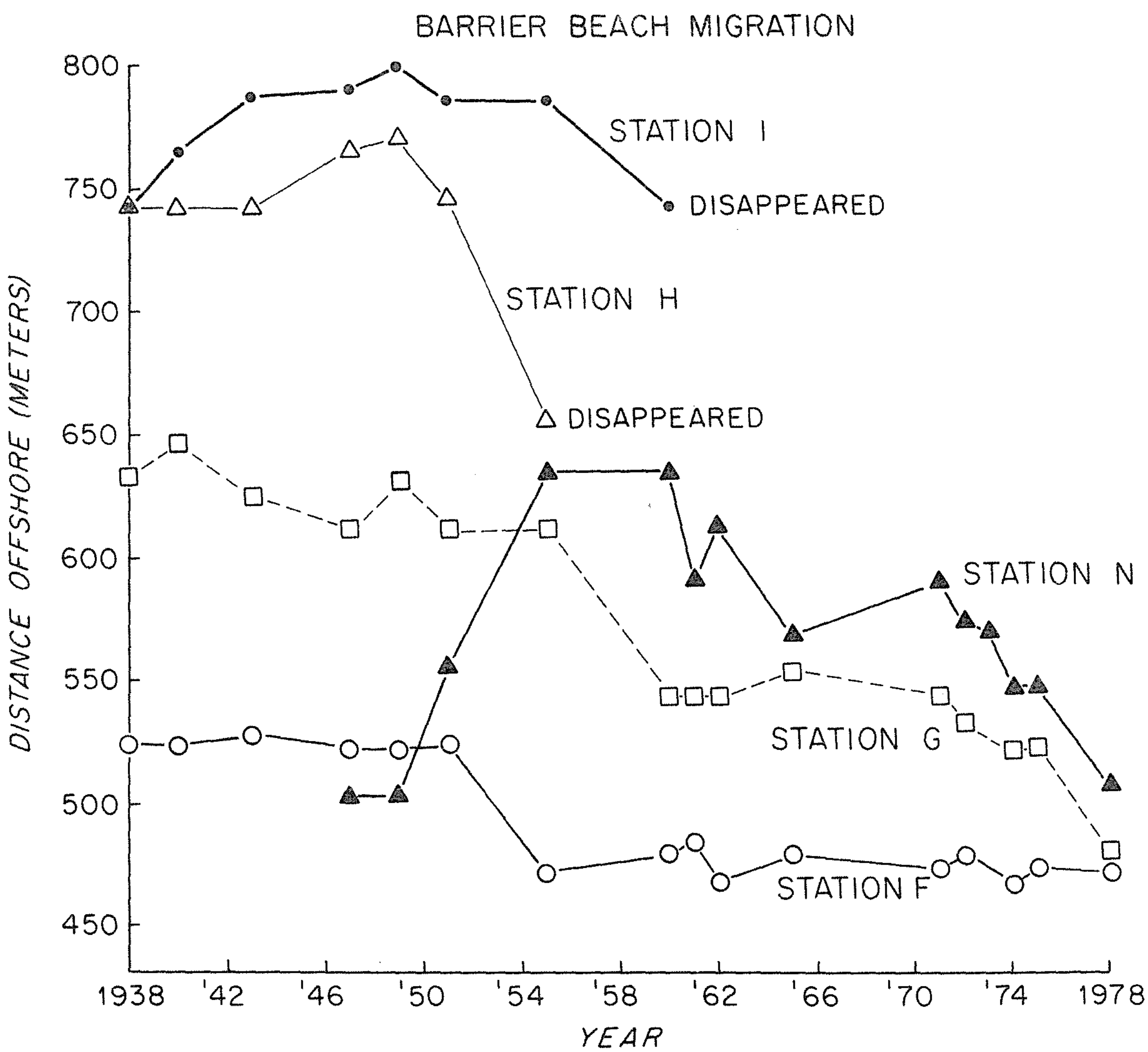

Figure 14. Onshore/offshore movement of the seaward shoreline at stations along Popponesset Spit (see fig. 10), 1938-1978.

slower, averaging less than 0.1 m/yr (0.3 ft/yr) before 1954 and about 0.2 m/yr (0.7 ft/yr) from 1955 through 1978, for a total of about 5 meters (16 ft) movement. The hurricane displacement at this station, however, amounted to about 50 meters (160 ft), by far the more significant amount. The difference in total onshore movement from one station to the other indicates the S.W. limb of Popponesset Spit has been rotating counterclockwise since 1938 or earlier.

The picture is more complicated along the N.E. limb of the spit because of other changes in beach geometry. All stations show a period of seaward movement, followed by shoreward movement. It may be significant that shoreward migration, which ultimately was associated with the destruction of this part of Popponesset Spit, began at Stations H and I before the 1954 hurricanes, suggesting the loss of the beach may have eventually occurred regardless of the occurrence of hurricanes. Station N, to which position the spit had grown by 1947, shows a general pattern similar to the other stations, but displaced in time (Fig. 14). Seaward movement at this station appears to have resulted from widening of the beach, discussed later. Loss of the last remnant of the barrier beach at this location is anticipated in the near future.

In addition to the direct effects of onshore migration, such as a reduction in the size of the bay and associated resources, landward spit migration can be expected to cause a small reduction in the tidal prism (amount of water exchanged in a tidal cycle between Popponesset Bay and Nantucket Sound) which, in turn, constricts the inlet and adversely affects navigation into and out of the bay.

Width of the barrier beach

As barrier beaches undergo onshore migration, the width of the beach may or may not vary. Narrowing of the beach is of concern since it reduces the effectiveness of the feature as a natural barrier against storm damage. Determination of beach width statistics from photographs involves two particular complicating factors. First, the resolution of features on photographs with the techniques used is about 10 meters. In effect this means beach widths were measured with a ruler graduated in 10 meter intervals, and changes less than that cannot be regarded as significant. The second complication is that natural beaches generally exhibit a seasonal cycle in width that must be distinguished from long term trends. Thus the quantity of interest in these figures is the variation of beach width trends exceeding 10 m.

Perhaps the most salient feature of the beach width data is that loss of the N.E. limb after 1955 is not associated with thinning of the spit (Fig. 15). Along the remnants of the N.E. limb of the barrier beach, widths have remained fairly constant through time, in spite of the fact the barrier itself moved shoreward a distance of over 100 m. At Stations H and I beach width remained about constant, and Stations J and K may actually have widened just prior to loss of the spit at those sites. This contradicts, once again, the concept that beach attrition at Popponesset resulted from losses by longshore drift but is consistent with the hypothesis that truncation of the ends of the spit, with landward sand movement, was responsible.

Along the S.W. limb the trend varies with location. At the extreme southwest end (Station F), the beach has retained a constant width of 40-50 m (regardless of temporary breaching events there). Where the 1961 dredged

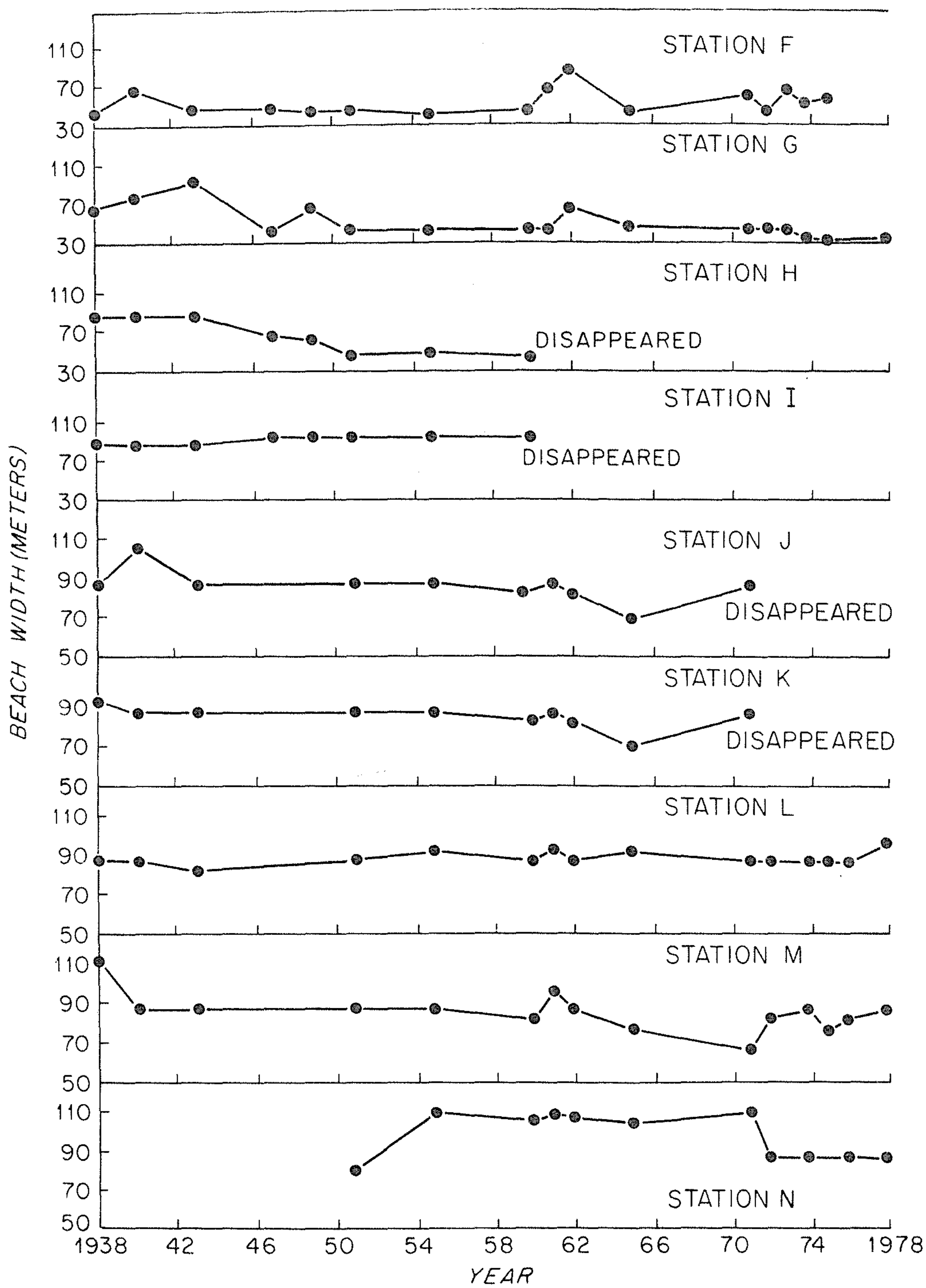

Figure 15. Beach widths at stations along Popponesset Spit, 1938-1978 (see fig. 10).

channel passes between Popponesset Island and the spit, however, thinning from the back side has become evident in recent years (Fig. 9) as a result of scouring by tidal currents as the spit migrates onshore. In future storms this location may be especially susceptible to overwash and breaching; and in view of the relatively well developed dredged channels leading to this point, a breach here may be stable (unlike the many temporary breaches at this site in years preceeding dredging).

The central portion of this spit (Station G) has been narrowing since 1938, from a width of about 70 m (230 ft) in 1938 to a low of 35 m (115 ft) in 1978, although as is evident in Fig. 15, large short term variations from this trend are suggested. It is also evident that at other sites on the present spit this long term trend is not evident (e.g., Station F). The beach near Station G has been overwashed and breached since at least 1892 (see Table 1) including several events since the early 1970's. At the north end of the present spit, the width temporarily increased due to the incorporation of Big Thatch Island onto the spit (which occurred by 1955). Since the merger, however, the beach has been narrowing at this point.

Measurements of the shoreline position at Dean Pond (Fig. 10, stations A-D) suggest the mean water line has actually moved slightly seaward of its former position over the period 1938-1980. This progradation is small (and in fact sea level position appears to have been relatively stable since 1951), but it clearly demonstrates that these beaches are not undergoing rapid erosion, as are other portions of Cape Cod.

Formation of breaches

Historical charts and aerial photographs indicate Popponesset Spit has been breached at 4 locations over the past two centuries, and suggest

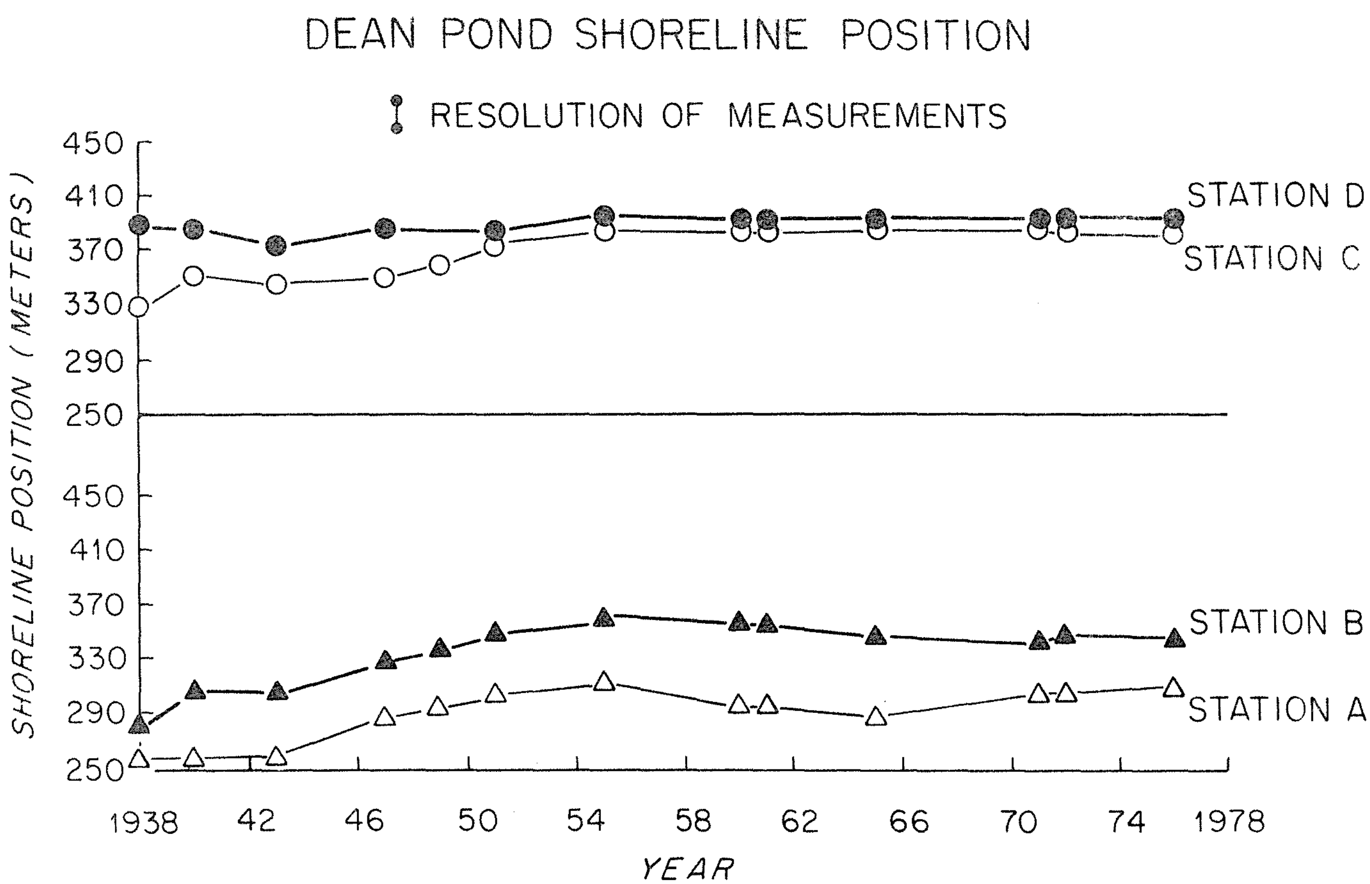

Figure 16. The position of the seaward shoreline near Dean Pond, relative to the reference line (see fig 10, Stations A-D), 1938-1978 .

breaching has been fairly common or persistent or both. Aerial photographs for the period 1938-1980 show several breaching events (Table 1) most of which occurred in three areas of Popponesset Spit: near Popponesset Island; near Little Thatch Island; and near Big Thatch Island. Big Thatch and Little Thatch Islands, in fact, probably originated as flood tide delta deposits associated with early breaching events.

Table 1 The history of breaches at Popponesset Spit as recorded on historical maps and charts, and aerial photographs, 1892-1981 (see Appendices 1 and 2 for references).

YEAR	LOCATION	SOURCE
1892	Little Thatch Island	Walker chart
1893	Big Thatch (west side)	Plan of Mashpee/Barnstable Town Line, 1894
1896	Big Thatch I. (west side)	USC&GS chart
1901	Big Thatch I. (west side)	USC&GS chart
1910	Big Thatch I. (west side)	USC&GS chart
1914-17	Big Thatch I. (west side)	USC&GS chart
1931	Popponesset Island	Anonymous map of Cape Cod
1932	Popponesset Island	Goffney map of Cape Cod
1936	Popponesset Island	Robbins Studio map of Cape Cod
1938	Popponesset Island	USGS aerial photograph
1947	Little Thatch Island	USAF aerial photograph
1949	Little Thatch Island	USAF aerial photograph
1951	Little Thatch Island	USC&GS aerial photograph
1955	Big Thatch Island and Popponesset Island	USC&GS aerial photograph

It is not clear why these sites have been most commonly the site of breaching. The permanent breachway formed east of Big Thatch Island in 1954 represents the first breach of the barrier spit at that specific location since the elongation process began nearly a century earlier (although breaching to the west of the Island was common). This site evidently represents the best location for a natural inlet to this system, based on its history of stability. Prior to 1779, it is not possible to say where the inlet was located because of the lack of detail in historical charts.

The patterns and frequency of breaching suggested on historical charts and aerial photographs implies that this is a relatively common occurrence. An apparent increased frequency of breaching from 1938 to 1955 is probably an artifact of the more dense data available for that period. Since 1955 there is no evidence of breaching of the barrier beach, although overwash has occurred in many occasions. We have no direct evidence of human modifications of breaches at Popponeset Spit, although it is possible that some of the post-1950 breaches were closed by man in an effort to maintain the integrity of the barrier beach. As mentioned previously, channels dredged in 1961 could change the future response to breaching, particularly near Popponesset Island, where artificially channelized flow could make this site more stable than the existing inlet.

Offshore sand waves

Seasonal onshore/offshore movement of sediment is well documented for beaches around the world. The offshore bedform in which sand resides is typically the longshore bar, which exchanges material with its onshore counterpart the beach berm. In the Popponesset study area, well defined sand waves offshore from Popponesset Spit are conspicuous on most vertical aerial photographs of this area. In addition to a set of sand waves nearly parallel to the shore, there occur larger numbers of more conspicuous, smaller ones sub-perpendicular to the shore (Fig. 17). In the twenty year period between 1951 and 1971, some of these smaller features appear to have migrated as much as 200 meters to the southwest, suggesting a possible mechanism for movement of large quantities of sediment. The likely possibilities for causing these migrations are asymmetrical tidal motions and weather-related flow patterns,

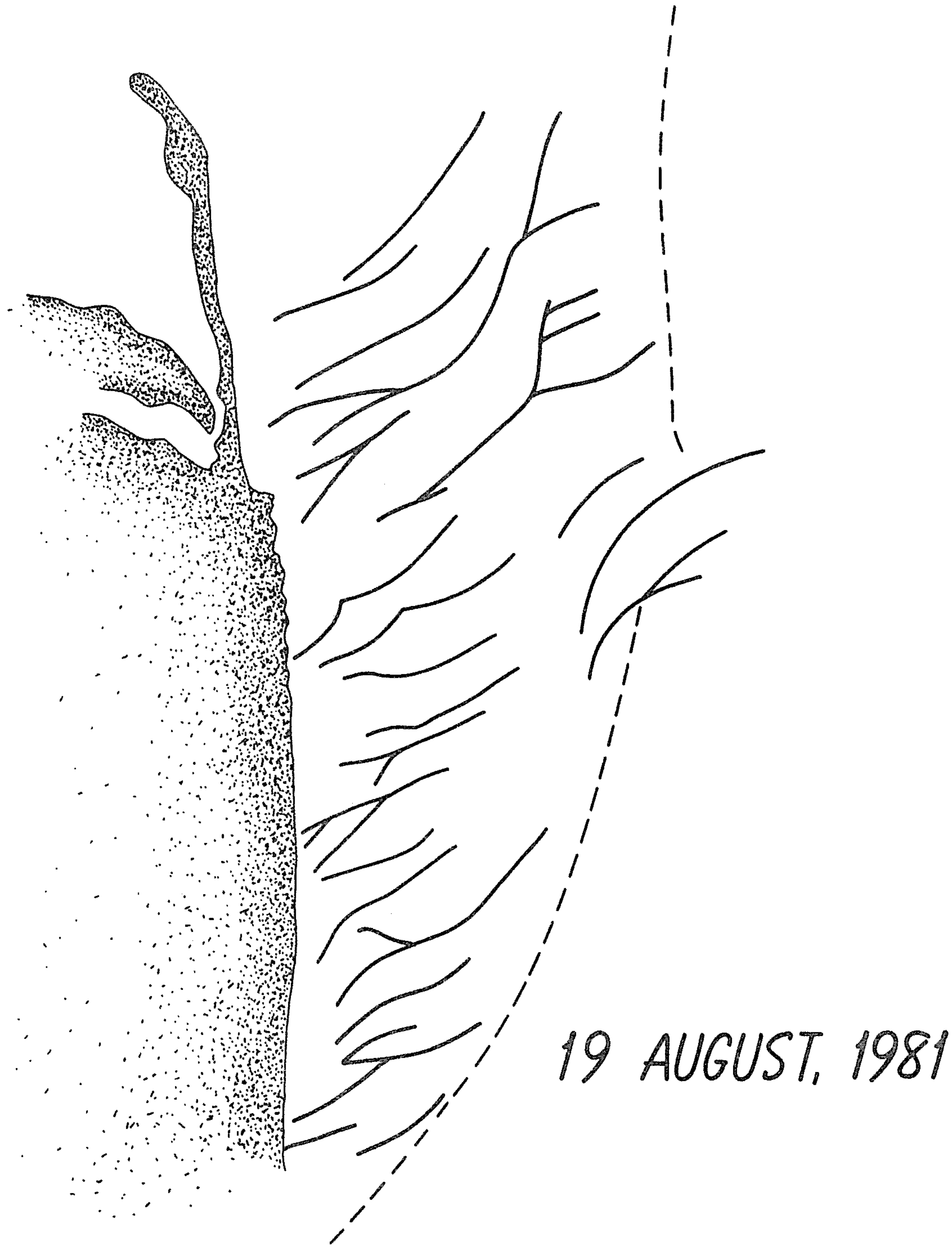

Figure 17. Sand wave crests in the Popponesset Spit study area. The dotted line indicates the approximate position of the 2 m isobath.

although no observations are available at this time to evaluate the relative importance of these two factors. Because of the potentially large volume of sediment moved through this sand wave migration, and their possible role in interacting with the nearshore, the motion and forcing of these features need to be clearly documented. The pathways for exchanging sand between the beaches and these offshore features also need to be investigated.

Sediment Budget

Elements typically included in a sediment budget are shown schematically in Fig. 18. Although ultimately it will be necessary to have quantitative information for the sediment budget, our immediate purpose is merely to place limits where possible and, otherwise, to identify important information gaps.

Cliffline erosion

The cliffline along the shore S.W. of Popponesset Beach represents a potential source of sediment for the Popponesset Spit littoral cell. The cliffline itself was difficult to identify in some aerial photographs, because of additions of structures, sun angle and vegetation changes. If cliff angle remains reasonably constant, however, transgression of the shoreline can be used as an indicator of cliffline erosion. As discussed earlier, these data show no significant erosion at 4 stations along the shoreline (Fig. 16). If we assume erosion of 10 meters over the study interval (the resolution of our measurements), this is equivalent to a rate of 0.23 meters (0.8 ft) per year which is small compared to many other locations on Cape Cod. This value could be exceeded locally by an appreciable amount. From the rate of erosion assumed above and average cliff height it is possible to estimate an upper limit for the rate of sediment supplied in this manner --- 3,000 m^3/yr The actual rate, of course, could be much less.

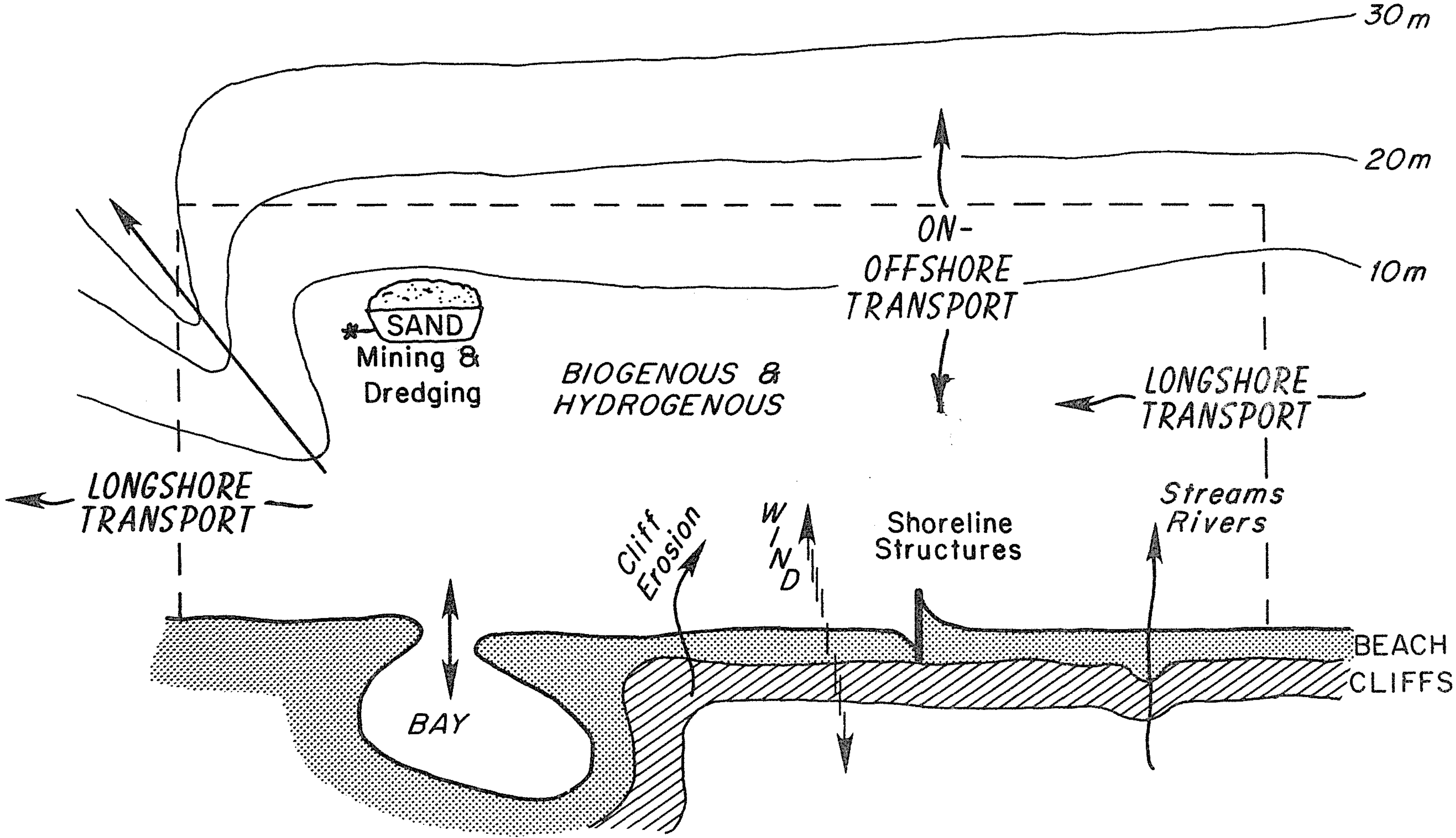

Figure 18. A generalized sand budget indicating potential sources, sinks and pathways of sand.

Longshore sand transport

The longshore sand transport in this area is a critical parameter in assessing the past, present, and future of the barrier beach. Since previous studies have linked beach erosion to longshore transport, consideration of this factor is a necessary part of the present study. The magnitude of this quantity is difficult to estimate, and in this general study area it is even hard to determine the dominant direction of longshore transport. In order to resolve these questions, one must resort to indirect lines of evidence, since field measurements of longshore transport have not been made. The particular transport which we consider here is the longshore sand transport caused by the breaking of obliquely incident waves upon a beach. This transport is primarily confined to the surf zone, and does not include longshore sand movement farther offshore which is driven by a combination of waves and currents (both tidal and wind-driven).

From the orientation of spits, the net longshore transport in the Popponesset area has been described as northeastward along Popponesset Beach, and westward along Dead Neck in Osterville, with a convergence, therefore, near the mouth of Cotuit Bay (e.g., Woodworth and Wigglesworth, 1934; Brownlow, 1979). This pattern is suggested by other observations. During its growth phase, the barrier spit at Popponesset developed toward the northeast, suggesting littoral drift in that direction; and small-scale changes in the configuration of Sampson's Island and Dead Neck in Barnstable suggests a sand source to the east for that barrier beach. The recurrent need for dredging at the entrance to Cotuit Bay and West Bay (Appendix 4), and the distribution of sediments at the jetties at the entrance to West Bay (impoundment on the east side) are additional support for this pattern of littoral drift. However, as

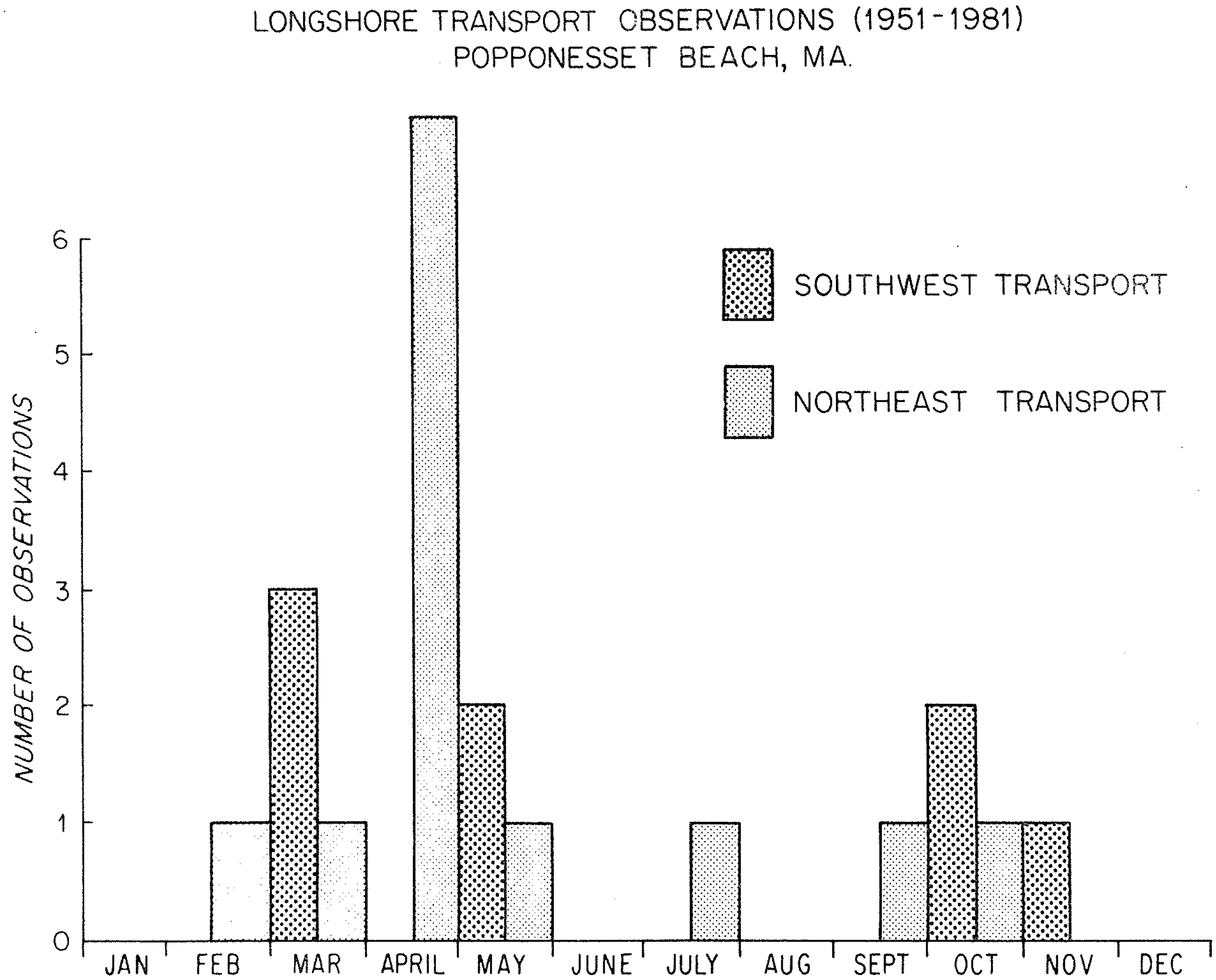

Figure 19. Longshore transport direction at the Popponesset Spit study area based on the orientation of accretion fillets at shoreline structures, as indicated on vertical aerial photographs, 1951-1981,

discussed next, the general pattern of transport must be qualified both in terms of the quantity of transport as well as seasonal variability in its direction.

Certain observations suggest longshore transport along the Popponesset Spit area must be small, regardless of its net direction. The stability of temporary inlets west of Big Thatch Island, near Popponesset Island and near Little Thatch Island for periods of ca. 20 yrs, 7 yrs. and 4 yrs., respectively (Table 1), suggests (but is not proof of) little sand transport past those sites. Furthermore, the persistence of relicts of the 1954 inlet channel (abandoned 27 years ago) along the shore off Cotuit Highlands would not be possible if longshore transport were significant; these depressions are visible on aerial photographs near Rushy Marsh Pond in Nantucket Sound on both sides of the remaining portion of the N.E. limb of the spit. Finally, the impoundment of sand by the groin field southwest of Popponesset Spit has not been sufficient either to appreciably change the "updrift" shoreline (Fig. 3) or to overtop these structures, as generally occurs where longshore transport is large.

Seasonal variability in the direction of longshore transport was documented from the pattern of sand entrapment along the groins (or jetties) at Popponesset Beach on aerial photographs from 1951 to 1980. Although the data are somewhat sparse, northward transport seems to be favored in the month of April, with southward transport favored in the fall (October and November; Fig. 19). Other months show no net preference for transport directions.

A possible source of longshore sand for the Popponesset region that must be considered is from west of Succonnesset Point. One way to evaluate this possibility is by measuring beach width and the size of the accretion fillet near adjacent Waquoit Bay jetties (Figs. 20 and 21). Beach widths in this

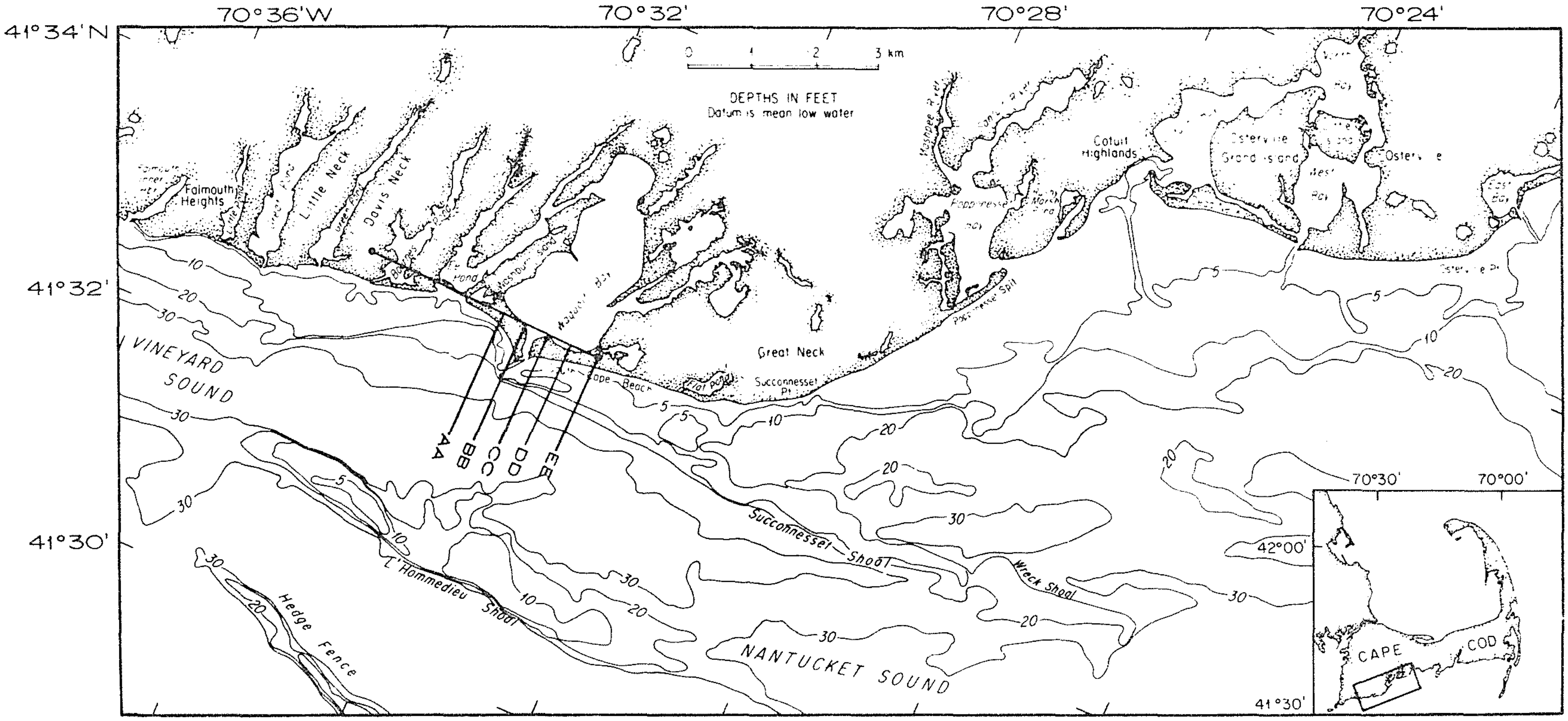

Figure 20. The reference line and perpendicular station lines used for shoreline measurements on vertical aerial photographs for the Waquoit Bay area. The ends of the reference line were well defined points readily visible on all photographs used.

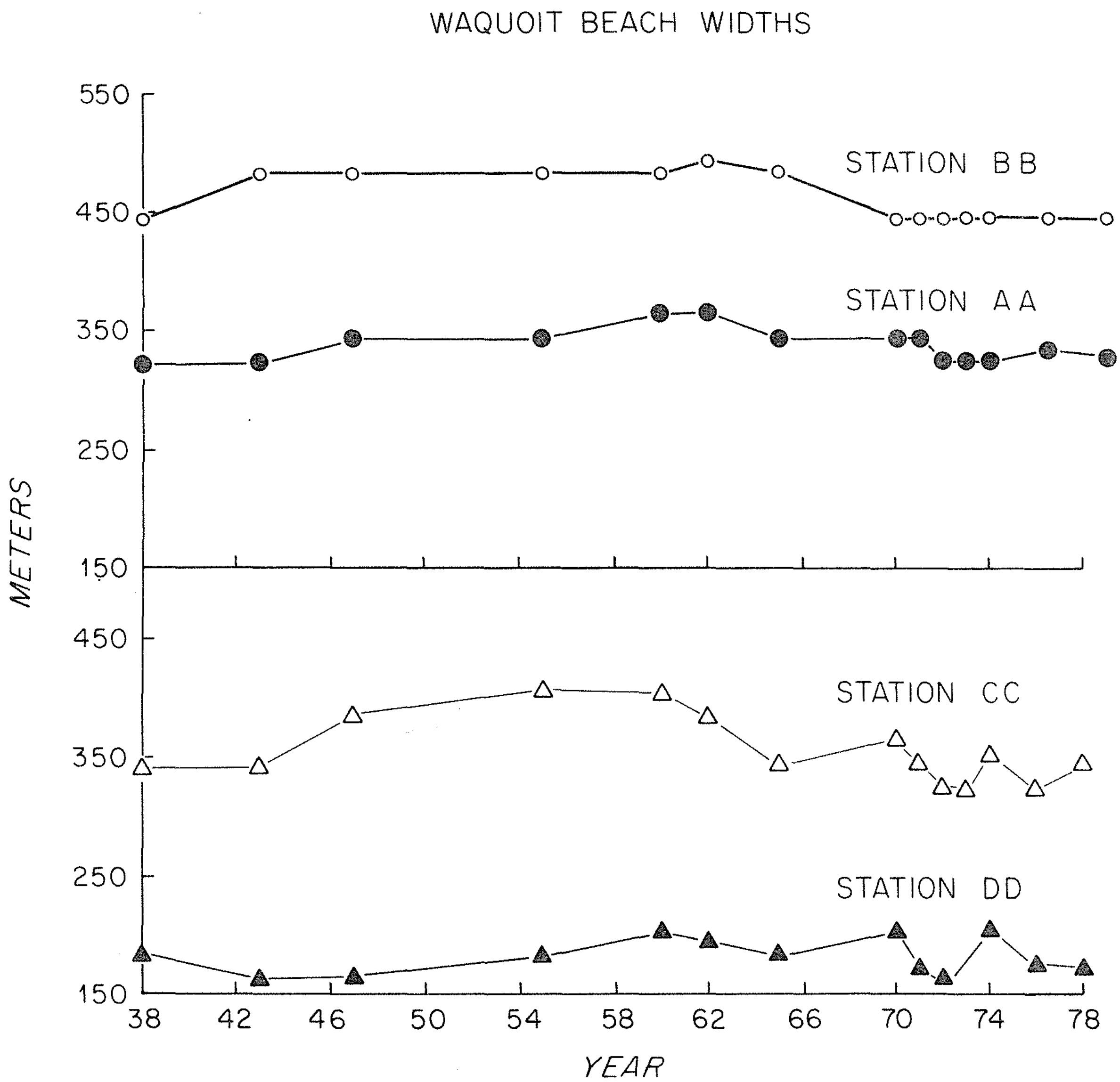

Figure 21. Beach widths at stations along the Waquoit barrier beach, 1938-1980.

area, measured from 1938 through 1980, show little net change but quite a bit of variability. Three stations showed no net change, while a fourth showed a narrowing of less than 15 meters. In all cases, however, there were fluctuations of 30-40 meters in width (all accretion) over the period of study. This accretion occurred over the period 1945 through 1970.

Dredging and spoil disposal

As indicated in Fig. 18, movement of sediment as a result of sand mining, or in this case dredging, can affect coastal geometry. In Massachusetts, both the U.S. Army Corps of Engineers and the Massachusetts Division of Waterways (Department of Environmental Quality Engineering) are responsible for permitting dredging and shoreline modification activities. According to their records, 84 permits or licenses have been issued for projects involving dredging in Popponesset Bay and the adjacent Cotuit Bay-West Bay-North Bay complex (see Appendix 4). Unfortunately, details of these dredging activities are dispersed among a number of depositories, are often poorly indexed, and in several cases are lost or incomplete. Nevertheless, using available information and certain conservative assumptions, it is possible to determine a rough estimate of the magnitude of dredging. These estimates are summarized in Table 2 which indicates 66% of known projects (the proportion containing adequate data for formulating estimates) involved a total of about 420,000 m^3 of sediment. A total for all dredging activities can be estimated using average volumes involved in 14 state projects (26,500 m^3) and 41 private projects (1,900 m^3) and the total number of each (20 and 64, respectively). This calculation indicates about 650,000 m^3 may have been moved as a result of dredging (Table 3). These estimates, though rough, indicate that dredging activities cannot be dismissed *a priori* in a study of coastal changes at Popponesset Beach. It further underlines the need for a rigorous understanding of mechanisms by which material can be reworked by natural processes before additional dredging is permitted.

The major dredging projects in Popponesset Bay have been conducted by the Massachusetts Department of Public Works (DPW). Portions of Popponesset Bay were dredged as early as 1916 and again in 1936 (U.S. Army Corps of Engineers, 1965) but engineering plans or other details of these early projects have not been found. Channels resulting from these projects are indicated on the USC&GS chart for 1916 (Fig. 6, -1916) and on the 1938 vertical aerial photographs (see Appendices 2 and 3). According to U.S. Army Corps of Engineers (1972), spoils from the 1916 project were disposed of along "the western shoreline". The third major dredging project, conducted in 1961, is better documented although the exact disposition of dredge spoils is not certain. It is known that licenses were issued to dispose of a total of 107,000 m^3 of dredge spoils on a portion of Popponesset Spit near Big Thatch Island and on the shore of Popponesset Creek and Popponesset Island (Massachusetts Department of Public Works, 1961). The "artificial fill" indicated at the latter locations by Oldale (1975) may have resulted from this project.

Neighboring bodies of water in the Town of Barnstable (Cotuit Bay, West Bay, etc.), that might interact with the Popponesset area, were dredged as early as about 1900, but again records are incomplete. As shown in Appendix 4, numerous small scale dredging and shoreline modification activities in the area occurred since 1930. Estimates of dredge volumes given in Appendix 4 suggest more than 60,000 m^3 of sediment has been disposed of on Dead Neck (Barnstable) over the years.

Table (2) Summary of dredging permitted in the vicinity of Popponesset Beach (see Appendix 3; MDPW = projects of the Massachusetts Department of Public Works; Other = all other projects).

Location	# Permits on file a/	# Permits with data b/	Recorded spoil volume (m3) c/
Popponesset Bay			
MDPW	3	3	160,200
Other	13	11	8,930
	16	14	169,130
Cotuit Bay			
MDPW	6	3	60,900
Other	11	7	6,850
	17	10	67,800
Seapuit River			
MPDW	3	3	36,400
Other	11	5	3,000
	13	8	39,400
West Bay			
MDPW	6	4	64,800
Other	10	8	28,400
	16	12	93,200
North Bay			
MDPW	2	1	26,000
Other	19	10	23,630
	21	11	49,630
TOTALS	84	55	419,000

a/ Permit records were obtained from the U.S. Army Corps of Engineers (Waltham, Mass.) and from the Massachusetts Department of Environmental Quality Engineering, Division of Waterways.
b/ Permits containing some record of spoil volumes. A few permits estimated spoil volumes directly. Some indicated dimensions of the area to be dredged. Others stipulated a channel width and describe endpoints, from which length was determined on a map. In cases where spoil volumes were not given, it was assumed a 1 meter thick layer of sediment was removed.
c/ Reported dredge spoil volume represents the volume determined from permits containing adequate data for volume determinations. As only 66% of permits contained such data, this estimate is undoubtedly low (see text).

Table (3) Dredging statistics and calculations for the Popponesset Beach area (MDPW = projects of the Massachusetts Department of Public Works; Other = all other projects).

	MDPW	Other
# permits with spoil volume data	14	41
mean spoil volume per project (m^3)	26,500	1,900
S.D.	26,600	3,380
# permits on file	20	64
calculated total spoil volume	530,000	121,600
TOTAL ca. 650,000m3		

There seems little question that this quantity of sediment must have significantly affected the geomorphology of that barrier spit.

With one exception, permits designating spoil disposal sites indicate land disposal above mean high water on adjacent property or disposal behind bulkheads. One project in 1954 in the entrance channel to Cotuit Bay indicates at least part of about 12,700 m^3 of dredge spoils were dumped in Nantucket Sound in 36 feet of water (3.5 miles south of the inlet).

Although dredging activities in the study area began about 1900, it is not known exactly when they actually started. One feature consistently shown on early maps was a small island (Gull Island) located southwest of Sampson's Island off the coast of Rushy Marsh Pond (Fig. 6). This island was shown on charts through 1892 (Walker, 1892) but is missing on the USC&GS chart of 1896 which shows a depression in that area instead. This suggests that the Island was removed as a result of navigation channel improvements, although we have no direct proof that this was actually the case. The alternative, that loss of this island resulted from natural causes, is equally startling.

Shoreline structures

Many small structures have been permitted in the bodies of water considered by this study but a large fraction of them are small docks and floats in the vicinity of Popponesset Creek. Those of greatest significance to this study are the groins and bulkheads along the Nantucket Sound shoreline. Records gathered in this study (Appendix 5) account for about 25 of about 50 structures that can be identified on recent aerial photographs of this region. All groins lie along coastal banks; none occurs on barrier beaches. The groins southwest of Popponesset Spit were constructed between 1950 and 1955. Most of the groins at Meadow Point were placed in 1958 after loss of that portion of the Popponesset barrier beach. Our records of the numerous groins located near Cotuit Highlands and near Wianno are less complete and we have found no permits for coastal structures on Nantucket Sound after 1967.

Past studies have identified the groin field at Popponesset Beach built in the 1950s as the cause of downdrift starvation of Popponesset Spit, which, in turn, is identified as the cause of beach attrition. We question this conclusion for several reasons, discussed elsewhere, including; a) "downdrift starvation" does not appear to be the best explanation for loss of the N.E. limb of Popponesset Spit; b) longshore drift appears to be much less significant than others have assumed, as suggested by the persistence of shoreline sediment traps; and c) the groins at Popponesset Beach do not appear to have impounded quantities of sand comparable to what was lost from the N.E. limb; finally, d) although the number of groins and other shoreline protection structures increased through at least 1967, there is no evidence of increased "beach erosion" (distinguished from onshore migration) on

Popponesset Spit at present.

One shoreline project that may have influenced coastal processes here is the jetties constructed to stabilize the artificial inlet to West Bay, built in about 1900, which may have been the first coastal structure in the study area (see Fig. 6, -1901). The effect of this stabilized inlet would probably be to diminish tidal flow through the Seapuit River and the entrance to Cotuit Bay (via North Bay) by providing direct exchange with Nantucket Sound. The connection of Sampsons Island with Dead Neck and other changes in that area at about the same time suggest some of the consequences of the diminished flow.

Onshore/offshore sand movement

A factor which is especially difficult to assess in formulating a sand budget for the Popponesset area is the amount of sand exchanged between the nearshore and farther offshore. Although there is probably a seasonal exchange of sand between the beach and areas farther offshore, it is not known whether the offshore regions serve as a net source or sink (if either) of sediment to the nearshore. These determinations are included in proposed future work.

Wind Transport and other elements

Movement of sediment by wind has not yet been determined for the Popponesset study area, although it is manifest in the limited dune deposits that occur on all three barrier beaches in the area. It may prove possible to obtain information on changes in dunes using stereographic methods of aerial photograph analysis, in connection with the beachgrass enhansement project on Popponesset Spit.

Streams and rivers are known to be important sources of sediment in certain coastal areas. However, in New England, and especially on Cape Cod, this source is generally negligible because streams here pass through effective sediment traps on their course to the sea (e.g., glacially formed kettle holes) and, especially on Cape Cod, the streams are small.

Biogenous sediments occur in the study area in the form of mollusk shells, but are not believed to represent an important fraction of the total sediment.

Finally, exchange of sediment between bays in the study area and Nantucket and Vineyard Sounds, especially up-estuary transport, may represent a significant sediment pathway and needs to be evaluated. This is especially true if longshore transport is as small as observations to date suggest.

CONCLUSIONS

This analysis of historical charts and aerial photographs has revealed new facets of shoreline evolution in the study area and suggests hypotheses regarding beach dynamics of possible broader significance. The remarkable growth of Popponesset Spit between 1857 and 1954 was previously not recognized, and places new constraints on explanations of the equally remarkable attrition of that feature following 1954. Physical forcing (waves and currents) responsible for sand transport is poorly defined in this region but appears to be of relatively low energy compared with other dynamic beaches. Although winds are documented historically through several local airports, the methods available to calculate directional wave climate are not sufficiently accurate to provide a firm basis for calculating sediment transport rates. However, several indirect lines of observation suggest littoral drift is small in this area, which puts yet another important constraint on explanations of dynamics here. Measurements of directional wave climate and tidal currents are needed.

Loss of the N.E. limb of Popponesset Spit began with breaching of the barrier beach by hurricanes in 1954 and appears to be associated with a process of landward movement of sediments at its S.W. end, with simultaneous loss of the subaerial beach and the former inlet channel behind it. Narrowing of the beach has not been associated with the process and it has proceeded independent of major storms (it is surprising, in fact, that remnants of the N.E. limb survived for 27 years, during which there were several major storms). Calculations of the inlet channel volume for the pre-1955 inlet compare closely with that of the sediment comprising the N.E. limb of the spit at the same time. This suggests destruction of this limb of the barrier beach should fill the channel with little surplus or deficit of sand, a supposition that is supported by aerial photographic evidence.

This coincidence in volume could also indicate that formation of the spit was related to formation of the inlet channel behind it. This suggests a new hypothesis of barrier beach formation; specifically, we propose that material building a barrier spit can be excavated by the ebb-tidal jet at the mouth of a growing inlet. The process(es) involves extension of the inlet throat and deposition of the removed material onto the end of the adjacent, growing spit. This hypothesis obviates the need for intense wave energy or large littoral drift and predicts the similarity in volumes of the inlet channel and the barrier spit. The destructive phase, involving loss of material from the end of a spit to fill the channel, similarly does not require large littoral drift rates to account for loss of subaerial beach.

An alternative or supplementary source of sand for the elongation of the N.E. limb of Popponesset Spit could be provided by cliff erosion S.W. of Popponesset Beach. Even though cliff erosion rates provide less than 3,000 m^3/yr of sand, an input of this magnitude could be significant over the 100 year period of spit growth. If this was in fact an important source, then we are left with the problem of where this material has gone, why it first became available in the mid 19th century and why the source abruptly stopped in 1954.

At present, the dominant evolutionary aspect of Popponesset Spit is continuing onshore migration, which does not appear to be associated with large losses of sediment (i.e., length and width of the beach do not appear to be decreasing). Our examination of dredging records suggests dredging has accounted for movement of significant quantities of sand in the area. The evidence of dredging is clear in the form of navigation channels and spoils on adjacent land areas, including on Dead Neck barrier beach in Barnstable. Dredging has evidently not contributed to beach erosion, with the exception of the area at the south end of Popponesset Island, where a dredged channel is responsible for narrowing of the spit and where breaching, and possibly a stable inlet, is likely in the future. This site is one of three that have shown a high incidence of breaching and overwash historically, but unlike the others (near Little Thatch Island and near Big Thatch Island) the dredged navigation channel now provides conduits for flow of water from distant parts of Popponesset Bay to this site. If a stable inlet forms at this site, diminished flow at the present inlet may cause it to close, attaching the spit to Meadow Point.

This study reveals some unconventional elements may have significance in the Popponesset Beach sediment budget. The field of sand waves on the shoals offshore from Popponesset Spit are particularly well developed and show some evidence of migration. The transport of sand by this mechanism needs to be evaluated as does the relationship of the sand waves to onshore/offshore movements of sand. The significance of Succonnesset Shoals as an offshore conduit and/or sink for material from the nearshore zone may introduce another unusual pathway into the sediment budget. Further study will focus on evaluating the quantitative significance of these processes.

Shoreline structures have had little effect on large scale dynamics of the barrier beach complex here, although on a small scale, of the order of a few meters, their effects have been conspicuous to shorefront landowners. The jetties at Waquoit and at West Bay, similarly, have probably had at least a local effect.

It is difficult to precisely define the Popponesset Beach littoral cell on the basis of this analysis of charts and aerial photos, mainly because littoral drift appears small and is variable in direction. The area from Succonesset Point to Osterville Point (Fig. 2) extending offshore to the seaward edge of Succonesset Shoals probably contains most sources and sinks of sediment affecting Popponesset Beach, but the possibility remains that the area west to Waquoit jetties interacts with this area as well.

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Appendix 1. Historical maps depicting the Popponesset Beach area.

Date	Scale[1/]	Source	Depository	Title (or Description)
1670	(1:328,000)	Anon.	WHOI 154m	A chart of the coast of Maine, New Hampshire, Massachusetts and New Plymouth....
1694	(1:398,000)	Southack	NA RG-23 844:1734	Chart of the Coast of Massachusetts from survey made by Capt. Cyprian Southack....
1738	(1:182,000)	Anon.	WHOI 152m	Colony of Plymouth.... (Map of Cape Cod and S.E. Massachusetts.)
1774	---	Green	LC	(Map of Massachusetts)
1779	(1:135,000)	Desbarres	LC	(Map of Cape Cod.)
177?	(1:450,000)	Anon.	LC	A Plan of the Sea Coast from Boston Bay to the Light House near Rhose Island.
1780	---	Universal Magazine	LC	Map of Massachusetts Bay Colony
1781	(1:137,000)	Atlantic Neptune	WHOI 162m	(Map of Cape Cod.)
1788	---	Green	LC	(Map of Cape Cod)
1788-9	---	Carlton	LC	(Map of Cape Cod)
1794	---	Stockdale	LC	(Map of Cape Cod)
1795	(1:1,200,000)	Lewis	WHOI 177m	(Map of Cape Cod.)
1795	(1:41,000)	Anon.	MA #1031 1794 ser. v.9, p.6	The line between Barnstable and Mashpee....
1795	(1:40,000)	Bassett	MA # 1025	A Plan of the Town of Barnstable.
1796	(1:1,000,000	Morse/ Jedidiot (Denison)	LC	A Map of Massachusetts.
1798	(1:160,000)	Anon.	WHOI 249m	(Map of Cape Cod; American Antiquities Society.)
1803	(1:140,000)	Anon.	WHOI 114m	(Map of Cape Cod.)
1810	(1:250,000)	Lewis	LC	(Geographic and political map of Massachusetts.)

1/ Values in () are estimates.

Appendix 1 (cont.) Historical maps depicting the Popponessett Beach area.

Date	Scale	Source	Depository	Title (or Description)
1820	(1:250,000)	Lewis	LC	(Geographic and political Map of Massachusetts)
1822	(1:680,000)	Carey/ Lea	LC	The State of Massachusetts.
1822	---	Carleton	NA U.S. 97	Map of Massachusetts
1822	---	Gillet	LC	(Map of Cape Cod)
1824	---	Finley (Lewis)	LC	(Map of Cape Cod)
1826	(1:690,000)	Lucas/ Fielding	LC	Geographical, Historical and Statistical Map of Massachusetts. No. 12.
1827	---	Morse (Lewis)	LC	(Map of Cape Cod)
1827	---	Carey/ Lea (Lewis)	LC	(Map of Cape Cod)
183?	---	Finley (Lewis)	LC	(Map of Cape Cod)
1831	(1:29,000)	Hales	MA #1842 1830 ser. V.13 p.10	Mashpee in the County of Barnstable.
1831	(1:25,000)	Hales	MA #1835 1830 Ser. V.15 p.6	Plan of the Town of Barnstable.
1832	(1:160,000)	Anon.	WHOI 101m	(Map of Cape Cod).
1833	---	Sumner (Lewis)	LC	(Map of Cape Cod)
1833	(1:830,000)	Tanner	LC	Massachusetts and Rhode Island.
1834	---	Mitchell (Lewis)	LC	(Map of Cape Cod)
1836	(1:400,000)	Otis/ Broaders	LC, 1 of 2	New Map of Massachusetts
1836	(1:490,000)	Wilcox	LC, 2 of 2	Map of Massachusetts, Rhode Island and Connecticut.
1836	---	Packard/ Brown (Lewis)	LC	(Map of Cape Cod)
1837	---	Mitchell	LC	(Map of Cape Cod)

Appendix 1 (cont.) Historical maps depicting the Popponessett Beach area.

Date	Scale	Source	Depository	Title (or Description)
1838	---	Bradford	LC	
1838	---	Brown/ Parsons	LC	
1840	---	Darr/ Howland	LC	
1841	(1:830,000	Tanner	LC	Massachusetts and Rhode Island
1841	---	Phelps/ Ensign	LC	Map of Massachusetts, Rhode Island and Connecticut
1844	1:316,800	Hitchcock	NARS RG-23 L&A 844 1844-3(2)	Geological Map of Massachusetts....
1844	1:158,400	Smith	NARS RG-23 L&A 844: 1844-2(1)	(Map of Massachusetts)
1857	(1:290,000)	Bache	NARS RG-77 B 84(1)	(Map of Cape Cod and Islands.)
1857	1:200,000	USC&GS	NARS RG-77 B 84 (2)	Cape Cod Mass. to Saughkonnet Point, R.I.
1858	(1:81,000	Walling	LC	(Map of Massachusetts)
1858	---	Whitlock's	MBL (displayed)	Barnstable. Barnstable Co., Mass.
1860	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 1	Coast Chart No. 12, Muskeget Channel to Buzzards Bay and Entrance to Vineyard Sound, Mass.
1861	---	Blunt	NARS L&A 844:1861	Map of Massachusetts Bay
1862	---	Rogers/ Pilot	LC	(U.S. Survey Chart)
1871	---	---	LC	(Fisheries Chart)
1877	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 3	Coast Chart No. 12, Muskeget Channel to Buzzards Bay and Entrance to Vineyard Sound, Mass.
1877	(1:570,000)	Gray	NARS RG-77 U.S. 373-59	Massachusetts, Rhode Island and Connecticut.
1892	(1:130,000)	Walker	LC	Map of Cape Cod and Vicinity.
1894	(1:5,000)	Anon.	MA #4019	Plan of the Mashpee/Barnstable Town Line
1896	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 8	Vineyard Sound and Buzzards Bay. Chart No. 112, 8th edition.
1901	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 9	Vineyard Sound and Buzzards Bay. Chart No. 112, 9th edition.

Appendix 1 (cont.) Historical maps depicting the Popponessett Beach area.

Date	Scale	Source	Depository	Title (or Description)
1902	---	Walker	LC	(Map of Cape Cod and Vicinity)
1905	---	Walker	LC	(Map of Cape Cod and Vicinity)
1907	---	Walker	LC	(Map of Cape Cod and Vicinity)
1908	---	Walker	LC	(Map of Cape Cod and Vicinity)
1909	---	Walker	LC	(Map of Cape Cod and Vicinity)
1909	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 11	Vineyard Sound and Buzzards Bay. Chart No. 112, 11th edition.
1910	---	Walker	LC	(Map of Cape Cod and Vicinity)
1911	---	Walker	LC	(Map of Cape Cod and Vicinity)
1914	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 15	Vineyard Sound and Buzzards Bay. Chart No. 112, 15th edition.
1915	---	Walker	LC	(Map of Cape Cod and Vicinity)
1917	1:80,000	USC&GS	NARS RG-23 Chart 112 ed. 15(2)	Vineyard Sound and Buzzards Bay. Chart No. 112 (Special Issue), 15th edition.
1917	1:62,500	USGS	NARS RG-57	Massachusetts, Barnstable Quadrangle.
1920	(1:80,000)	US Bureau of Soils	LC	Soils Map, Massachusetts Barnstable County Sheet
1922	---	Bureau of Public Works	LC	(Map of Cape Cod)
1926	---	Malanie	LC	(Pictoral chart of Cape Cod)
1930	---	---	LC	(Pictoral map of Cape Cod)
1931	(1:160,000	Tripp	LC	(Illustrated map of Cape Cod.)
1932	---	Goffney	LC	(Map of Cape Cod)
1933	---	Crawford Press	LC	(Pictoral map of Cape Cod)
1934	---	Cape Cod Chamber Commerce	LC	Tourist Map of Cape Cod

Appendix 1 (cont.) Historical maps depicting the Popponessett Beach area.

Date	Scale	Source	Depository	Title (or Description)
1935	---	National Ocean Survey Co.	LC	(Tourist map of Cape Cod for Copley Plaza)
1936	---	Robbins Studio	LC	Wallet Map of Cape Cod
1938	(AERIAL PHOTO COVERAGE STARTS HERE - See Appendix 2)			
1939	---	Barnstable Plan. Bd.	LC	(Map of Popponesset Beach area)
1939	---	Gulf Oil	LC	(Road map of Cape Cod)
1939	1:31,680	USGS	WHOI	Cotuit, Mass. Quadrangle Map.
1941	---	Auto League	LC	(Auto map of Cape Cod)
1944	1:20,000	USC&GS	USC&GS Chart 259	Nantucket Sound. Osterville to Green Pond.
1947	---	Miller	LC	(Map of Cape Cod)
1949	1:24,000	USGS	WHOI	Cotuit, Mass. Quadrangle Map.
1956	---	Map Corp.	LC	(Map of Cape Cod)
1959	---	Community Advertising	LC	(Map of Cape Cod)
1961	1:24,000	USGS	WHOI	Cotuit, Mass. Quadrangle Map.
1967	1:24,000	USGS	WHOI	Cotuit, Mass. Quadrangle Map.
1979	1:25,000	USGS	WHOI	Cotuit, Mass. Quadrangle Map., (photorevised)

Abbreviations

LC = Library of Congress Geography and Maps Room
MA = Commonwealth of Massachusetts Archives. Office of the Secretary, Archives Division, Room 55, State House, Boston, Ma.
MBL= Library, Marine Biological Laboratory, Woods Hole, Ma.
NARS = National Archives. General Services Administration Cartographic Archives Division Rm 2W, 8 Pennsylvania Avenue, Washington, D.C.
USC&GS = U.S. Coast & Geodetic Survey.
USGS = U.S. Geological Survey, Washington, D.C.
WHOI = Woods Hole Oceanographic Institution, Records Library, Woods Hole, Mass.

Appendix 2. Aerial photographs depicting the Popponesset Beach area. (For information on depositories see Appendix 3).

Date	Scale	Source	Depository	Frame Numbers
21 Nov. 1938	1:24,000	USGS	NARS	95, 97, 102, 104, 106, 107, 109
18 Dec. 1940	1:20,020	USAF	NARS	13, 15, 26, 27, 38, 107
24 June 1943	1:25,000	USAF	NARS	2, 21, 20, 23, 28, 30, 5, 7, 61 110
6 Oct. 1947	1:24,500	USAF	NARS	16, 17, 19, 21, 32, 33, 34
Oct. 1949	1:18,000	LAPS	LAPS	3
19 Oct. 1949	1:40,500	USAF	NARS	3, 25, 45
22 Oct. 1951	1:20,250	USDA	WHOI (DGA)	16, 38, 40
23 Oct. 1951	1:9,800	USC&GS	NOS	66, 67, 76, 78, 80, 82
26 July 1952	1:66,200	RAS	RAS	
15 Nov. 1955	1:30,200	USC&GS	NOS	1, 15, 17, 53, 57
6 May 1960	1:63,750	USAF	NARS	30, 31, 32, 33
2 May 1960	1:7,600	TDG	TDG	26
2 May 1960	1:7,600	TDG	TDG	1581, 1705, 1576 1499, 1096, 1143 1654, 1652, 1647, 1649, 1707
12 April 1961	1:29,900	USC&GS	NOS	45, 46, 47, 48, 49, 50
11 April 1962	1:24,242	USC&GS	NOS	71, 72, 73, 74, 78, 79, 80
1 April 1965	1:40,000	LKBI	LKBI	12, 13, 14, 15, 16
13 Sept. 1969	1:120,000	NASA	EROS	8
6 Oct. 1970	1:40,000	USDA	USDA	3, 33
29 Oct. 1970	1:40,000	USDA	USDA	9, 10, 11
5 Aug. 1971	1:20,000	USDA	USDA	15, 16, 17, 24, 29, 30, 31, 32, 42, 51, 52
27 May 1972	1:40,000	LKBI	LKBI	271, 272, 406, 407, 408, 409
25 March 1973	1:22,600	USGS	EROS	15, 16, 17, 21, 22, 23, 24, 25
25 March 1973	1:132,400	KAS	KAS	
15 March 1974	1:9600	COL	COL	19, 20
7 April 1974	1:9600	COL	COL	1-2

Appendix 2 (cont.). Aerial photographs depicting the Popponesset Beach area.

Date	Scale	Source	Depository	Frame Numbers
18 April 1974	1:30,200	USC&GS	NOS	22, 23, 24, 25, 26
2 May 1974	1:9600	COL	COL	6
5 March 1975	1:9600	COL	COL	3-3, 4-3, 3-5, 5-2
20 Aug. 1975	1:144,000	NASA	EROS	8754
Nov. 1976	1:11,900	REDI	REDI	30
May 1976	1:11,900	REDI	REDI	35, 38, 37A, 29
1 April 1977	1:82,000	USGS	EROS	63, 64, 66, 82
17 April 1977	1:83,000	USGS	EROS	9, 10
29 April 1978	1:18,000	(check)	ANCO	163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 201, 202, 204, 205
8 May 1978	1:25,000	LMI	LMI	90, 91, 92, 109, 110, 111, 112, 113, 114
20 April 1978	1:115,000	NASA	EROS	39
21 April 1979	1:115,000	NASA	EROS	99

Appendix 3. Depositories of vertical aerial photographs.

A. Private

APNE	Aerial Photos of New England, Inc.	Norwood Municipal Airport Access Road,Norwood, MA 02062
AGC	Aero-Graphics Corp.	Box 248, Bohemia, NY 11716
AMS	Aero-Marine Surveys	38 Green Street, New London, CT 06320
AIT	Air Image Technology	Boxboro Road, Stow, MA 01775
ANCO	Anderson-Nichols Co.	150 Causeway Street, Boston, MA 02114
AVIS	Avis Air Map, Inc	454 Washington Street, Braintree, MA 02184
BSC	Boston Survey Consultants	263 Summer Street, Boston, MA 02210
COL	Col-East, Inc.	Harriman Airport, North Adams, MA 01247
DFS	Dutton Flying Service	239 Newton Road, Haverhill, MA 01830
FAS	Fairchild Aerial Surveys	Los Angeles, CA
RK	Mr. Richard Kelsey	20 Heritage Lane, Chatham, MA
KAS	Keystone Aerial Surveys, Inc.	North Philadelphia, PA
LKBI	Lockwood, Kessler & Bartlett, Inc	One Aerial Way, Syosset, NY 11791
LMI	Lockwood Mapping, Inc.	P.O. Box 5790, 580 Jefferson Rd., Rochester, N.Y. 14623
LAPS	Lowry Aerial Photo Service	234 Cabot Street, Beverly, MA 01915
NESS	New England Survey Service	1220 Adams Street, Box 412, Dorchester, MA 02122

Appendix 3 (cont.). Depositories of vertical aerial photographs.

NEAA	Northeast Airphoto Association, Inc.	29 Grafton Circle, Shrewsbury, MA 02576
REDI	Real Estate Data, Inc.	Northeast Division, 629 Fifth Avenue, P.O. Call Box D, Pelham, N.Y. 10803
RAS	Robinson Aerial Surveys	
JWS	James W. Sewall Company	West Wareham, MA 02576
TDG	Teledyne Geotronics	725 E. 3rd Street, Long Beach, CA 90802
WHOI	Data Library	Woods Hole Oceanographic Institution, Woods Hole, MA 02543

B. Government

NED	U.S. Army Corps of Engineers	New England Division, 424 Trapelo Road, Waltham, MA 02154
USDA	U.S. Department of Agriculture	Agricultural Stabilization and Conservation Service, 2222 W. 2300 South, P.O. Box 30010, Salt Lake City, Utah 84125 and, Soil Conservation Service, Cartographic Division, Federal Center Building No. 1, Hyattaville, MD 20782
NARS	National Archives and Record Service	General Services Administration, Cartographic Archives Division Rm 2W, 8 Pennsylvania Avenue NW, Washington, D.C. 20408
NCIC	U.S. Department of Defense	Central Film Library, U.S. Geological Survey, National Cartographic Information Center, National Center, Mail Stop 507, Reston, VA 22092
EROS	U.S. Department of Interior	EROS Data Center, Sioux Falls, SD 57198
NOS	Chief, Photo Map & Imagery Section	Coastal Mapping Division, C3415, National Ocean Survey, NOAA, Rockville, MD 20852

Appendix 4. Certain dredging statistics for Popponessett Bay and adjacent areas (data from U.S. Army Corps of Engineers permitting records, Waltham, and from the Massachusetts Department of Environmental Quality Engineering, Division of Waterways permitting records; figures in () are estimates).

A. Popponesset Bay

Date	Reference	Volume (m3)	Comments
1916*	----	(22,000 -45,500)	No records located. Project indicated by USC&GS (1916)and by U.S. Army Corps of Engineers (1972).
1936*	----	(30,400)	No records located. Project indicated by U.S. Army Corps of Engineers (1972).
1957	MA-COTU-57-56	1,400	(a).** Private structure, channel and basin
1960*	MA-COTU-60-187	107,000	Channel from Popponesset Creek to inlet. Spoil disposed of on Popponesset Beach near Big Thatch island and on shores of Popponesset Creek and Island (See contract No. 2074, sheets 1 and 2; Account No. 04071 A, B; (Mass. Dept. Public Works, 1961).
1962	MA-COTU-62-259	----	Popponesset Creek and Holly Marsh.
1962	MA-COTU-62-275	100	Spoondrift Cove (Popponesset Creek). Private structure and basin.
1962	MA-COTU-62-286	----	Popponesset Creek.
1965	MA-COTU-65-19(?)	85	Popponesset Creek. Private structure and basin.
1966	MA-COTU-66-236	45	(a). Ockway Bay. Private structure and basin
1967	MA-COTU-67-220	40	(a). Popponesset Creek. Private structure and basin.
1968	MA-COTU-68-266	2,600	(a). Santuit River. Private structure and basin.
1969	MA-COTU-69-202	150	(a). Popponesset Creek. Private structure and basin.
1969	DPW 5622	150	(a). Popponesset Creek (MA-COTU-69-215).
1969	DPW 5926	720	(a).
1970	MA-COTU-?	200	(a). Shoestring Bay. Private structures and basin.
1973	DPW 6080	3,440	Santuit River and Mashpee River.

* Asterisk indicates projects of the Massachusetts Department of Public Works.

** (a). = Dredge spoil disposed of above mean high water level or behind bulkhead on adjacent property.

Appendix 4 (cont.) Dredging Records.

B. Cotuit Bay

Date	Reference	Volume (m3)	Comments
1947*	MA-COTU-47-121	----	Three shoal areas in Cotuit Harbor. Records destroyed.
1949*	MA-COTU-49-105	----	Structures and dredging at Cotuit Heights.
1950	MA-COTU-50-72	----	Private structure and basin in Tim's Cove.
1951	MA-COTU-51-213	----	Private structure and channel.
1952	MA-COTU-52-228	(900)	(a). Private boat basin and channel at Grand Island near Seapuit River. Spoils placed on Grand Island
1952	MA-COTU-52-229	(200)	(a). Private boat basin. Spoils placed on Grand Island
1952	MA-COTU-52-230	(3,000)	(a). Private boat basin. Spoils placed on Grand Island.
1953*	MA-COTU-53-93	----	Approaches to Cotuit Bay in Nantucket Sound. Spoils placed on east end of Dead Neck (see plan for Contract No. 1335, Account No. 03143-A. Mass. Dept. Public Works, Div. Waterways).
1954*	MA-COTU-54-77	(12,700)	Channel near Cotuit Highlands. Spoils disposed of in Nantucket Sound, 3.5 miles offshore (see plan for Contract No. 1377, Account No. 03207. Mass. Dept. Public Works, Div. Waterways).
1961	MA-COTU-61-102	(2,100)	Private channel and basin.
1962	MA-COTU-62-87	----	Private basin. Tim's Cove.
1962	MA-COTU-62-98	----	Private structure and basin in The Narrows.
1964	MA-COTU-147?	(100)	(a). Private structure and basin.
1967*	MA-COTU-67-100	(16,800)	Entrance channel to Cotuit Bay. Spoils disposed of on Dead Neck (see plan for Contract No. 2590, Account No. 04608. Mass. Dept. Public Works, Div. Waterways).
1968	MA-COTU-68-200	(350)	(a). Private structure and boat basin.
1968	MA-COTU-69-139	200	(a). Private structure and boat basin.
1971*	MA-COTU-71-94	31,400	Navigation channel. Spoils disposed of on Grand Island (see plan for Contract No. 2681, Account No. 04785-A, sheets 1 and 2. Mass. Dept. Public Works, Div. Waterways).

Appendix 4 (cont.) Dredging Records.

C. Sepuit River

Date	Reference	Volume (m3)	Comments
1949	MA-COTU-49-50	----	Private basin. Spoils placed on adjacent shore.
1950*	MA-COTU-50-236	4,900	(a). Spoils disposed of on Dead Neck.
1952	MA-COTU-52-8	----	Private boat basin.
1952	MA-COTU-52-259	----	Private boat basin.
1955*	MA-COTU-55-42	(10,000)	Channel dredged. Spoils disposed of on east end of Dead Neck (see plan for Contract No. 1465, Account No. 03333. Mass. Dept. Public Works, Div. Waterways).
1955	MA-COTU-55-143	(85)	Private structure and boat basin.
1958	MA-COTU-58-210	(400)	Private structure and boat basin.
1958	MA-COTU-58-184	(250)	Private structure and boat basin.
1959*	MA-COTU-59-41	(21,500)	Channel dredged.
1959	MA-COTU-59-100	(800)	Private boat basin.
1959	MA-COTU-59-92	----	Private structure and boat basin.
1962	MA-COTU-62-24	----	Private channel.
1962	MA-COTU-62-143	----	Private structure and boat basin.
1969	MA-COTU-69-100	1,500	(a). Private structure and boat basin.

D. West Bay

Date	Reference	Volume (m3)	Comments
(1900*)	----	----	Dredging associated with construction of West Bay inlet and jetties, between 1896 and 1901 (depicted on USC&GS 1901).
1947*	MA-COTU-47-120	----	Approach channel to West Bay in Nantucket Sound. Records destroyed.
1950*	MA-COTU-50-237	(33,100)	(a). Channel in West Bay from entrance to bridge at Osterville.
1952	MA-COTU-52-258	----	Private structures and boat basin.
1953	MA-COTU-53-38	----	(a). Private structure and boat basin near Little Island.
1953*	MA-COTU-53-93	----	Approach channel to West Bay. See related project at Cotuit Bay under same reference number.
1953*	MA-COTU-53-194	(6,800)	(a). Entrance channel to West Bay. Spoils disposed of on Dead Neck and in Nantucket Sound.
1957	MA-COTU-57-299	(100)	Private structure and boat basin.
1958*	MA-COTU-58-200	(8,900)	Entrance channel to West Bay. Spoils disposed of on Dead Neck.

Appendix 4 (cont.) Dredging Records.

D. West Bay (cont.)

Date	Reference	Volume (m3)	Comments
1958	MA-COTU-58-304	(9,300)	Private channel and turning basin in Great Cove.
1959	MA-COTU-59-171	(500)	Private structures and boat basin.
1961	MA-COTU-61-161	(13,800)	Private project in Eel River.
1964	MA-COTU-64-63	(2,000)	Private channel and basin.
1966*	MA-COTU-66-139	16,000	(a). Entrance channel to West Bay. Spoils disposed of on Dead Neck.
1967	MA-COTU-67-61	460	(a). Private basin.
1967	MA-COTU-67-158	840	(a). Private basin.
1970	MA-COTU-	1,400	(a). Private structure and boat basin.

E. North (Great) Bay

Date	Reference	Volume (m3)	Comments
1948	MA-COTU-48-76	----	Private structure and basin.
1949	MA-COTU-49-55	----	Private structure and basin.
1950	MA-COTU-50-71	----	Private structure and basin near bridge to Little Island.
1952	MA-COTU-52-138	----	Private structure and basin near Little Island.
1953*	MA-COTU-53-199	----	(a). Dredge two basins near Little Island at highway bridge (see plan for Contract No. 1335, Account No. 03143-A and B. Mass. Dept. Public Works, Div. Waterways).
1957*	MA-COTU-57-54	(26,000)	(a). Dredge basin and entrance channel from North Bay, Prince Cove to Osterville.
1957	MA-COTU-57-339	(1,700)	Private basin near Little Island.
1959	MA-COTU-59-118	----	Private structure and basin.
1961	MA-COTU-49-193	1,200	Private basin.
1961	MA-COTU-61-204	(2,700)	Private channel.
1962	MA-COTU-62-199	----	Private channel.
1961	MA-COTU-62-172	----	Private channel.
1964	MA-COTU-64-280	(1,700)	(a). Private basin.
1966	MA-COTU-66-31	(30)	Private structure and basin.
1966	MA-COTU-66-116	99,800_	Private structure and basin; the proposed dredged volume is assumed to be incorrect
1966	MA-COTU-66-119	(14,400)	(a). Private structure and basin.
1966	MA-COTU-66-129	----	(a). Private structure and basin.
1968	MA-COTU-68-11	600	(a). Private basin.
1968	MA-COTU-68-123	340	(a). Private structure and basin.
1969	MA-COTU-69-225	200	(a). Private structure and basin.
1970	MA-COTU-70-273	760	(a). Private channel.

Appendix 5. Man-made structures in Nantucket Sound in the Popponesset Beach area. Reference numbers with "MA-COTU" prefix are U.S. Army Corps of Engineers (Waltham, Mass.) permit records.

Date	Reference No.	Location	Comments
(1900)	USC&GS (1909)	West Bay	Jetties stabilizing cut through Dead Neck to West Bay (USC&GS, 1901)
1950	MA-COTU-50-10	Popponesset Beach	Five stone jetties in Nantucket Sound (see plan for Contract No. 1124, Account No. 02788. Mass. Dept. Public Works, Div. Waterways).
1952	MA-COTU-52-69	Wianno	Four wooden bulkheads, located 2,600' east of entrance to West Bay, extending 27-40' seaward.
1953	MA-COTU-53-253	Osterville	Jetty one mile east of entrance to West Bay, extending 90' seaward of MHW .
1953	MA-COTU-54-3	Popponesset Beach	Two stone groins about 1.5 miles SW of entrance to Popponesset Bay (MDPW).
1954	MA-COTU-54-51	Osterville	Stone jetty in Nantucket Sound.
1954	MA-COTU-54-244	Popponesset Beach	Two stone jetties in Nantucket Sound about 2.1 miles SW entrance to Popponesset Bay near Nick Trail and Kim path (see plans for Contract No. 1437; Account No. 03291, Massachusetts Dept. Public Works, Div. Waterways).
1956	-----	Popponesset Beach	Stone mound and concrete sea wall (see plan for Contract No. 1673, Account No. 03605. Mass. Dept. Public Works, Div. Waterways).
1958	MA-COTU-58-130	Cotuit Highlands	Two stone groins.
1958	MA-COTU-58-282	Wianno Beach	Pier.
1958	MA-COTU-58-334	Cotuit (Meadow Pt.)	Eleven stone groins, precast seawall set on stone base, with riprap and fill shoreward of wall and sand fill on beach between groins (MDPW).
1960	MA-COTU-60-153	Wianno Beach	Stone groin.
1967	MA-COTU-67-99	Nantucket Sound	Pier, float, ramp and extended stone groin.

Appendix 6. Attendees at a public hearing convened to discuss beach changes at Popponesset Beach. August 18, 1980 (Chaired by Dr. David G. Aubrey and Dr. Arthur G. Gaines).

Norman and Alice Andrew	Off Wading Pl. Road, Popponesset
Robert Bennett	76 Buccaneer Way, Mashpee, MA 02649
Barbara Bennett	76 Buccaneer Way, Mashpee, MA 02649
Jerry Cahir	State Representative
Frank X. Carroll	Squaw's Lane, Popponesset
Karen Rodine Carroll	Squaw's Lane, Popponesset
John and Cheryl Cullen	Shore Dirve, Popponesset
Kevin F. Herrington	44 Shore Drive, Mashpee, MA 02649
Albert Hollander	473 Popponesset Island Rd., Mashpee, MA 02649
Walter and Shirley Kalnin	Wading Place Road, Box 585, Popponesset
Chester Koblinsky	Monomoscoy Road, Mashpee, MA 02649
William and Rowena Lammers	Starboard Lane, P.O. Box 442, Popponesset, Mashpee, MA 02649
Paul W. Lumsden	58 Captains Row, Mashpee, MA 02649
Marguerite Orlando	30 Captains Row, Mashpee, MA 02649
James Orlando	30 Captains Row, Mashpee, MA 02649
Edith Paparelle	279 Popponesset Island Rd., Mashpee, MA 02649
James F. Rich	1 Massasoit Circle, Mashpee, MA 02649
David A. Ross	53 Green Pond Rd., Falmouth, MA
Virginia T. Sandry	RFD 1 Box 401, 5 Starboard Lane, Popponesset
Leah and Mark Silva	Frog Pond Close Rd., Mashpee, MA 02649
Ted and Matt Steffora	Tidewater Village, New Seabury
Susan Stevens	Maushop Village, New Seabury
Dorothy A. Stone	6 Jeep Place, Box 354, Popponesset, Waquoit, MA 02536
B. Jean Thomas	17 Shorewood Drive, Mashpee, MA 02649
Mark L. Warcik	Shore Drive W., New Seabury
Mildred C. Wood	4 Starboard Land, Box 30, Popponesset, Mashpee, MA 02649

May 1980

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David G. Aubrey and Arthur G. Gaines, Jr.

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16. Abstract (Limit: 200 words)

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3. Popponesset Beach, Cape Cod, MA.

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