MORPHOLOGY OF COASTAL BARRIERS, DELAWARE, U.S.A.

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ABSTRACT

The Atlantic Coast of Delaware consists of four separate but continuous segments including (from north to south): (1) a northward-projecting spit complex (Cape Henlopen); (2) eroding Pleistocene headlands; (3) a linear coastal washover barrier; and (4) an area of migrating inlets with associated modern and relict ebb and flood tidal deltas. Coastal process studies show that continuing coastal erosion is accompanied by longshore transport of sand eroded from headlands, offshore transport to the nearshore marine area, and overwash processes transporting sand landward across the barrier. Studies of the adjacent nearshore marine area show that the barrier and its various geomorphic elements lay at the outer edge of the continental shelf approximately 12,000 years ago, and migrated landward and upward to the present position as the Holocene marine transgression continued. The sequence of coastal sediments of the barrier system consist of (landward to seaward) tidal marsh fringe, lagoonal muds and sands, barrier sands (including washover, dune, and beach deposits), and shallow nearshore sand and gravel. Drill-hole studies provide information on the subsurface configuration of the barrier from which the three-dimensional structure and stratigraphy of coastal sedimentary environmental lithosomes may be defined.

INTRODUCTION

The Atlantic coast of Delaware lies on the northwestern flank of the Baltimore Canyon Trough geosyncline of the Atlantic continental shelf of eastern North America (Figure 1). This geosyncline has been subsiding at various rates since Jurassic time (180-135 million years B.P.) and includes marine and non-marine sediments deposited along the eastern edge of the North American continent. There appears to be a geologic "hinge line" near the present Delaware shoreline indicated by different rates of subsidence northwest and southeast of this hinge line (Kraft & others, 1976; Kraft & John, 1976; Belknap & Kraft, 1977). The Atlantic coast of Delaware is presently undergoing a marine transgression causing landward and upward movement of the coastal barrier in time and space. This transgression is the result of a combination of eustatic sea level rise as a consequence of the melting of continental glaciers over the past 12,000-14,000 years, and of tectonic subsidence and compaction.

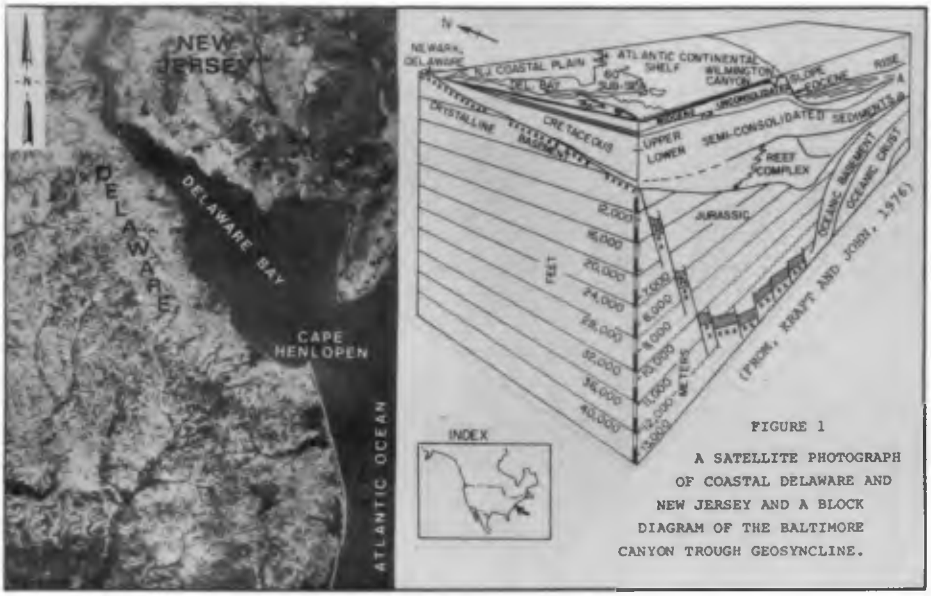

FIGURE 1
A SATELLITE PHOTOGRAPH OF COASTAL DELAWARE AND NEW JERSEY AND A BLOCK DIAGRAM OF THE BALTIMORE CANYON TROUGH GEOSYNCLINE.

GEOMORPHIC DIVISIONS AND COASTAL PROCESSES

The Atlantic coastal barrier of Delaware can be divided into four separate but continuous segments from north to south (Figure 2) as follows:
(1) A spit-beach-dune complex;
(2) Barrier against marsh;
(3) Barrier against pre-Holocene highlands, and
(4) Linear barrier-ebb and flood tidal delta-lagoon system.
(Kraft, 1971; John, 1977).

Studies of the barrier and the nearshore marine area adjacent to the Atlantic continental shelf show that the barrier and its various geomorphic elements at one time lay farther to the east of the present position, towards the outer edge of the continental shelf. Since about 12,000 years before present, this barrier system has been migrating landward and upward as the marine transgression continues. Continuing coastal erosion is accompanied by northward longshore transport of sands eroding from pre-Holocene highlands which crop out along the barrier coastline. Sand and gravel are deposited at the spit, Cape Henlopen, and into deeper water (20 m) at the mouth of the large estuary, Delaware Bay, at the northern end of the barrier system. In addition, sand is trapped in the ebb and flood tidal deltas associated with this barrier system at the Indian River inlet (Figure 2). It is estimated that the net longshore transport to the

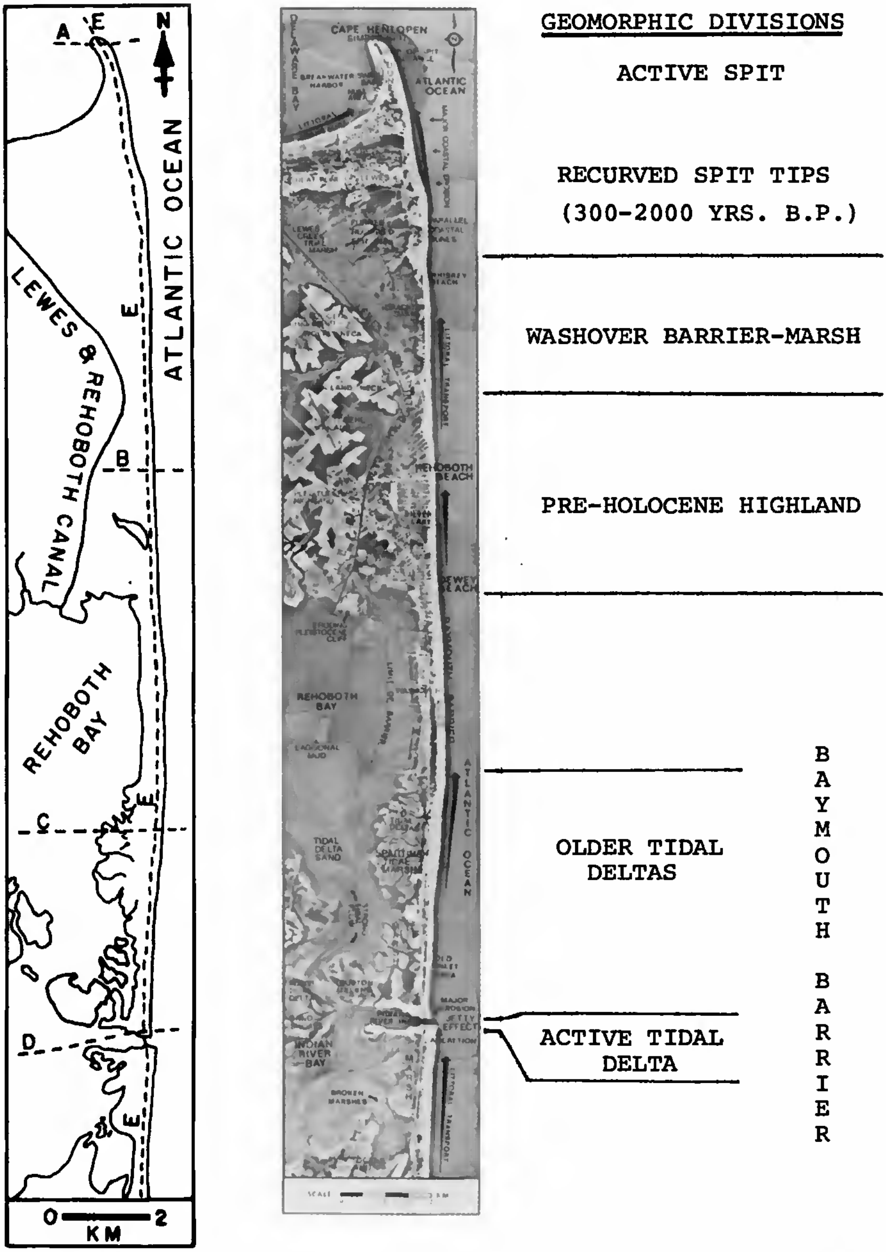

Figure 2. An index map and an aerial photo mosaic of Delaware's coastal zone indicating prominent geomorphic features. Lines of cross-section of figures in this paper are shown.

north along the Atlantic Coast ranges from 100,000-340,000 cubic meters per year (Turner, 1968).

In this area the average wave approach direction is from the east or southeast throughout the year. High intensity storms known as "northeasters" with a northeasterly wave component occur approximately once every two years in this region (Mather, 1965). Depending upon the position of the storm center as it passes the Atlantic Coast of Delaware, the longshore transport during storms may be to the north or south. In addition, large amounts of sand along the edge of the barrier may be transported offshore into the inner shelf region, or washed landward across the barrier into adjacent tidal marshes and coastal lagoons, forming washover fans. The major coastal processes in action are littoral transport of sand along the shoreface of the barrier accompanied by overwash of the barrier during times of high intensity

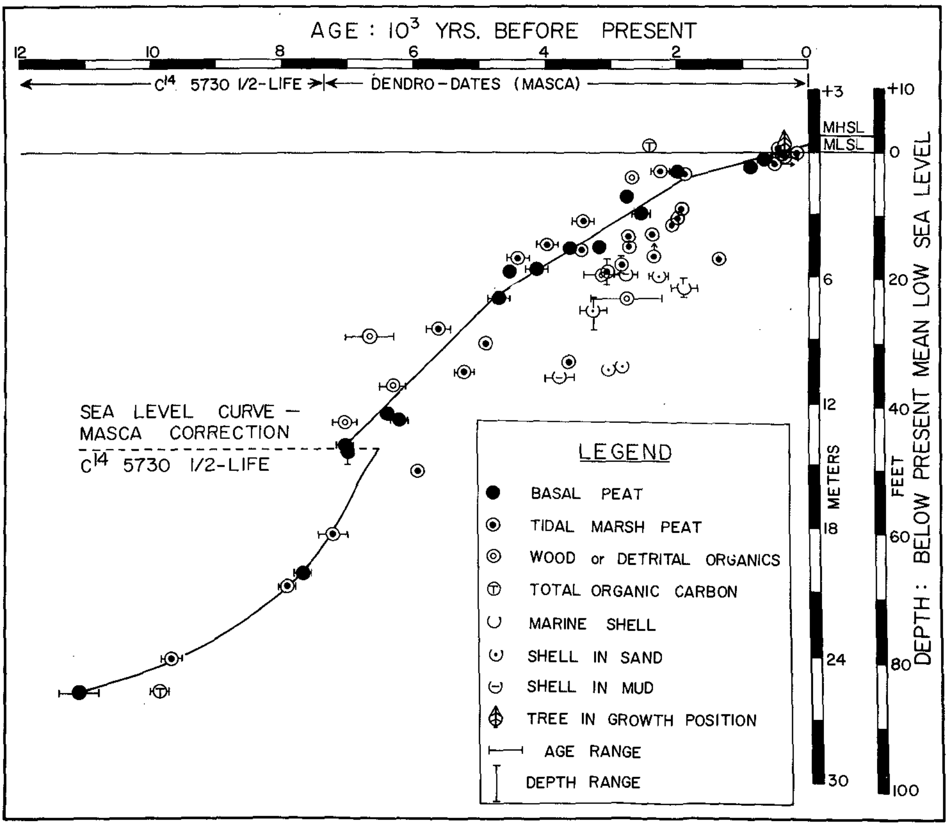

Figure 3. A local relative sea-level rise curve for coastal Delaware (Kraft, 1976).

storms. Transport of sand in the beach-berm and foreshore area can be by littoral transport in northerly or southerly direction, overwash across the barrier, transport by winds into dunes along the barrier, erosion and seaward transport and deposition on offshore bars, and transport through tidal inlets into flood and ebb tidal deltas.

Radiocarbon dates from basal salt marsh peats have enabled the construction of a local relative sea level curve for this area (Figure 3). This curve shows a continuing relative sea level rise in the Delaware Atlantic coastal region. During the Holocene Epoch (past 10,000 years) the local relative sea level shows different rates of change varying initially from 30 cm/century to the present 20 cm/century from approximately 5000 years before present (Kraft, 1976; Belknap and Kraft, 1977).

Tide gage records from the Delaware coastal area supported by tidal information from adjacent areas in New Jersey and Virginia, indicate a relative sea-level rise of approx. 33 cm/century based on an observation over the past 50 years (Figure 4).

Historical map records from various sources including the U. S. Coast and Geodetic Survey, U. S. Army Corps of Engineers, and National Ocean Survey may be used to determine average annual rates of shoreline change (Figure 5). These maps show persistent landward migration of the barrier system as a whole. Erosion rates varied from 0.4 to 3.1 meters per year over the time interval from 1765 to 1972. The only exceptions to these pervasive rates of landward erosion of the coast are those caused by construction of groins and jetties for stabilizing the coastline. However, even in the areas of groin fields net landward migration of the shoreline is occurring.

GEOLOGY

Figure 6 is a schematic representation of coastal processes in action modifying the coastline and the coastal environments undergoing transgression. Surface coastal environments, proceeding from land to sea, include pre-Holocene highlands, a tidal-marsh fringe, lagoonal muds and sands, back-barrier marshes, the Atlantic washover barrier including dunes, and the nearshore marine sands and gravels. Barrier sands tend to fill in the seaward side of the lagoon while tidal marsh sediments form at the leading edge of the Holocene transgression on the landward side of the lagoon. The beach-berm area is one of continual erosion and deposition with infrequent large washovers caused by hurricanes or "northeasters". Drill core studies of the subsurface stratigraphic units that have resulted from the landward Holocene

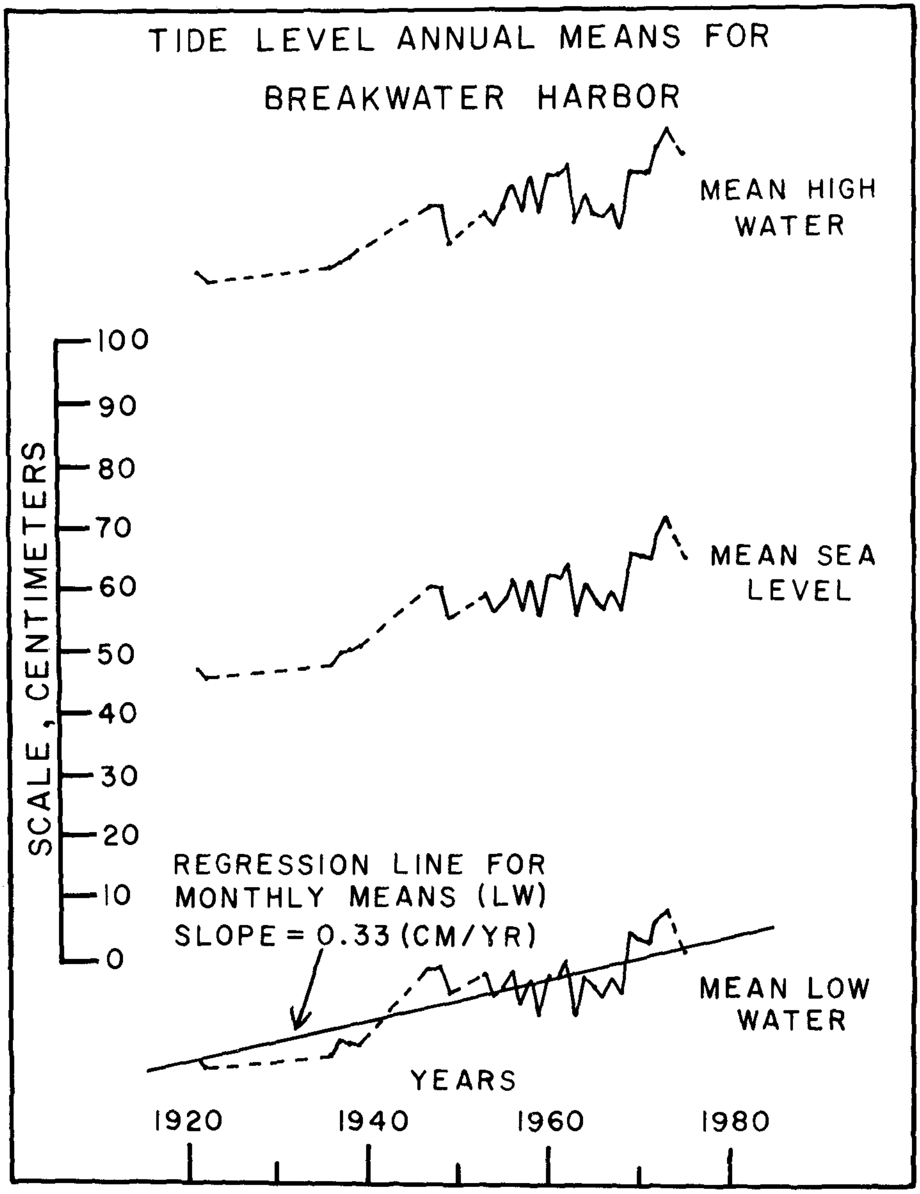

Figure 4. Tidal gage records from Breakwater Harbor at Lewes, Delaware showing relative sea-level rise during the 20th century (modified from Hicks and Crosby, 1974, and Demarest, 1978).

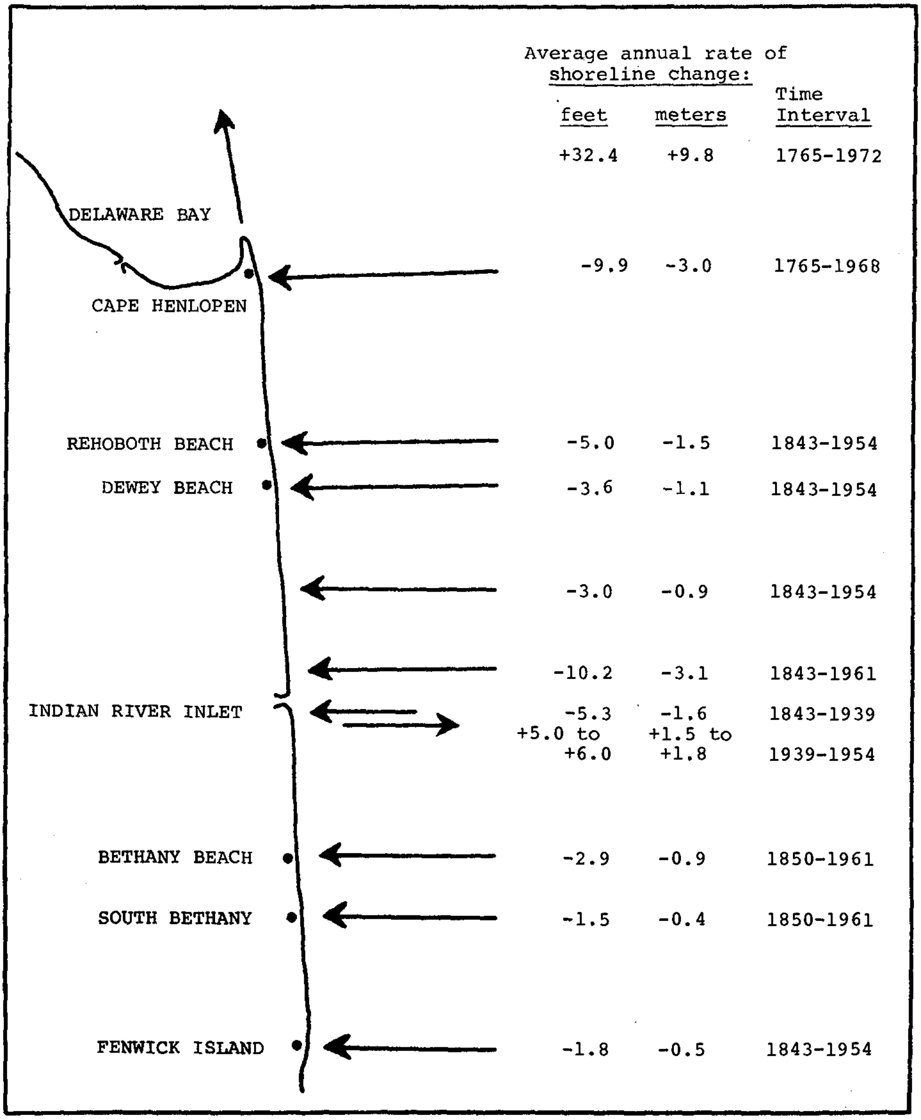

Figure 5. Average annual rate of shoreline changes for the Atlantic coast of Delaware (compiled from Moody, 1964 and U. S. Army Corps of Engineers, 1968).

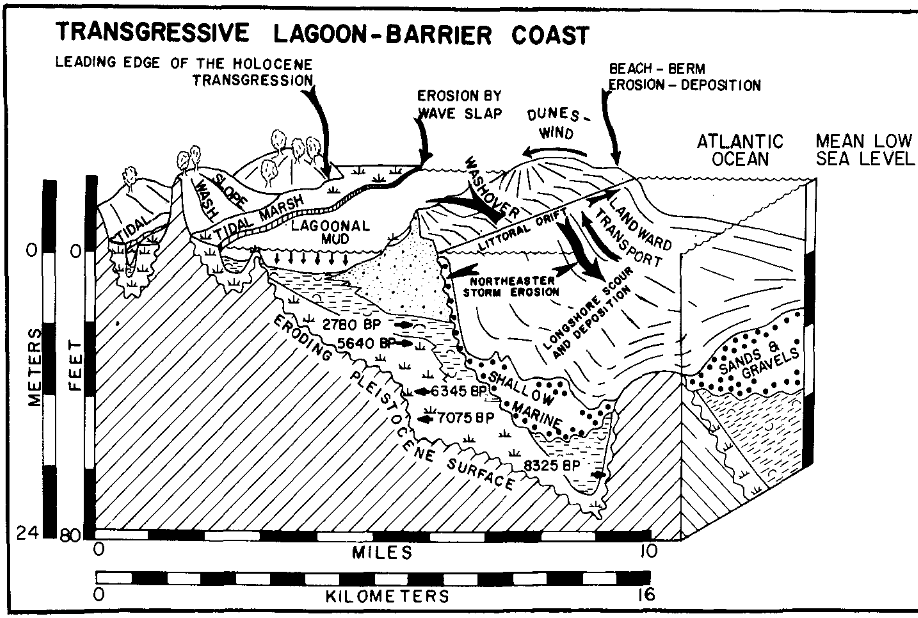

Figure 6. A schematic block diagram illustrating coastal sedimentary facies of the Delaware coastal zone (Kraft and John, 1976).

transgression of the coastal zone indicate that the vertical stratigraphic sequences of sediments seen in cores are equivalent to the lateral surficial sedimentary lithosomes undergoing land transgression (Figure 6). Essentially, this is an excellent illustration of Johannes Walther's Law of Correlation of Sedimentary Facies. In the vertical sequence, barrier sands overlie lagoonal muds and sands overlying a sequence of marsh fringe muds which unconformably overly the pre-Holocene sediments undergoing transgression.

The subsurface structure of this coastal barrier has been clearly delineated with the aid of a large number of drill cores taken along the length of the barrier, in the lagoon, and in the nearshore marine area (Figures 7 and 8). Cross sections of the four geomorphic variations of Delaware's Atlantic coastal barrier, described earlier in this paper, are shown in Figure 7. The Cape Henlopen spit (Fig. 7-A) is advancing rapidly (about 10 m/year averaged over the past 150 years) in a northwest direction into deep waters (20 m) at the junction of Delaware Bay and the Atlantic Ocean, as a result of deposition of sediment moving by littoral transport from the south. Erosion of the coastal barrier and pre-Holocene highlands such as at Rehoboth Beach

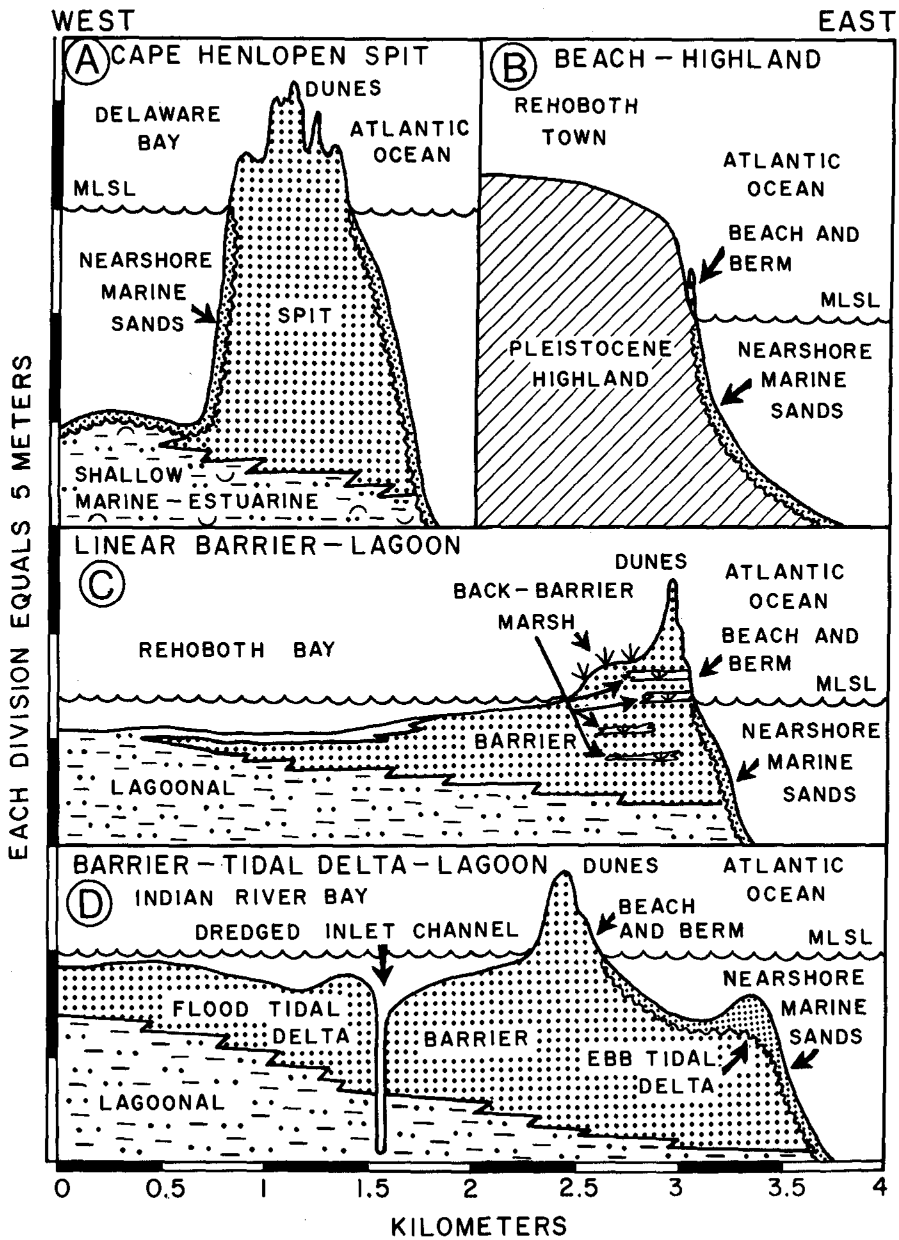

Figure 7. Schematic cross-sections of geomorphic variants of Delaware's Atlantic coastal zone. See Figure 2 for lines of cross-section (modified from John, 1977).

provide sediment to the littoral transport system. Erosion of the Atlantic coast of Cape Henlopen has been relatively constant, averaging approximately 3 m/yr. over the past two centuries (Moody, 1964; U. S. Army Corps of Engineers, 1968). Rates of advance of the spit tip, however, increased steadily from 5 m/yr (in the 18th century) to 30 m/yr (at present) (Maurmeyer, 1974). At present, the Cape Henlopen spit is in the form of a simple linear spit with narrow recurves at its tip and is tending to arc from the north and west around a breakwater built early in the 19th century. Formerly, this spit had the form of a cuspate foreland and recurved spit over the past 300 to 2,000 years (Kraft and others, 1978). Ebb tide currents winnow out sand from the spit tip and deposit it on an offshore shoal (Hen and Chickens Shoal) lying to the east and extending southeast of the spit tip into the Atlantic Ocean. The thickness of the spit sands and gravels is 18 m and they overlie shallow marine-estuarine sediments.

Pre-Holocene highlands such as at Rehoboth Beach (Figure 7-B) are encountered at various positions in the landward marine transgression across a pre-Holocene drainage system which includes the large drowned river estuary, Delaware Bay, of the ancient Delaware River of more than 14,000 years before present. The barrier here is in the form of a narrow beach with the beach sediments directly overlying pre-Holocene sediments. The beach in this case is so narrow that it could be completely destroyed by large waves resulting from high intensity storms. However, after such storms abate the thin beach is built back again but this time a little farther landward than its position before the storm.

The internal structure of the linear barrier (Figure 7-C) shows a number of back-barrier marshes in the internal composition of the barrier. These sediments represent the back-barrier marsh positions during the past 3000 years, when the barrier was farther east (seaward) of its present position. As shown in Figure 7-C the barrier sediments extend laterally to about 2.5 km into the Rehoboth Bay lagoon and interfinger with the lagoonal muds and sands and overlie them. In this section of the Atlantic coastal barrier the thickness of the barrier including the dunes and the back-barrier marsh sequences within the barrier is about 10 m.

In some areas along the Atlantic coastal barrier, tidal inlets cut across the barrier and form ebb and flood tidal deltas. Tidal inlets are known to have migrated along the barrier in historic times. Figure 7-D shows the barrier associated with the Indian River inlet which is now stabilized by a rock jetty. The barrier sands in inlet areas, including dunes, are 12 m thick and thin out laterally where they interfinger with the tidal delta and lagoonal sediments. In this case the sub-lagoonal barrier and flood tidal delta extend to about 4 km into the Indian River Bay lagoon (Figure 7-D). In all the four cases illustrated (Figure 7) the barrier sands unconformably lie against nearshore marine sands on the ocean side.

The present transgression is overriding a pre-Holocene trellis-patterned drainage system incised up to 70 m below sea-level in the Delaware coastal area. As the Holocene transgression continued landward across the Atlantic continental shelf, accompanied by sea level rise, the trellis drainage system was inundated by tidal waters. This led to the highly irregular surface of inundation being filled with sediments of various coastal environments. Lagoonal and marsh sediments were deposited along the axes of the stream valleys. Subsurface studies in the Delaware estuary and in the area of Delaware's Atlantic coast suggest that tidal intrusion commenced approximately 12,000 years before present (Kraft and others, 1976).

A cross section parallel to the Atlantic coastal barrier of Delaware is shown in Figure 8. The nature of the tributary valleys incised in the pre-Holocene surface and the infill of lagoonal, salt marsh, and shallow marine-estuarine sediments can be seen in this cross section (Figure 8). It is apparent from this cross section (Figure 8) that the thickest sections of Holocene sediments are found infilling the ancestral stream valleys. Hence, in such areas, the chances of preservation of barrier sediments in the geologic record are much better than at other areas along the barrier.

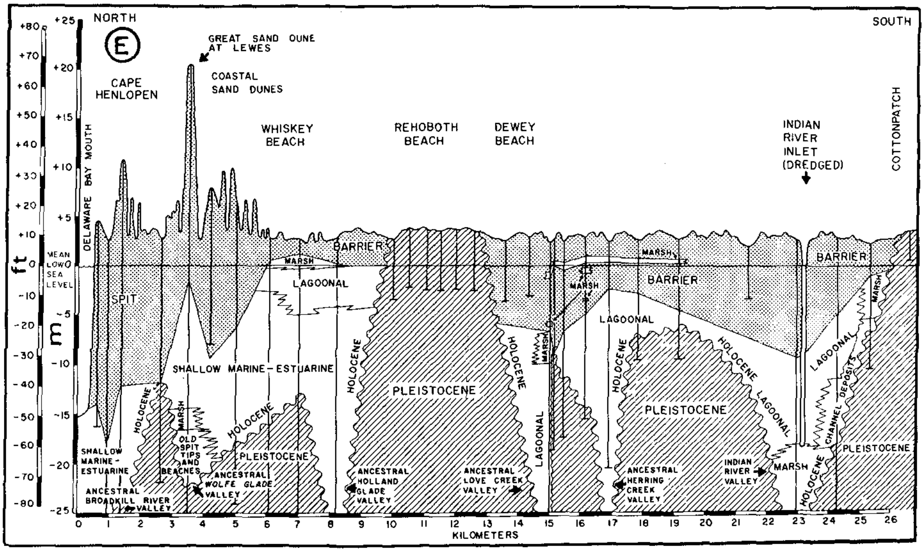

Figure 8. A longitudinal section of Delaware's coastal zone parallel to the shoreline (John, 1977). Holocene coastal sedimentary facies are shown relative to the incised pre-Holocene stream valley topography.

CONCLUSIONS

Based on analysis of the long-term stratigraphic record (past 10,000 years), historic rates of erosion and accretion, and present coastal processes, the nature of coastal change along the Delaware Atlantic Coast may be precisely defined. Thus it should be possible to make logical projections of change in the coastal environments in the short-term future. An understanding of the short- and long-term geological processes in the coastal zone should allow prediction of the impact of engineering structures on the nearshore marine and coastal areas, so that rational plans for the development of the coastal zone can be made.

REFERENCES

Belknap, D. F. and J. C. Kraft, 1977, "Holocene relative sea-level changes and coastal stratigraphic units on the northwest flank of the Baltimore Canyon trough geosyncline", Jour. Sed. Petrology, v. 47, p. 610-629.

Demarest, J. M., 1978, "The shoaling of Breakwater Harbor-Cape Henlopen area, Delaware Bay, 1842 to 1971", DEL-SG-1-78, College of Marine Studies, Univ. of Delaware, Newark, 169 p.

Hicks, S. D., and J. E. Crosby, 1974,"Trends and variability of yearly mean sea level:" NOAA Tech. Memo. NOS-13, Rockville, Maryland, 14 p.

John, C. J., 1977, "Internal sedimentary structures, vertical stratigraphic sequences, and grain-size parameter variations in a transgressive coastal barrier complex-The Atlantic Coast of Delaware", DEL-SG-10-77, College of Marine Studies, Univ. of Delaware, Newark, 287 p.

Kraft, J. C., 1971, "Sedimentary facies patterns and geologic history of a Holocene marine transgression", Geol. Soc. Amer. Bull., v. 82, p. 2131-2158.

Kraft, J. C., 1976, "Radiocarbon dates in the Delaware coastal zone (eastern Atlantic coast of North America)", DEL-SG-19-76, College of Marine Studies, Univ. of Delaware, Newark, 20 p.

Kraft, J. C. and C. J. John, 1976, "The geological structure of the shorelines of Delaware", DEL-SG-14-76, College of Marine Studies, Univ. of Delaware, Newark, 106 p.

Kraft, J. C., E. A. Allen, D. F. Belknap, C. J. John and E. M. Maurmeyer, 1976, "Delaware's Changing Shoreline", Tech. Rept. No. 1, Delaware's Coastal Management Program, Delaware State Planning Office, Executive Dept., 319 p.

Kraft, J. C., E. A. Allen and E. M. Maurmeyer, 1978, "The geological and paleogeomorphological evolution of a spit system and its associated coastal environments: Cape Henlopen spit, Delaware;" Jour. Sed. Petrology, v. 48, p. 211-226.

Mather, J. R., 1965,"Climatology of damaging storms" in Burton, I., R. W. Kates, J. R. Mather, and R. E. Snead, eds., The Shores of Megalopis: Coastal occupance and human adjustment to flood hazard: Pub. in Climatology, v. 18, no. 3, p. 525-549.

Maurmeyer, E. M., 1974, "Analysis of short- and long-term elements of coastal change in a simple spit system: Cape Henlopen, Delaware", M.S. Thesis, Dept. of Geology, Univ. of Delaware, Newark, 150 p.

Moody, D. W., 1964,"Coastal morphology and processes in relation to the development of submarine sand ridges off Bethany Beach, Delaware:" Ph.D. dissertation, The Johns Hopkins University, Baltimore, Maryland, 167 p.

Turner, P. A., 1968, "Shoreline history, Atlantic Coast Delmarva Peninsula", (abs.) 1968 Ann. Mtg., Northeastern Section, Soc. Econ. Paleon. and Mineralogists, Washington, D.C.

U. S. Army Corps of Engineers, 1968,"Delaware Coast, beach erosion control and hurricanes protection:" Senate Doc. 90, 90th Cong., 2nd Sess., Philadelphia, 110 p.