CHAPTER 47

EFFECTS OF NONUNIFORM WAVE ENERGY IN THE LITTORAL ZONE

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Abstract

Bi-weekly monitoring of four closely-spaced permanent beach profile stations located on the northeast end of Monomoy Island (Cape Cod) has revealed major variations in the amount of erosion and accretion occurring along this portion of the Massachusetts shoreline During the 27-month monitoring period a close relationship was observed between changes in the beach and offshore portions of the profiles Three distinct types of bars were noted

(1) Subtidal bars which are parallel to the shoreline and located one to two thousand feet off those portions of the shoreline undergoing relatively small amounts of beach erosion,

(2) Subtidal bars which are perpendicular to the shoreline and attached to areas of the shore undergoing large amounts of erosion, and

(3) Large intertidal bars which are oriented obliquely to the shoreline and associated with the formation of the ebb-tidal delta and the resulting wave refraction patterns

The large variations in erosion and accretion occurring along the beach at any one time are related to the nonuniform distribution of energy within the waves arriving at this section of the coastline This nonuniformity of wave energy is attributed to refraction of the waves around the irregular bathymetry offshore from Monomoy, and it appears to produce shoreline protuberances of sand which are flanked updrift and downdrift by erosional zones

Wave refraction calculations indicate zones of alternately converging and diverging orthogonals in the wave fronts impinging upon Monomoy Island, with a correlation observed between the zones of converging orthogonals, i e wave energy concentrations, and the areas of the beach presently undergoing the greatest amounts of erosion

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INTRODUCTION

Rythmic beach topography and its relationship to adjacent intertidal and subtidal bathymetry has been discussed by several authors (Bruun, 1954, Robinson, 1960, Hom-ma and Sonu, 1963, Sonu et al, 1966, Bakker, 1968, Sonu, 1968, Dolan and Ferm, 1968, Van Beek, 1969, Niederoda and Tanner, 1970) Attempts to relate nonuniform shoreline changes to wave refraction over irregular offshore bathymetry has been limited to large-scale effects (Munk and Taylor, 1947, Shepard and Inman, 1950, Jordaan, 1964, Roberts, 1964) In this study the nonuniform wave energy distribution produced by wave refraction over uneven offshore bathymetry is related to the large variations in erosion and accretion occurring at closely-spaced intervals on Monomoy Island

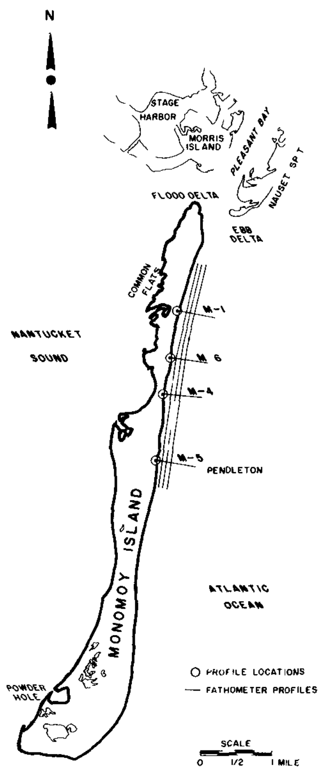
Monomoy Island is located on the "elbow" of Cape Cod, Massachusetts Monomoy was formed in Holocene time as a sand spit in response to the longshore currents resulting from the dominant northeast and eastnortheast waves impinging upon the outer beach of Cape Cod

Since June 1968, twelve beach profiles on Monomoy Island and four profiles on Nauset Beach to the north have been monitored at bi-weekly intervals throughout the year Approximately twice per year, fathometer profiles have been run to extend these profiles seaward from the high tide line to a distance of one and one-half miles from shore Fathometer profiles parallel to the shore were also obtained The variations in erosion and accretion occurring at these closely-spaced profiles are quite significant This discussion is limited to the four northernmost profiles on Monomoy so that variations between these profiles, and their relationship to changes in the offshore region, may be examined in detail (Fig 1)

BEACH PROFILES

The northernmost profile, M-1, underwent 35 feet of erosion on the terrestrial portion of the profile in the first year of observations (June 1968 to June 1969) but was accretional during the second year (Fig 2) In the offshore area of the M-1 profile a series of intertidal swash bars had migrated to the northwest (i e , onshore and into the page) during the period of these observations (Fig 2) This movement is a result of the refraction of northeast waves around the large ebb-tidal delta so that these waves actually approach from the southeast at the M-1 profile location One of the swash bars has become attached to the beach 300 feet north of the M-1 profile, causing a large accumulation of sand south of the bar at the M-1 profile (Fig 3)

The changes observed at the other three profiles suggest a slightly different interpretation but, nevertheless, illustrate the close relationship between changes in the terrestrial and offshore portions of the profiles The second profile, M-6, underwent 30 feet of erosion the first year (Fig 4) However, the rate of erosion increased substantially during the second year such that by March 1970 the beach had retreated 135 feet at the M-6 location Since March 1970 this profile has undergone



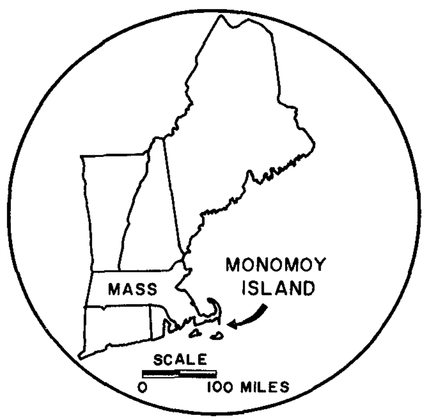
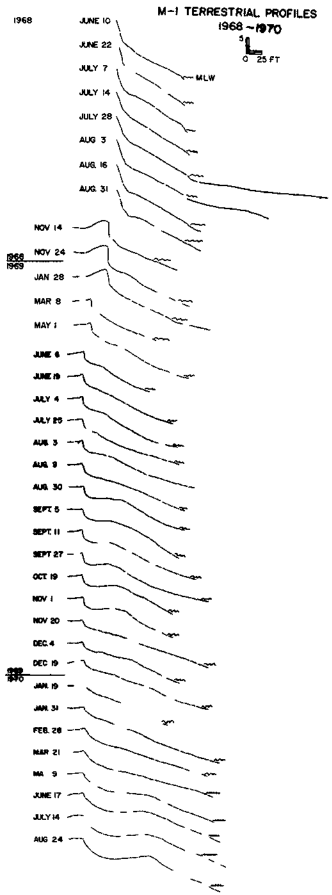


Fig 1 Locations are shown for the four northernmost profiles and the fathometer profiles discussed in this study The location of the study area, on the elbow of Cape Cod, Massachusetts, is shown in the insert



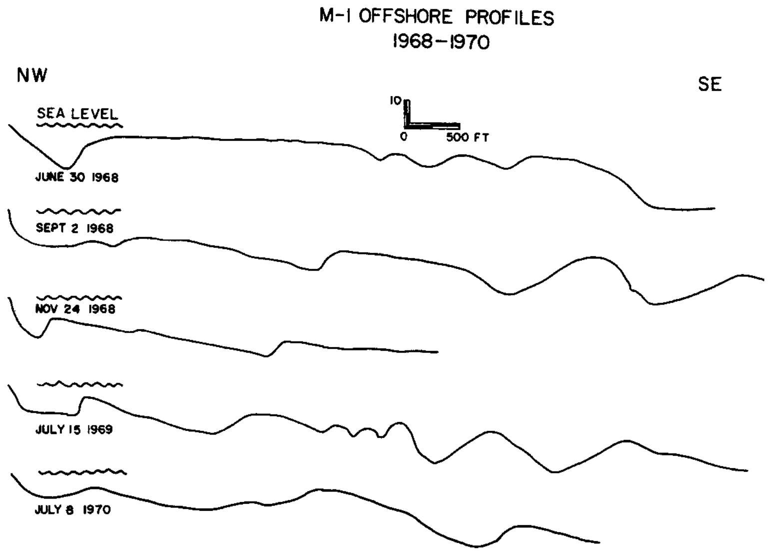


Fig 2 The M-1 terrestrial and offshore profiles Note that the terrestrial portion of the profile was erosional the first year and accretional the second year

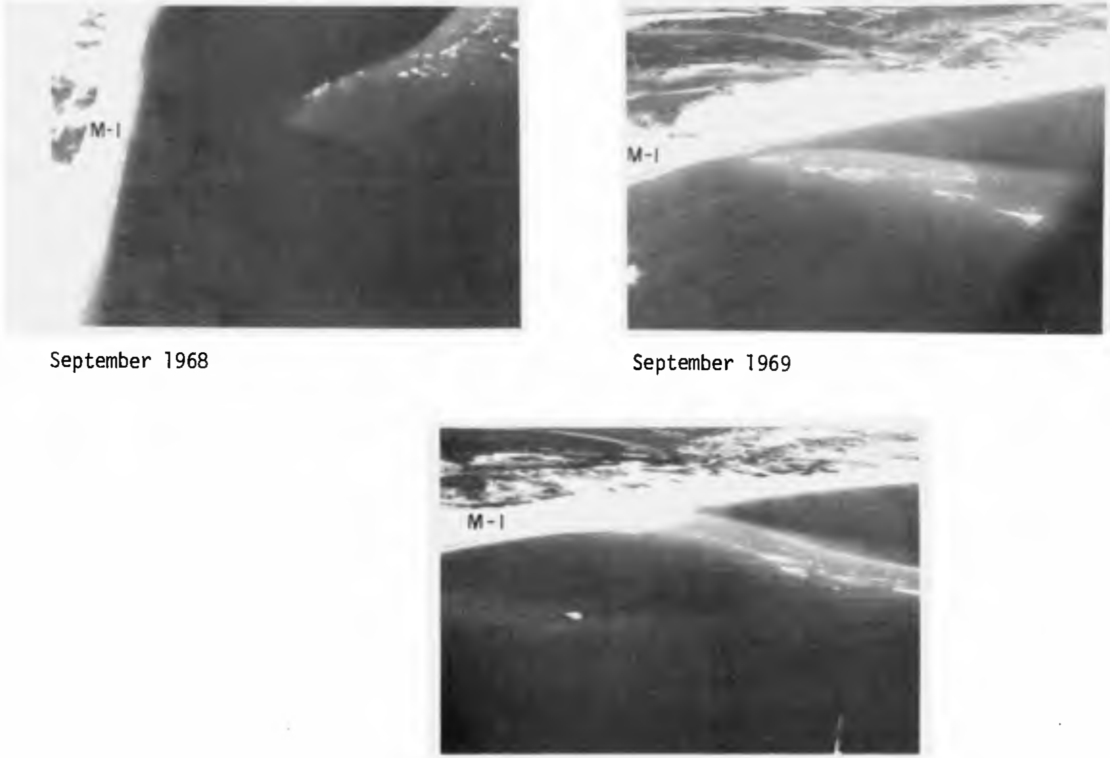


Fig. 3. Migration of a large intertidal swash bar to the northwest resulting from wave refraction around the ebb-tidal delta. In September 1968 the bar was opposite the profile, 600 feet from shore, and separated by a 12-foot deep channel. Note the waves approaching from the southeast. After the bar became attached to the shore in September 1969 the M-1 profile, south of the bar, became accretional as observed in July 1970.

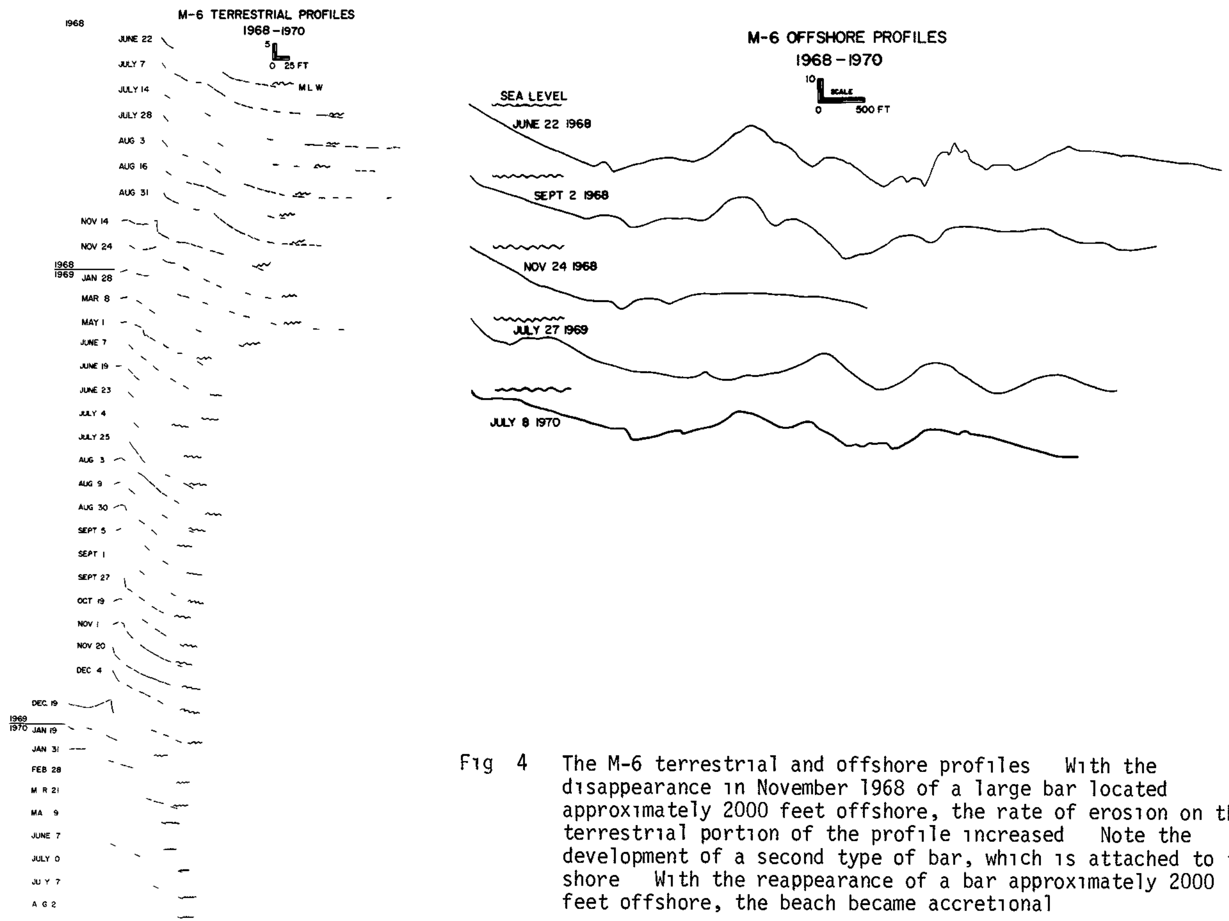


Fig 4 The M-6 terrestrial and offshore profiles With the disappearance in November 1968 of a large bar located approximately 2000 feet offshore, the rate of erosion on the terrestrial portion of the profile increased Note the development of a second type of bar, which is attached to the shore With the reappearance of a bar approximately 2000 feet offshore, the beach became accretional

approximately 50 feet of accretion. In June 1968 a large bar with an elevation of twelve feet above the adjacent sea bed, was located approximately 2000 feet from shore and oriented parallel to the shore. By November 1968 this bar had disappeared from the profile and the terrestrial portion of the profile had become highly erosional. With the development of a new bar on the profile, as seen in the July 1970 fathometer profile, the rate of erosion decreased sharply and the profile became accretional. Associated with the severe erosion was the development of a shoreline protuberance of sand downdrift from the M-6 profile (Fig. 5).

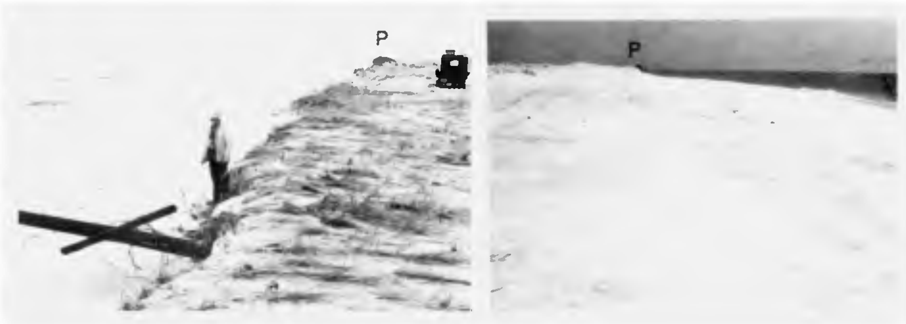
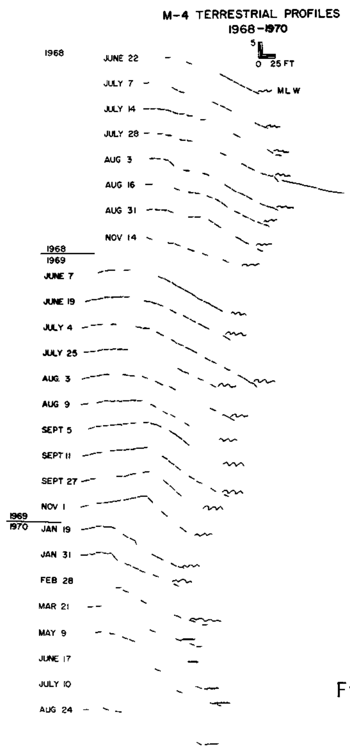


Fig. 5. Two views of the M-6 beach protuberance on December 19, 1969. The updrift erosional zone is shown on the left (looking south), and the accretional zone, downdrift from the view on the left, is shown on the right (looking north). Point P is the same in each photograph.

The offshore extension of the protuberance, in the form of an attached subtidal bar oriented approximately perpendicular to the shoreline, is recorded in the July 1969 fathometer profile (Fig. 4).

The M-4 profile is located at the narrowest part of the island (600 feet wide at high tide), yet it underwent the least amount of change in both the terrestrial and offshore portions of the profile (Fig. 6).

The M-5 profile is located adjacent to a beach protuberance much like the one near the M-6 profile. Therefore, the M-5 profile is similar in behavior to the M-6 profile in that an offshore bar parallel to the shore, is present when the terrestrial portion is accretional and absent when the terrestrial portion is most erosional (Fig. 7). During the erosional



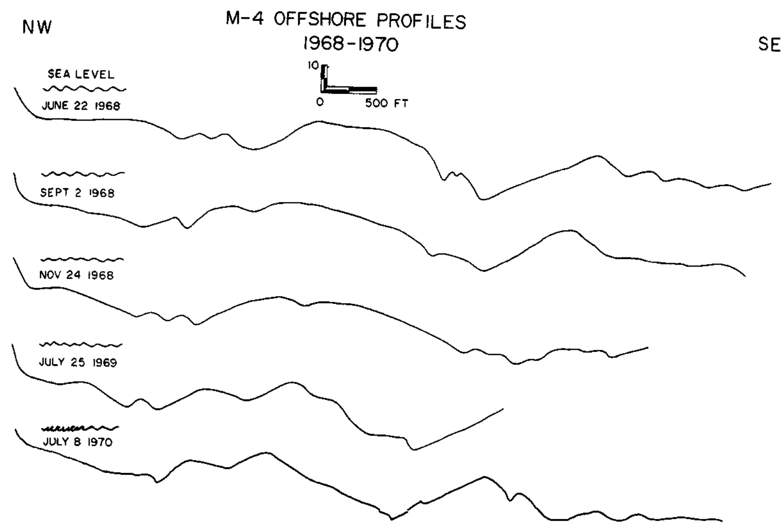


Fig 6 The M-4 terrestrial and offshore profiles Note that both portions of the profile underwent the least amount of change of the four profiles

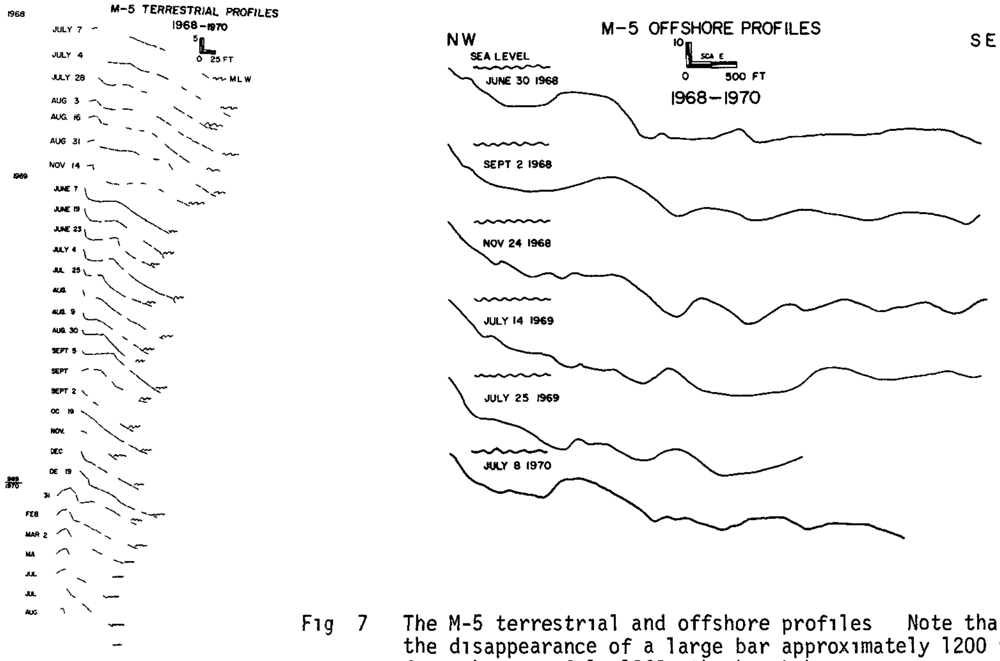


Fig 7 The M-5 terrestrial and offshore profiles Note that with the disappearance of a large bar approximately 1200 feet from shore in July 1969, the beach became more erosional With the development of a new bar in the previous location in July 1970 the rate of erosion decreased sharply

periods the second type of subtidal bar, which is perpendicular to the shoreline, began to form and is recorded on the July 25, 1969, fathometer profile The close relationship between erosional zones and the presence of subtidal bars perpendicular to the shoreline and attached to the shore is illustrated in Figure 8

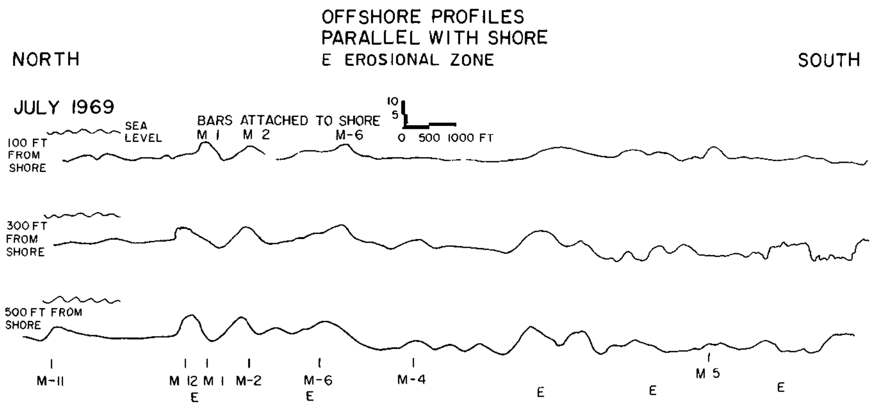


Fig 8 Fathometer profiles run parallel with, and 100, 300, and 500 feet from shore The areas of the Monomoy shoreline undergoing the severest amounts of erosion are indicated with the letter E Note the correlation between the maximum erosion and the presence of nearshore subtidal bars which are perpendicular to the shoreline

A summary of the erosion or accretion occurring at these four closely-spaced profiles during the 27 months of observations is given in Figure 9 and Table 1 It is readily apparent that there is a large variation in the rate of beach retreat along this shoreline This suggests the hypothesis that there is a considerable spatial variation in the wave energy arriving at Monomoy Island and that the formation of the beach protuberances can be associated with this nonuniformity of wave energy in the littoral zone

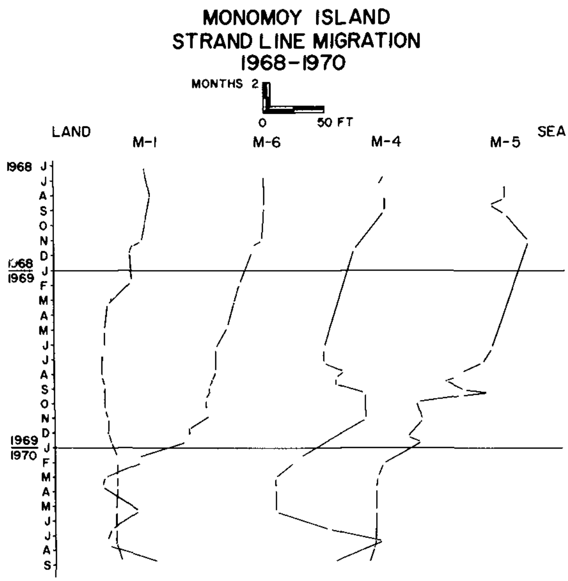


Fig 9 Rates of erosion and accretion at four permanent beach profiling stations located approximately one mile apart on Monomoy Island Leftward movement of the line under the profile number indicates erosion, while movement to the right indicates accretion

	M-1	M-6	M-4	M-5	
June 1968 - June 1969	35	30	35	0	Feet
June 1969 - March 1970	-10	105	40	75	
March 1970 - August 1970	- 7	-50	-48	6	
TOTALS	18	85	27	81	

Table 1 Summary of beach retreat at four profiles on Monomoy Island Negative amounts signify beach advance (accretion)

WAVE REFRACTION

A mechanism by which zones of wave energy concentration can be produced is illustrated schematically in Figure 10. Waves passing

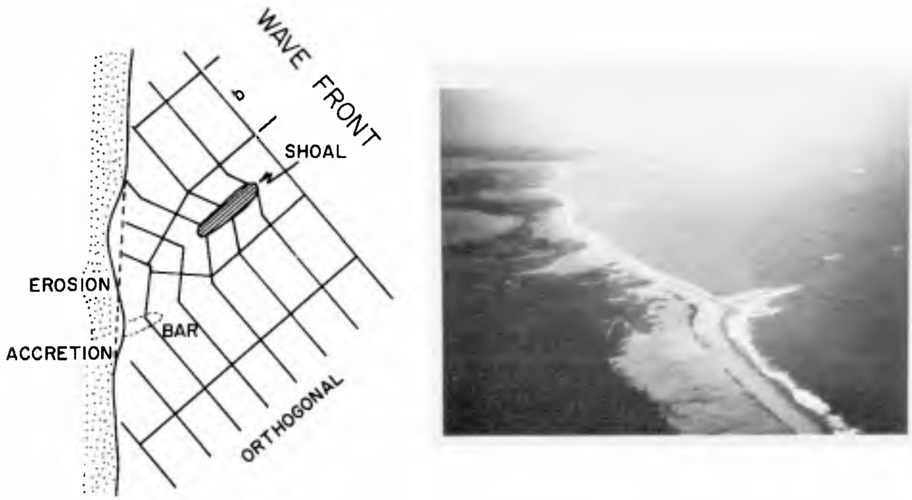


Fig. 10. A schematic diagram (left) illustrates the effects of wave refraction over irregular offshore bathymetry. This process results in differential erosion of the shoreline and causes segments of the shoreline to orient themselves perpendicularly to the dominant wave approach direction. Three beach protuberances are shown in the northward view of Monomoy Island (right).

over the highly irregular bathymetry offshore of Monomoy are refracted such that alternate zones of converging and diverging orthogonals are produced, indicating portions of the wavefront with increased or decreased wave energy concentration. When that portion of the wave front which contains the higher wave energy concentration impinges upon the shoreline, an increased rate of erosion can be expected to occur along that portion of the shoreline.

To test this hypothesis, a series of wave refraction computations were made with the aid of a digital computer (CDC 3600), using the Stanford University Wave Refraction Program originally developed by Dobson (1967) and adapted by the authors for use at the University of Massachusetts Research Computing Center. The computational techniques employed by this program have been summarized by Mogel et al (1970).

The bathymetric grid used in these computations is shown in Figure 11 The wave periods and approach directions chosen for the computations were based on the authors' personal observations of the dominant waves approaching Monomoy, and on deep water observations of the waves in the Marsden Square adjacent to Monomoy as compiled by the National Oceanographic Data Center The wave refraction diagrams resulting from the computations are illustrated in Figures 12 through 15 on the following pages

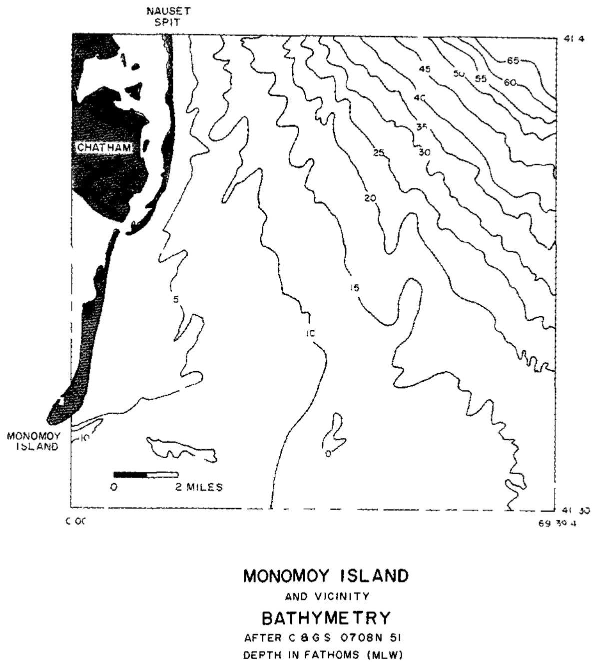


Fig 11 Bathymetric data used in the wave refraction computations covered the area shown as a square grid with a 0 2 nautical mile grid spacing The original C & G S Chart (No 0708N-51) upon which this grid is based has a one-fathom contour interval

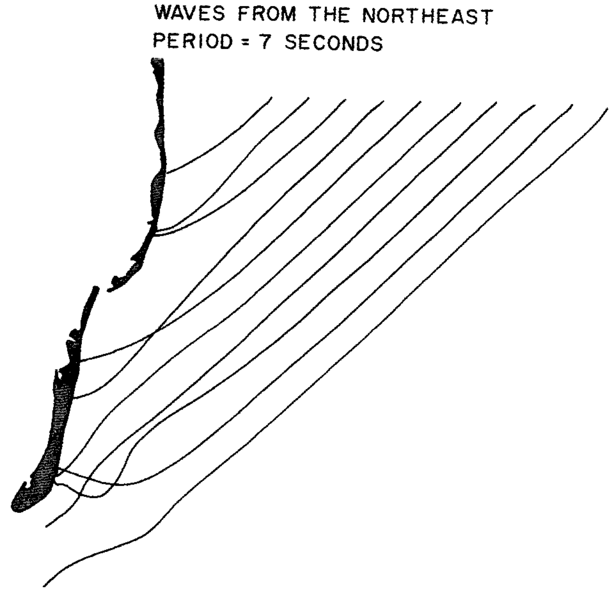


Fig 12 Refraction diagram showing rays (orthogonals) for waves from the northeast with 7-second period Initial separation of rays is one nautical mile

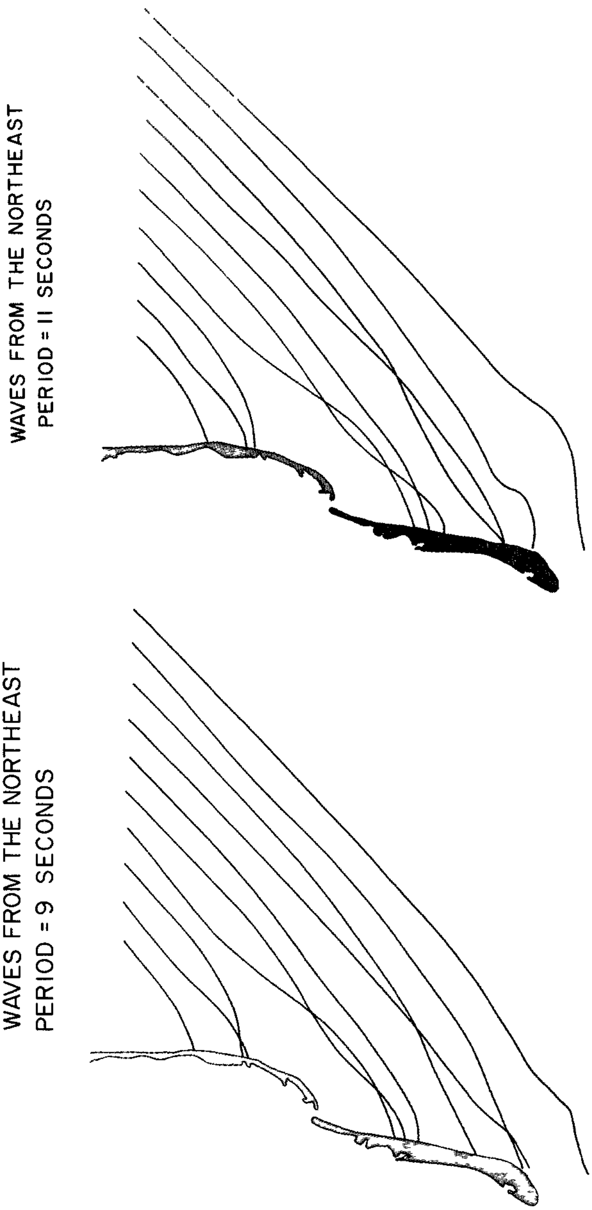


Fig 13 Refraction diagrams showing rays for waves from the northeast with 9-second (left) and 11-second periods (right) Initial separation of rays is one nautical mile

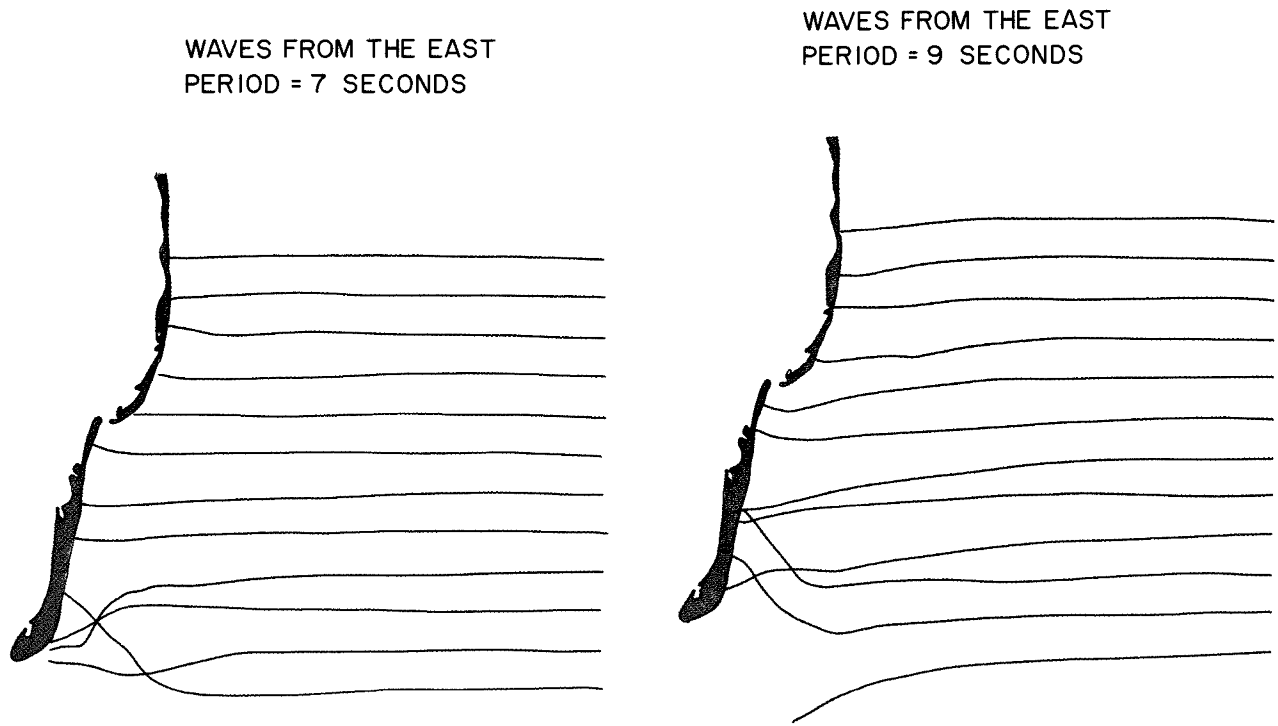


Fig 14 Refraction diagrams showing rays for waves from the east with 7-second (left) and 9-second periods (right) Initial separation of rays is one nautical mile

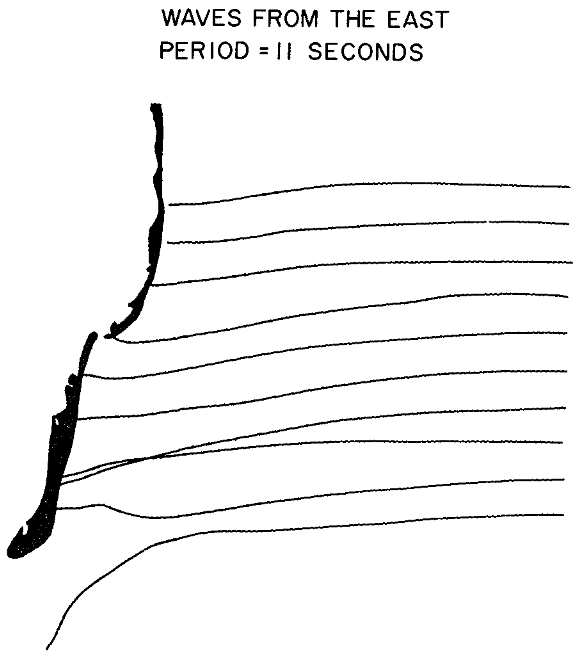


Fig 15 Refraction diagram showing rays for waves from the east with 11-second period Initial separation of rays is one nautical mile

CONCLUSIONS

Wave refraction computations indicate that wave energy is distributed rather unevenly along closely-spaced intervals of the Monomoy Island shoreline Field data suggest a strong correlation between concentrations of wave energy and those portions of the shoreline which are undergoing increased rates of erosion producing shoreline protuberances of sand which are flanked updrift and downdrift by erosional zones This implies that areas of increased erosion can be predicted by wave refraction computations and that coastline changes resulting from variations in the offshore bathymetry may be similarly predicted

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