Appendix A

LITERATURE SURVEY OF PREVIOUS WORK
VIRGINIA BEACH COASTAL COMPARTMENT
SOUTHEASTERN VIRGINIA

by

Victor Goldsmith

Principal Investigator

(DACW 72-74-C-0008)

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

Report to

Coastal Engineering Research Center

U.S. Army Corps of Engineers

Kingman Building

Fort Belvoir, Virginia

22060

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September 10, 1974

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1.0 # LITERATURE SURVEY OF PREVIOUS WORK, VIRGINIA BEACH COASTAL COMPARTMENT, SOUTHEASTERN VIRGINIA

by

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2.0 ## INTRODUCTION

2.1 This literature survey of previous work is part of a study of beach changes involving monthly measurements at 18 beach profile locations (Fig. 1). This report consists of two major sections. The first section (3.0) surveys the regional geological and coastal literature and the second section (4.0) surveys in more detail the specific literature relating directly to beach processes of the Virginia Beach Coastal Compartment.

2.2 The nomenclature "Virginia Beach Coastal Compartment" is unique to this investigator, though by no means is it arbitrary usage. Historically, the northern limit of the Outer Banks was at Caffey's Inlet, near the Virginia-North Carolina state line. This inlet has been closed since about 1875 (Fig. 2a). However, it makes more sense geologically to consider the stretch of coast between Cape Henry and Cape Hatteras (encompassing the study area) as a classic coastal spit-barrier island complex, with Cape Henry being which the headland, and the net annual drift to the south. This has long been recognized (Fisher, 1967). The northern two-thirds of this coast is one long continuous spit, called Currituck Spit,

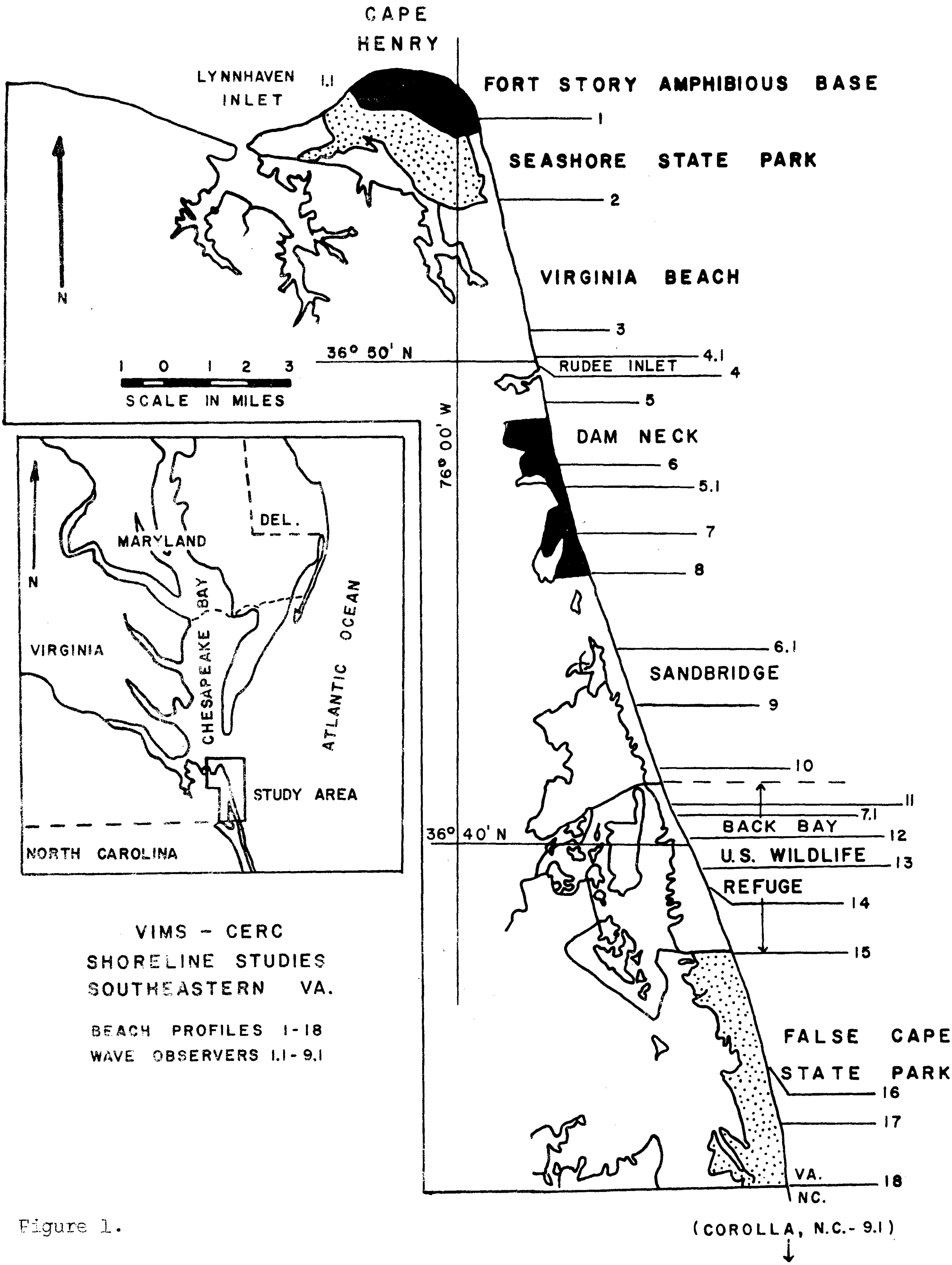

CAPE
HENRY
LYNNHAVEN
INLET
1.1
FORT STORY AMPHIBIOUS BASE
1
SEASHORE STATE PARK
2
VIRGINIA BEACH
3
36° 50' N
4.1
RUDEE INLET
4
1 0 1 2 3
SCALE IN MILES
N
5
76° 00' W
DAM NECK
6
5.1
7
8
DEL.
MARYLAND
N
CHESAPEAKE BAY
ATLANTIC OCEAN
VIRGINIA
STUDY AREA
NORTH CAROLINA
6.1
SANDBRIDGE
9
10
11
7.1
36° 40' N
BACK BAY
12
U.S. WILDLIFE
13
REFUGE
14
15
VIMS - CERC
SHORELINE STUDIES
SOUTHEASTERN VA.
BEACH PROFILES 1-18
WAVE OBSERVERS 1.1-9.1
FALSE CAPE
STATE PARK
16
17
VA.
18
NC.
(COROLLA, N.C.- 9.1)

Figure 1.

may be subdivided into two long concave-seaward portions of coast, separated by a convex-seaward bulge called False Cape. It is the northern concave-seaward stretch of coast from False Cape to Cape Henry, that we herewith refer to as the Virginia Beach Coastal Compartment, and which is our beach profile study area.

In addition to shoreline morphology, this compartmentalization is related to the area's coastal processes. The Corps' recent summary (U.S. Army Corps of Engineers, 1971) states that False Cape is adjacent to a longshore drift nodal point, in that north of this area the net annual drift is to the north, wheras south of this area the net annual drift is to the south.

2.3 The complete description of this area, given in the Corps' National Shoreline Study (U.S. Army Corps of Engineers, 1971), is organized in Table 1 by reaches and subjects. These reaches are related to population zonation of the coast and not to the geological aspects previously discussed.

3.0 REGIONAL OVERVIEW

3.1 This section includes references on the pre-Holocene and Holocene geology, coastal process studies of the Cape Henry-Cape Hatteras barrier-spit complex, Corps' studies, environmental studies, and offshore inner-shelf studies.

3.1.1 Pre-Holocene and Holocene Geology in the vicinity of the study area

The physiography and geology, both immediately underlying the study area and at the surface to the west, is directly related to the six or more Pliocene (?) and Pleistocene cycles of emergence and submergence, with maximum submergent sea levels near +45 feet (Oaks and Coch, 1973). Figures 3 and 4 (from Oaks and Coch, 1963) give some of the details of the geology and geomorphology seaward of the Suffolk Scarp. The Sandbridge Formation (youngest Pleistocene), shown in Fig. 5 (from Oaks and Coch, 1973) is often exposed after storms in the intertidal zone at 44th Street, Virginia Beach. The Pleistocene Geology of this area is also discussed by Rogers and Spencer (1968). Other aspects of coastal plain geology are discussed by Sanford (1912), Wentworth (1930), Cederstrom (1941), Richards (1950), and the early literature is summarized by Ruhle (1965). Harrison, et al. (1965) presents evidence for a late Pleistocene uplift in the area. More recent coastal plain studies are discussed by Calver (1973a and 1973b). Pleistocene sea level changes are discussed by Milliman and Emery (1968) and Oaks and Coch (1963). Historical sea level changes at Hampton Roads, Virginia are shown in Figure 6 (from Hicks, 1972).

Holocene geomorphology and stratigraphy at Chesapeake Bay Entrance are discussed by Meisberger (1972) and Nelson (1972) and the Holocene evolution of a portion of the Hatteras barrier island chain has been discussed by Pierce and Colqhoun (1970a, 1970b) and White (1966).

3.2.0 Coastal studies of the Cape Henry - Cape Hatteras barrier spit complex

3.2.1 Historical Studies

A definitive study on the historical geography of the North Carolina Outer Banks has been made by Dunbar (1958). More detailed historical studies of inlets, and their relict features, on the Outer Banks are reported in Fisher (1962, 1967). These data are summarized in Figures 2a and 2b. Note the former presence of inlets at the Virginia-North Carolina line, and just to the south, from the 16th to the mid 19th century. The geomorphic expression of these former inlets is quite apparent (Fig. 2b), and probably influences present coastal processes. Another interesting aspect of these changing inlets is the steady decrease in number of inlets per 100 miles from 4.2 to 0.8, during the years 1600 to 1961, between Cape Henry and Cape Hatteras, as shown below (Fisher, 1962, Table 1).

Table 2
(from Fisher, 1962, Table 1)
Spatial Inlet Distribution During Historical Times

Period	Inlets per 100 miles*	
	C. Henry - C. Hatteras	C. Hatteras - C. Lookout
1600-1700	5/120 mi. = 4.2/100 mi.	6/70 mi. = 8.6/100 mi.
1700-1800	3/120 mi. = 2.5/100 mi.	6/70 mi. = 8.6/100 mi.
1800-1850	3/120 mi. = 2.5/100 mi.	2/70 mi. = 2.0/100 mi.
1850-1900	3/120 mi. = 2.5/100 mi.	3/70 mi. = 4.3/100 mi.
1900-1945	2/120 mi. = 1.7/100 mi.	5/70 mi. = 7.1/100 mi.
1945-1961	1/120 mi. = .8/100 mi.	6/70 mi. = 8.6/100 mi.

* First figure is number of inlets per actual distance. Second figure is number of inlets recalculated per 100 miles.

Additional studies of historical shoreline changes have been made by Rude (1922), and Athearn and Ronne (1963). Pierce (1969) has used historical changes determined from charts in an attempt to formulate a sediment budget for a portion of the Outer Banks, with mixed results. Comparisons of vertical aerial photographs have been used to study shoreline changes within the last 50 years by Shepard and Wanless (1971), Al Ashry and Wanless (1968), Langfelder, et al. (1968) and Stafford (1971). Wahls (1973, Fig. 6) has summarized the most recent shoreline changes, 1949-1971, in Currituck and Dare Counties, N.C., from existing aerial photographic coverage (Fig. 7).

Langfelder, et al. (1970) attempted to correlate historical shoreline erosion with "computed erosion" from wave refraction computations (using Wilson's program), with mixed results.

3.2.2 Beach Studies

Detailed studies of beach behavior on the Outer Banks have been made by Dolan (Dolan, 1966; Dolan and Fern, 1968; Dolan, et al., 1969; Dolan, 1970; Dolan, 1972; Dolan, 1971) and Sonu (Sonu and Van Beek, 1971; and Sonu, 1973). Results of Sonu's intensive studies are that of all the parameters measured, the previous sediment storage, the wave approach direction and the three dimensional nearshore topography appear to be among the most important variables affecting beach erosion on the Outer Banks.

Vincent (1973) attempted to statistically quantify shoreline meanders (also called giant cusps, sandwaves, protuberances, etc.).

Vincent concluded that there were two basic meander types which greatly affect beach processes on the Outer Banks between Oregon Inlet and Cape Hatteras. He then suggested that these two meander types, "short" and "long" wavelength meanders, were related to short-term cycles of accretional and storm-erosional conditions, respectively. Preliminary observations suggest that similar shoreline meanders may also be prevalent between Cape Henry and the Virginia-North Carolina state line.

Beach sedimentological studies of the Outer Banks have been made by Swift, et al. (1971), Swift, Dill and McHone (1971), Shideler (1973a, 1973b, 1973c, Shideler, 1974) and Sabet (1973). These studies, which show that the interpretation of coastal processes from grain size and mineralogical data in this area is a very complex problem, are summarized in Figures 8 and 9 (from Shideler, 1973b and Swift, Dill and McHone, 1971, respectively).

3.2.3 U.S. Army Corps of Engineers studies

Because of the Outer Banks' beach erosion problems, and historical and tourist interest, several studies have been made by the Corps. In one of these studies (U.S. Army Corps of Engineers, 1948) shoreline changes, 1858 to 1933, were summarized by reaches (Fig. 10). Revealed in this data, and of interest here, is the abundance of alternate zones of relative erosion and accretion along the shoreline. Other studies of historical shoreline changes, Cape Henry to Cape Hatteras, being made by the principal investigator using larger scale charts and better control, support the existence of this alternate zonation. Such alternations may be due to nonuniform shoreline wave energy distributions caused by wave refraction over the adjacent continental shelf (Goldsmith and Colonell, 1974).

A later study (U.S. Army Corps of Engineers, 1965) also presents much useful information, including a history of hurricanes affecting the Outer Banks (reproduced here as Table 3).

The most recent Corps study is a draft environmental impact statement of CERC's Field Research Facility at Duck, N.C. (U.S. Army Corps of Engineers, 1973.

3.3 Dune Vegetation Studies

A critical aspect of beach and dune stability is the presence of vegetation in the back beach and dune areas. Studies of vegetation on the Outer Banks have been made by Oosting (1954), Brown (1959) and Woodhouse and Hanes (1967). On a recent visit to the site of the future CERC facility at Duck, large experimental tracts of vegetation were observed, indicating that such studies are presently occurring at the south end of this study area (discussed in U.S. Army Corps of Engineers, 1973).

3.4 Environmental Aspects

With increasing environmental consciousness, such aspects have become important considerations in all beach studies, and so will be briefly mentioned here.

3.4.1. The Overwash Problem

Dolan and Godfrey have suggested that through the abundant use of sand fencing in stabilizing the foredunes of the North

Carolina Outer Banks much sand has been permanently lost to this barrier island system which would otherwise have been deposited through storm overwash processes (Godfrey, 1970; Dolan, 1973; Dolan, et al., 1973; Godfrey and Godfrey, 1973). The same sand fencing that was first implemented in the 1930's by the WPA on the Outer Banks continues north to Sandbridge. The possible effects of this sand fencing on beach processes in the study area will be considered in this study.

3.4.2 Currituck County

Most of the environmental issues in the study area revolve around access routes through the remote, and presently, largely natural areas. A summary of various access and land development alternatives for Currituck County is given in Envirotek (1972), within which it is recommended that much of the Corolla area and the area to the north, presently in a natural state, be kept as close to the present state as possible, and that construction be restricted in the area seaward of a 500 foot ocean front set-back line.

3.5.1 Back Bay Wildlife Refuge

Observations and studies by personnel of the U.S. Back Bay Wildlife Refuge (e.g., Smith, 1972) indicated that the heavy visitor traffic through and within the Refuge (several hundred thousand vehicle trips per year) was doing permanent damage to the flora and fauna within the refuge. As a result of court action (Baird, 1973; Smolen, 1973) vehicular access is now temporarily limited to owners of property south of the Virginia-North Carolina state line and a limited number of visitors. However, the question of access through the Back Bay Federal Refuge is still in the courts. Part of the problem revolves around the open question of damage to the beach, if any, by a large amount of vehicular traffic.

3.5.2 False Cape State Park

Access to False Cape State Park, located between the Back Bay Wildlife Refuge and the Virginia-North Carolina state line (Fig. 1) is presently limited to four-wheel drive vehicles passing along the beach and back dune areas, and which is subject to the limitations discussed in paragraph 3.5.3. A study of various proposed access routes by Zeigler and Marcellus (1972) concluded that all proposed hard-surfaced automobile routes would ultimately cause permanent damage to the area and that the only acceptable access to False Cape Park would be: (a) some sort of monorail or rapid transit system, or (b) a ferry crossing from Knotts Island, N.C. across Back Bay to the bay side of Currituck Spit at False Cape Landing. State-sponsored studies of this problem are continuing.

3.6 Offshore Inner-Shelf Studies

A definitive study summarizing the shelf geomorphology of the Chesapeake Bight part of the Virginian Sea, (i.e., Cape Henry to Cape Hatteras) and the complex relationships between the shelf geomorphology and the ocean surface wave climate over the shelf and along the shoreline, is presented in Goldsmith, et al., 1974. A copy of this study which is in press, will be forwarded to CERC. Pertinent field studies are outlined below.

3.6.1 Marine Geology

False Cape, because of its large submarine ridge system, has been the scene of several studies (Sanders, 1963; Swift et al., 1972; and McHone, 1972). These studies point out the process interaction between the beach and the nearshore morphology. Unpublished beach profile data collected separately by Swift, Shideler, McHone and Goldsmith indicate that the False Cape Ridge system has an important influence on the behavior of the adjacent beaches.

Additional inner shelf studies are by Payne (1970), Shideler and Swift (1972); Shideler, et al. (1972), Fisher (1973); and Shideler et al. (1973).

3.6.2 Physical Oceanography

The most detailed current study of the adjacent shelf area was made by Harrison, et al. (1967). A recent summary of physical oceanography studies was made by Bumpus, et al. (1973).

Wave refraction studies in the area, previous to Goldsmith, et al., 1974, have been made by Pierce, et al. (1970) and Chao (1972).

4.0 BEACH AND RELATED STUDIES - CAPE HENRY TO FALSE CAPE

4.1 Metrologic and Oceanographic Data

Pertinent data copied from an intensive study of proposed shoreline improvements for Virginia Beach (U.S. Army Corps of Engineers, 1971) are presented here in Figures 11 to 19. Also presented are wave observations, from Marsden subsquare No. 116-55 as summarized in Goldsmith, et al., 1974 (Figs. 20 and 21).

On the basis of field studies, Harrison, et al. (1964) proposed that a nontidal drift eddy, with clockwise motion, exists between Cape Henry and Rudee Inlet.

4.2 Longshore Drift Studies

An investigation of the rate of littoral transport between Cape Henry and the Virginia-North Carolina line by an analysis of wave energy (as computed from Saville's (1954) hindcast data) was made by Weinman (1971). He determined a net annual transport to the north of $9.8 \times 10^5 yds^3$/year. Though this total is probably too high, the results qualitatively agree with other studies, and emphasize the importance of southeast waves in this area (Goldsmith, et al., 1974).

Longshore drift rates were also calculated from tracer analyses at Rudee Inlet by Bunch (1969). An approximate mean northerly drift of 70,000 yd^3 was calculated from five tests conducted between November 8, 1968 and March 20, 1969, during times of moderate wave heights.

An additional indication of the amount of northerly drift can be gotten from Corps' dredging data (U.S. Army Corps of Engineers,

1973) for Thimble Shoal Channel. Approximately 1 x 10^6 yd^3 of material is removed every two to three years from just the main channel, located within the Chesapeake Bay entrance. Thus, the dredge data probably gives only a minimal estimate of the longshore drift along the study area.

4.3 Beach Studies in the Virginia Beach Coastal Compartment

4.3.1 Previous Studies

Previous beach studies and those beach profile locations that have been reoccupied in this present study, are summarized in Table 3.

Watts (1959) studied effects of beachfill on Virginia Beach and calculated net volume changes in the nearshore and intertidal portions of the profile between 1946, 1952, 1955 and 1958. The first detailed studies of beach changes in Virginia were undertaken by Harrison and Wagner (1964). In this study monthly, weekly and daily changes were monitored at four locations in Virginia Beach and one at Camp Pendleton (Table 3 and Fig. 4). These profiles were measured intermittantly between November 1956 and May 1963. The beach profile data indicated that beach changes were not always directly related to the changes in the wave regime, but that a rhythmic pattern of change unrelated directly to the waves, was also quite important (Harrison and Wagner, 1964, p. 1, 2, 8 and 9). The precise location of these beach profile locations have been reoccupied. Additional studies were conducted at Fort Story, north of Virginia Beach (Fig. 1) by Harrison, et al., in 1968. The importance of the beach water table in the Fort Story area was investigated by Fausak

(1970). Studies of the beach water table at Camp Pendleton in 1966 and at Fort Story in 1969 are reported in Harrison, et al., 1971. Fausak's Fort Story beach profile, which was monitored in August and September, 1969, was reoccupied in September, 1972 by this investigator.

Harrison and Bullock have recently completed a detailed study of beach changes along the outer coast of Virginia. This work has been reported in Bullock, 1971; and Harrison, et al, 1972. In this study sixteen beach profile locations were monitored between the Virginia-Maryland and the Virginia-North Carolina state lines for a period of twenty months. This data was then used to calibrate a model which would attempt to forecast changes in beach sand volume resulting from storm conditions. "The results indicated that it may be possible to develop prediction equations to forecast beach changes for sections of ocean beach that do not exhibit complex offshore bathymetry" (Bullock, 1971, p. vii). Six out of seven of these beach profiles in the Virginia Beach Coastal Compartment were precisely located and remeasured at bimonthly intervals between September 1972 and January 1974 by Goldsmith and Smith. Numerous studies of the False Cape area, including beach profile measurements, have been conducted by D.J.P. Swift and others. However, the beach profile data is, as yet, unpublished. Three out of four of these beach profiles, going back to 1969, were reoccupied in September 1972 by VIMS and ODU personnel, and have been measured since then by Goldsmith and Smith at bimonthly intervals, through January 1974. All these previous beach profile data are in the possession of the principal investigator.

4.3.2 <u>Present beach profile studies</u>

Beach changes are being monitored once a month at Virginia Beach at 1,000 foot intervals between 49th Street and Rudee Inlet by an engineering firm under contract to the City of Virginia Beach and the Corps of Engineers, Norfolk District. Once a year these profiles are extended out to depths of 25 feet (Mr. Fine, Chief, Water Resources Planning Branch, Norfolk District, U.S. Army Corps of Engineers, personal communication, 1972). This 2.5 mile stretch of shoreline includes the major zone of public concern about beach erosion, but less than 10% of the total shoreline of the Virginia Beach Coastal Compartment.

A beach profile network consisting of 13 beach profiles over a 15 mile stretch of coast between Rudee Inlet and the Virginia-North Carolina border was set up by the principal investigator in the summer of 1972. These profiles were monitored at bimonthly intervals with the cooperation and assistance of the personnel of the Back Bay Wildlife Refuge, U.S. Fish and Wildlife Service and graduate student volunteers at VIMS. This profile network consisted of the five older profiles of Harrison and Bullock and three profiles of Swift and others (enumerated above) and the present profiles of the Back Bay Wildlife Refuge personnel (5 profiles).

Some of these preliminary results, which were partially reported in Wardrop (1973), indicate a highly variable rate of erosion and accretion between adjacent beach profile locations. A summary of the False Cape beach profile data, in preparation by this investigator, also indicates similar variability between adjacent beach profile locations.

4.3.3 Grain Size Studies, Virginia Beach, Virginia

The behavior of sand on Virginia Beach has been studied by Harrison and Alamo (1964) and by Tuck (1969). Tuck suggested that a reversal in the slope-grain size relationship occurs under storm conditions on the beach coincident with profile changes, and that such a reversal is generally present in the "zone of shoaling waves" portion of the beach profile at Virginia Beach.

REFERENCES

Athearn, W.D. and Ronne, C., 1963. Shoreline changes at Cape Hatteras: an aerial photographic study of a 17-year period: Naval Research Reviews June 1963, p. 17-24.

Baird, E., 1973. Memorandum of points and authorities in opposition to plaintiff's motion for temporary restraining order: Coupland et als. vs. Morton, et als., Civil Action No. 145-73-N, Eastern District of Virginia, 10 p.

Brown, C.E., 1959. Vegetation of the Outer Banks of North Carolina: L.S.U. Press, Baton Rouge, 178 p.

Bullock, P.A., 1971. The feasibility of developing forecast systems to predict changes in beach sand volume on ocean beaches during storms. Masters thesis, VIMS and The College of William & Mary, 78 p.

Bumpus, D.F., Lynde, R.E. and Shaw, D.M., 1973. Physical Oceanography: p. 1-1 to 1-72 <u>in</u> Saila, S.B. (Proj. Coord.), Coastal and Offshore Environmental Inventory--Cape Hatteras to Nantucket Shoals: Marine Publ. Series No. 2, Univ. of Rhode Island, Kingston 02881

Bunch, J.W., 1969. A fluorescent tracer study at a tidal inlet (Rudee Inlet, Virginia): M.S. thesis, Inst. of Oceanography, Old Dom. Univ., Norfolk, Virginia, 51 p.

Calver, J.L., 1973a. Geological Studies, Coastal Plain of Virginia: Virginia Div. of Mineral Resources Bulletin 83 (parts 1 and 2).

Calver, J.L., 1973b. Geological Studies, Coastal Plain of Virginia: Virginia Div. of Mineral Resources Bulletin 83 (part 3). Charlottesville, Virginia.

Cederstrom, D.J., 1941. Ground-water resources of the southeastern Virginia coastal plain: Circular 1, p 1-11, Virginia Conservation Commission, Richmond, Virginia.

Chao, Y.Y., 1972. Wave refraction phenomena over the continental shelf near the Chesapeake Bay Entrance: final report for U.S. Naval Ocean. Office and Coastal Eng. Res. Center, 53 p.

Dolan, R., 1966. Seasonal variations in beach profiles along the outer banks of North Carolina: Shore and Beach, Oct. 1955, 5 p.

Dolan, R., 1970. Sandwaves--Cape Hatteras, North Carolina: Shore and Beach, v. 38, p. 23-25.

Dolan, R., 1971. Coastal landforms: crescentric and rhythmic: GSA Bulletin, v. 82, p. 177-180.

Dolan, R., 1972. Barrier dune system along the Outer Banks of North Carolina: a reappraisal: Science v. 176, No. 4032, p. 286-288.

Dolan, R., 1973. Barrier islands: natural and controlled: p. 263-278 in Coates, D. (ed.), Coastal Geomorphology, S.U.N.Y., Binghampton, 404 p.

Dolan, R. and Ferm, J.C., 1968. Crescentic land forms along the Atlantic Coast of the United States. Science v. 159, p. 627-629.

Dolan, R., Ferm, J.D., McArthur, D.S., McCloy, J.M., 1969. Measurements of beach process variables, Outer Banks, North Carolina: Coastal Studies Series No. 24, p. 1-79, L.S.U. Press, Baton Rouge.

Dolan, R., Godfrey, P.J., Odum, W.E., 1973. Man's impact on the barrier islands of North Carolina: Amer. Scientist v. 61, No. 2, p. 152-162.

Dunbar, G.S., 1958. Historical geography of the North Carolina Outer Banks: L.S.U. Press, Baton Rouge, La., 234 p.

El-Ashry, M.T., and Wanless, H.R., 1968. Photo interpretation of shoreline changes between Cape Hatteras and Cape Fear (N.C.): Mar. Geol. v. 6, p. 347-379.

Envirotek, Inc., 1972. The Currituck Plan. Outer Banks Development Potential: Box 8, Currituck, North Carolina 27929.

Fausak, L.E., 1970. The beach water table as a response variable on the beach-ocean-atmosphere system: M.S. thesis, VIMS, Gloucester Point, Virginia, 53 p.

Fisher, J.J., 1962. Geomorphic expression of former inlets along the Outer Banks of North Carolina. Univ. North Carolina thesis, Chapel Hill.

Fisher, J.J., 1967. Development pattern of relict beach ridges, Outer Banks barrier chain, North Carolina: Ph.D. thesis, Chapel Hill, North Carolina, 244 p.

Fisher, J.J., 1973. Late quaternary stratigraphy of the inner Virginia continental shelf: A proposed standard section: Discussion: G.S.A. Bull. v. 84, p. 2159-2160.

Godfrey, P.J., 1970. Oceanic overwash and its ecological implications on the Outer Banks of North Carolina. Office of Natural Science Studies, National Park Service, U.S. Dept. of the Interior, Washington, D.C., 37 p.

Godfrey, P.J. and Godfrey, M.M., 1973. Comparison of ecological and geomorphic interactions between altered and unaltered barrier island systems in North Carolina: p. 219-239 in Coates, D. (ed.), Coastal Geomorphology, S.U.N.Y., Binghamton, 404 p.

Goldsmith, V. and Colonell, J.M., 1974. Results of ocean wave continental shelf interaction: 14th Inter. Coastal Eng. Conf., A.S.C.E., 15 p. (in press).

Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave climate model of the mid-Atlantic continental shelf and shoreline: I - model description, shelf geomorphology, and preliminary data analysis: VIMS SRAMSOE No. 38 (in press).

Harrison, W., Brehmer, M.L. and Stone, R.B , 1964. Nearshore tidal and nontidal currents, Virginia Beach, Virginia. U.S. Army Coastal Engrg. Res. Center, CE., Wash., D.C., Technical Memorandum No. 5, 20 p.

Harrison, W., and Bullock, P.A., 1972. Changes in sand volume of Virginia's ocean beaches (abs.): Proc. Thirteenth International Conference on Coastal Engineering. Vancouver, B.C., p. 261-264.

Harrison, W., Boon, J., Fang, C.S., Fausak, L, and Wang, S., 1971. Investigation of the water table in a tidal beach: ONR final report, VIMS Spec. Sci. Report No. 60, 165 p.

Harrison, W., Malloy, R.J., Rusnak, G.A., and Ferasmae, J., 1965. Possible late Pleistocene uplift, Chesapeake Bay entrance: J. Geol. v. 73, p. 201-229.

Harrison, W. and Morales, A.R., 1964. Dynamic properties of immersed sand at Virginia Beach, Virginia. U.S. Army Coastal Engineering Research Center Tech. Memo. No. 9, 52 p.

Harrison, W., Norcross, J.J., Pore, N.A. and Stanley, E.M., 1967. Shelf waters off the Chesapeake Bight: ESSA Prof. Paper 3, p. 1-82.

Harrison, W., Rayfield, E., Boon, J., Reynolds, G., Grant, J., and Tyler, D., 1968. A time series from the beach environment: ESSA Research Labs. Tech. Memo. AOL-1, Miami, 28 p. + app.

Harrison, W. and Wagner, K.A., 1964. Beach changes at Virginia Beach, Virginia, U.S. Army Coastal Engrg. Res. Center, CE., Wash., D.C., Miscellaneous Paper 6-64, 25 p.

Hicks, S.D., 1973. Trends and variability of yearly mean sea level 1893-1971. NOAA Tech. Memo NOS 12, Mar. 1973, p. 1-4, 7-13.

Langfelder, J., Stafford, D., Amein, M., 1968. A reconnaissance of coastal erosion in North Carolina: Department of Civil Engineering, Raleigh, NCSU, 127 p.

Langfelder, L., Stafford, D.B., and Amein, M., 1970. Coastal erosion in North Carolina: Amer. Soc. Civil Eng. Proc. v. 96, paper 7306, Waterways and Harbs. Div., No. WW1, p. 531-545.

McHone, J.F., Jr., 1972. Morphologic time series from a submarine sand ridge on the south Virginia coast: M.S. thesis, Institute of Oceanography, Old Dominion University, Norfolk, Virginia, 59 p.

Meisburger, E.P., 1972. Geomorphology and Sediments of the Chesapeake Bay entrance. U.S. Army Coastal Engrg. Research Center, C.E., Washington, D.C., 66 p.

Milliman, J.D. and Emery, K.O., 1968. Sea levels during the past 35,000 years: Science, v. 162, p. 1121.

Nelson, E.G., 1972. Holocene sedimentary facies in Chesapeake Bay entrance (abs.), Dept. of Earth Sciences, Univ. of New Hampshire, Durham, N.H.

Oaks, R.Q., Jr. and Coch, N.K., 1963. Pleistocene sea levels, southeastern Va.: Science, v. 140, p. 979-983.

Oaks, R.Q. and Coch, N.K., 1973. Post-Miocene stratigraphy and morphology, Southeastern Virginia: Bull. 82, Va. Div. of Mineral Resources, 135 p.

Oosting, H.J., 1954. Ecological processes and vegetation of the maritime strand in the southeastern U.S.: Bot. Rev. v. 20, p. 226-262.

Payne, L.H., 1970. Sediments and morphology of the continental shelf off southeast Virginia: Thesis, Columbia Univ., 70 p.

Pierce, J.W., 1969. Sediment budget along a barrier island chain: Sed. Geol. v. 3, p. 5-16.

Pierce, J.W., and Colquhoun, D.J., 1970a. Holocene evolution of a portion of the North Carolina coast. GSA Bull. v. 81, p. 3697-3714.

Pierce, J.W. and Colquhoun, D.J., 1970b. Configuration of the Holocene primary barrier chain, Outer Banks, North Carolina. Southeastern Geology, v. 11, No. 4, p. 231-236.

Pierce, J.W., So, C.L., Roth, H.D., and Colquhoun, D.J., 1970. Wave refraction and coastal erosion, southern Virginia and northern North Carolina. Abs. with Programs, v. 2, No. 3, GSA, p. 237.

Richards, H.G., 1950. Geology of the Coastal Plain of North Carolina: Transactions of the American Philosophical Society, New Series Volume 40, part 1.

Rogers, W.S. and Spencer, R.S., 1968. The Pleistocene geology of Princess Anne County, Va.: Southeastern Geology, v. 9, Issue 2.

Rude, G.T., 1922. Shore changes at Cape Hatteras: Ann. Assoc. Amer. Geogr., v. 12, p. 87-95.

Ruhle, J.L., 1965. Geologic Literature of the Coastal Plain of Va., 1783-1962. Information Circular 9, p. 1-95. Va. Div. Min. Res., Charlottesville, Va.

Sabet, M.A., 1973. Textural trend analysis of coastal barrier sediments along the middle Atlantic Bight, North Carolina--Some comments: Sedimentary Geology v. 10, p. 311-312.

Sanders, J., 1963. North-south trending submarine ridge composed of coarse sand off False Cape, Virginia (abs.): A.A.P.G. Bull. v. 46, p. 278.

Sanford, S., 1912. The underground water resources of the coastal plain province of Virginia: Virginia Geological Survey, U. Va., Charlottesville, Va., Bulletin No. V.

Saville, T., Jr., 1954. North Atlantic coast wave statistics hindcast by Bretschneider--revised Sverdrup-Munk method: US Army Corps of Engs., CERC Tech. Memo, No. 55, 18 p.

Shepard, F. and Wanless, H., 1971. Our changing coastlines: McGraw-Hill, 579 p.

Shideler, G.L., 1973a. Evaluation of a conceptual model for the transverse sediment transport system of coastal barrier chain, middle Atlantic bight: J.S.P. v. 43, p. 748-764.

Shideler, G.L., 1973b. Textural trend analysis of coastal barrier sediments along the middle Atlantic bight, N.C.: Sed. Geol. v. 9, p. 195-220.

Shideler, G.L., 1973. Textural trend analysis of coastal barrier sediments along the middle Atlantic bight, North Carolina--a reply: Sedimentary Geology v. 10, p. 313-316.

Shideler, G.L., 1974. Evaluation of textural parameters as beach-dune environmental discriminators along the Outer Banks barrier, North Carolina: Southeastern Geology v. 15, p. 201-222.

Shideler, G.L. and Swift, D.J.P., 1972. Seismic reconnaissance of quaternary deposits of the middle Atlantic continental shelf - Cape Henry, Va. to Cape Hatteras, N.C.: Marine Geol. v. 12, p. 165-185.

Shideler, G.L., Swift, D., Johnson, G.H., Holliday, B.W., 1972. Late quaternary stratigraphy of the inner Virginia continental shelf: a proposed standard section: G.S.A. Bull. v. 83, p. 1787-1804.

Shideler, G.L., Swift, D.J.P., Johnson, G.H. and Holliday, B.W., 1973. Late quaternary stratigraphy of the inner Virginia continental shelf: a proposed standard section: Reply: GSA Bull. v. 84, p. 2161-2164.

Smith, F., 1972. Comparison of wildlife usage on beaches with and without intensive vehicular traffic: Report of Wildlife Management Study, Division of Wildlife Refuges, Region 4, Back Bay, Virginia, 4 p.

Smolen, T., 1973. Affidavit, unpublished, 5 p.

Sonu, C.J. and VanBeek, J.L., 1971. Systematic beach changes on the Outer Banks, North Carolina. Journal of Geology, 79(4), p. 416-425.

Sonu, C.J., 1973. Three-dimensional beach changes: J. of Geology v. 81, p. 42-64.

Stafford, Donald B., 1971. An aerial photographic technique for beach erosion surveys in North Carolina: Tech. Memo. No. 36, U.S. Army Corps of Engineers, Coastal Engineering Research Center.

Swift, D., Dill, C., McHone, J., 1971. Hydraulic fractionation of heavy mineral suites on an unconsolidated retreating coast: JSP v. 41, p. 683-900.

Swift, D., Holliday, B., Avignone, N., and Shideler, G., 1972. Anatomy of a shore face ridge system, False Cape, Virginia: Mar. Geol. v. 12, p. 59-84.

Swift, D., Sanford, R., Dill, C., Jr., and Avignone, N., 1971. Textural differentiation of the shore face during erosional retreat of an unconsolidated coast, Cape Henry to Cape Hatteras, western north Atlantic shelf: Sedimentology, v. 16, p. 221-250.

Turk, D.R., Jr., 1969. Major environmental variables affecting grain size distribution in the shoaling-wave zone under storm conditions at Virginia Beach, Virginia: M.S. Thesis, Dept. of Marine Sci., College of William and Mary, 57 p.

U.S. Army Corps of Engineers, 1948. North Carolina shoreline, beach erosion study: 80th Congress, 2nd Session, Doc. No. 763, 30 p.

U.S. Army Corps of Engineers, Wilmington, N.C. District, 1965. Outer Banks between Virginia state line and Hatteras Inlet, N.C.--Interim survey report of hurricane protection: U.S. Army Engineer District, Wilmington, 44 p. + 5 app.

U.S. Army Corps of Engineers, Norfolk District, 1971. Feasibility report for beach erosion control and hurricane protection, Virginia Beach, Virginia: 95 p. + 7 app.

U.S. Army Corps of Engineers, 1973. Environmental impact statement, Coastal Engineering Research Center Field Research Facility at Duck, North Carolina, Corps of Engineers, Wilmington, N.C.

U.S. Army Corps of Engineers, 1973. Final environmental impact statement, Thimble Shoal Channel maintenance dredging: Norfolk Army Engineer District, 34 p.

Vincent, Linwood, 1973. Quantification of shoreline meandering: ONR Tech. Rpt. No. 7, Dept. of Env. Sci., U. Va., Charlottesville, 93 p.

Wahls, H.E., 1973. A survey of North Carolina beach erosion by air photo methods: Report No. 73-1, The Center for Marine Coastal Studies, North Carolina State University, Raleigh.

Wardrop, W.J., 1973. The Back Bay Wildlife Refuge: class report, MSC 529, unpublished, 12 p + app.

Watts, G.M., 1959. Behavior of beach fill at Virginia Beach, Virginia: B.E.B. Tech. Memo. No. 113, 26 p.

Weinman, Z.H., 1971. Analysis of littoral transport by wave energy: Cape Henry, Virginia to the Virginia-North Carolina border: M.S. Thesis, Old Dominion Univ., Norfolk, Va., 64 p.

Wentworth, C.K., 1930. Sand and gravel resources of the coastal plain of Virginia. Bulletin 32, State Commission on Conservation and Development, Richmond, Virginia, 146 p.

White, W.A., 1966. Drainage asymmetry and the Carolina capes: Bull. G.S.A. v. 77, p. 223-240.

Woodhouse, W.W., Jr. and Hanes, R.E., 1967. Dune stabilization with vegetation on the Outer Banks of North Carolina: U.S. Army Coastal Engrg. Research Center, Tech. Memo. No. 22, 45 p.

Zeigler, J.M. and Marcellus, K., 1972. Access routes into the proposed False Cape State Park--an appraisal: VIMS, for Division of Parks, Commonwealth of Virginia, 31 p + app.

Reach	Profile Number	Distance (miles)	Physical Characteristics
Willoughby Spit to Cape Henry	None	21	Characterized by an irregular dune line with a beach width varying from 100 to 125 feet at an average elevation of about 5 feet mean sea level. The dune elevation is generally about 12 feet mean sea level. Segments of this reach near the western tip have, of necessity been stabilized with timber groins
Cape Henry to 49th Street	1 2	3.8	Characterized by an irregular dune line.

Shore Ownership	Shore Use and Development	Shore History
Encompasses two military reservations. Little Creek Amphibious Base and Fort Story; the Seashore State Park, and the resort beach of Ocean View. Of the shoreline composing Ocean View, 4 miles are owned privately and 5 miles publicly.	Used extensively for public and private recreation. Several miles of non-recreational shoreline are devoted to the Little Creek Amphibious Base.	West of Cape Henry, to Little Creek the shoreline has shown alternate periods of erosion and accretion with the overall trend being one of gradual accretion. Between 1891 and 1916 the 4.8 mile section of shoreline between Lynnhaven Inlet and Little Creek eroded at an average rate of 12 feet per year. Since then, the overall trend has been one of gradual accretion. Based on complete shoreline surveys of the 4.9-mile reach between the lighthouse and Lynnhaven Inlet, made in 1962, and the 4.8 miles of beach between Lynnhaven Inlet and Little Creek, made in 1946, the average annual rate of accretion was 1.98 feet, which is equivalent to slightly more than 100,000 cubic yards per year. The 11-mile segment of shoreline from Little Creek Inlet to Willoughby Spit has been relatively static to change in recent years. Erosion has removed material from this reach during storm periods, but natural return has usually occurred. Drift west of Cape Henry to Willoughby Spit is westerly. Rates in this zone are moderate to small. No information on drift west of Willoughby is available.
The 2.7-mile segment between 49th Street and 89th Street, known as North Virginia Beach, is centered about 3 miles south of Cape Henry and is publicly owned. The U.S. Army's Fort Story extends along the Atlantic Ocean for a distance of about 1.1 miles from 89th Street to a point opposite Cape Henry Lighthouse which is the south point of Chesapeake Bay.	The stretch of shore north of Rudee Inlet to Fort Story is publicly used for recreational purposes. In 1970, the annual visitation at the Virginia Beach resort areas was 4,320,000 persons. Development is residential and commercial.	Material placed artificailly to rebuild the Atlantic Ocean shoreline at Sandbridge, Virginia Beach proper, and North Virginia Beach after the 6-8 March 1962 storm has continued to erode at rates comparable to those experienced historically. Except for a few reaches of beach accreting, there has been a general recession of the entire shoreline. Based on the latest complete survey of 1968 for the reach from the state line to the Cape Henry Lighthouse, the 27.0 miles of beachfront along the Atlantic Ocean was undergoing an average annual rate of erosion of 0.72 feet, which is equivalent to approximately 100,000 cubic yards per year.

Authorized Federal Projects	Authorized Federal Survey Studies	Suitable Type of Remedial Action
None	Chesapeake Bay Basin--This study, currently under way, is comprehensive in scope and includes the entire Chesapeake Bay and its tidal tributaries. It will provide an appraisal of the water resources needs and of the economic interrelations among the several portions of the basin. Water resources being considered in the study include navigation, fisheries, flood control, noxious weeds, water pollution, water quality control, beach erosion and recreation. Future progress on the study is contingent on appropriation of funds.	Except for the highly developed areas of Virginia Beach proper, much of the shore is undeveloped or developed for summer use only. Beaches for recreational use are important to these types of development. Therefore, beach restoration and periodic artificial placement of sand would be a suitable type of remedial action. In the more highly developed areas, bulkheading with fill would be essential. Costs of beach restoration or bulkhead types of protection would depend to a great extent on the locality and extent of shore to be protected. It is estimated that effective protection could be provided for the shore along this reach for approximately $31,600,000.
None	Virginia Beach - A beach erosion control and hurricane protection study of the 38 miles of Virginia Beach shoreline is under way. The Division and District engineers have recommended structural improvement for beach erosion control and hurricane tidal flood protection in the area between Rudee Inlet and 89th Street and consisting of the placement of a protective beach to elevation 10; a new sheet pile and concrete cap wall plus riprap between Rudee Inlet and 57th to 89th Streets. The protective beaches and dunes would be maintained by periodic sand replenishment.	Same as above.

Reach	Profile Number	Distance (miles)	Physical Characteristics
49th Street to Rudee Inlet	3 4	3.3	From Rudee Inlet to Cape Henry, a distance of 7 miles a flat unstable sandy beach 100 to 200 feet wide and averaging 5 feet mean sea level in elevation is visited annually by more tourists than any resort beach in Virginia. Photographs V-1 and V-2 show this area. The 3.3 miles of shoreline between 49th Street and Rudee Inlet are devoid of dunes.

Shore Ownership	Shore Use and Development	Shore History
The 3.3 miles of beach between 49th Street and Rudee Inlet are publicly owned and constitute the most significant ocean front area of Virginia Beach in terms of mass recreational use and commercial development.	The stretch of shore north of Rudee Inlet to Fort Story is publicly used for recreational purposes. In 1970, the annual visitation at the Virginia Beach resort areas was 4,320,000 persons. Development is residential and commercial.	Material placed artificially to rebuild the Atlantic Ocean shoreline at Sandbridge, Virginia Beach proper, and North Virginia Beach after the 6-8 March 1962 storm has continued to erode at rates comparable to those experienced historically. Except for a few reaches of beach accreting, there has been a general recession of the entire shoreline. Based on the latest complete survey of 1968 for the reach from the state line to the Cape Henry Lighthouse, the 27.0 miles of beachfront along the Atlantic Ocean was undergoing an average annual rate of erosion of 0.72 feet, which is equivalent to approximately 100,000 cubic yards per year.

Authorized Federal Projects	Authorized Federal Survey Studies	Suitable Type of Remedial Action
One Federal beach erosion control project has been authorized for the shoreline of Virginia Beach between Rudee Inlet and 49th Street, a distance of about 3-1/3 miles. The project, Virginia Beach, Virginia, Beach Erosion Control, provided Federal funds for beach restoration, construction of approximately 24 groins, and a 25-year program for periodic artificial placement of sand fill on the beach within the City between Rudee Inlet and 49th Street. The beach restoration work has been completed. The groins have not been constructed because experience to date indicates that periodic placement of sand by hydraulic pumping is the more suitable and economic method of maintenance stability of the shore. The 25-year program for artificial placement of sand on the beach is under way.	A beach erosion control and hurricane protection study of the 38 miles of Virginia Beach shoreline is under way. The Division and District engineers have recommended structural improvement for beach erosion control and hurricane tidal flood protection in the area between Rudee Inlet and 89th Street and consisting of the placement of a protective beach to elevation 10; a new sheet pile and concrete cap wall plus riprap between Rudee Inlet and 57th to 89th Streets. The protective beaches and dunes would be maintained by periodic sand replenishment.	Except for the highly developed areas of Virginia Beach proper, much of the shore is undeveloped or developed for summer use only. Beaches for recreational use are important to these types of development. Therefore, beach restoration and periodic artificial placement of sand would be a suitable type of remedial action. In the more highly developed areas, bulkheading with fill would be essential. Costs of beach restoration or bulkhead types of protection would depend to a great extent on the locality and extent of shore to be protected. It is estimated that effective protection could be provided for the shore along this reach for approximately $31,600,000.

Reach	Profile Number	Distance (miles)	Physical Characteristics
Rudee Inlet to North of Sandbridge	5 6 7 8	4.4	The beach narrows and is separated from the mainland by low dunes. Beach grasses have been planted along sections of this reach in an attempt to stabilize the ever shifting sands.
North of Sandbridge to North Carolina line	9 10 11 12 13 14 15 16 17 18	12	Narrow undeveloped barrier strip of land with a sandy beach facing the Atlantic Ocean on one side and several picturesque bays on the other extends a distance of 9 miles before approaching the rapidly developing resort area of Sandbridge Beach. This relatively undisturbed zone varies in width from .25 mile to 1.5 miles and is frequently breached by both sound and ocean waters during storm periods. Access to this area is limited to vehicles capable of traveling on sand since no paved roads exist.

Shore Ownership	Shore Use and Development	Shore History
Largely occupied by the U.S. Anti-Air Warfare Training Center at Dam Neck. A setment of publicly owned beach does, however, exist immediately south of Rudee Inlet.	Development is primarily military, the U.S. Anti-Air Warfare Training Center being found here.	Material placed artificially to rebuild the Atlantic Ocean shoreline at Sandbridge, Virginia Beach proper, and North Virginia Beach after the 6-8 March 1962 storm has continued to erode at rates comparable to those experienced historically. Except for a few reaches of beach accreting, there has been a general recession of the entire shoreline. Based on the latest complete survey of 1968 for the reach from the state line to the Cape Henry Lighthouse, the 27.0 miles of beachfront along the Atlantic Ocean was undergoing an average annual rate of erosion of 0.72 cubic feet, which is equivalent to approximately 100,000 cubic yards per year.
The 12 miles of beach are divided among Federa, public, and private interests. Sandbridge Beach, a reach of 3 miles, is publicly owned.	The shoreline south of Sandbridge is generally undeveloped and publcly used for recreation. The Back Bay Wildlife Refuge and the Little Island Municipal Park are located in this reach. Sandbridge Beach is privately used for recreational purposes and developed for summer residence. Summer residential development south of Sandbridge is expected to continue. Some additional development as parks and conservation areas is likely.	Observations indicate that south of False Cape, an area approximately 25 miles south of Cape Henry, the drift is southerly. North of False Cape, the drift has a net northerly component. The rate and volume of drift in this zone is relatively large.

Authorized Federal Projects	Authorized Federal Survey Studies	Suitable Type of Remedial Action
None	None	Except for the highly developed areas of Virginia Beach proper, much of the shore is undeveloped or developed for summer use only. Beaches for recreational use are important to these types of development. Therefore, beach restoration and periodic artificial placement of sand would be a suitable type of remedial action. In the more highly developed areas, bulkheading with fill would be essential. Costs of beach restoration or bulkhead types of protection would depend to a great extent on the locailty and extent of shore to be protected. It is estimated that effective protection could be provided for the shore along this reach for approximately $31,600,000.
None	None	Same as above

Table 3. Beach Profiles, Distances, and Profile History

Profile No.	Distance to Next Profile	Previous Investigators	Dates Sampled	References
1	2.0 mi.	Fausak	Daily 10 Aug -> 9 Sept. 1969	Fausak 1970
2	3.1 mi.	Harrison	4 Nov 1956 -> Sept. 1958 7-8 Mar. 1962	Harrison and Wagner 1964
3	0.9 mi.	Harrison	25 Mar., 10 Apr. 1963 11 June -> 5 July 1963	Harrison and Wagner 1964
4	0.9 mi.	Harrison	25 Mar., 10 Apr. 1963 11 June -> 5 July 1963	Harrison and Wagner 1964
5	1.4 mi.	Harrison	Mar. and Apr. 1963 10 June -> 5 July 1963	Harrison and Wagner 1964
6	1.7 mi.			
7	1.0 mi.	Goldsmith and Smith (Back Bay Refuge)	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
8	3.1 mi.	Goldsmith and Smith (Back Bay Refuge)	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
9	1.7 mi.	Goldsmith and Smith (Back Bay Refuge)	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
10	1.3 mi.	Bullock	Monthly July 1969 -> Mar. 1971	Bullock 1971
		Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
11	0.5 mi.	Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
12	0.8 mi.	Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	

Table 3, Cont'd.

Profile No.	Distance to Next Profile	Previous Investigators	Dates Sampled	References
13	0.5 mi.	Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
14	1.6 mi.	Bullock	Monthly July 1969 -> Mar. 1971	Bullock, 1971
		Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
15	2.9 mi.	Goldsmith and Smith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
16	1.3 mi.	Goldsmith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	
17	1.5 mi.	Shideler, Swift, McHone	Oct. 1970 -> Oct. 1971	In Preparation
		Goldsmith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	In Preparation
18		Bullock	Monthly July 1969 -> Mar. 1971	Bullock 1971
		Goldsmith	Bi-monthly (approx.) Sept. 1972 -> Jan. 1974	

Total of 26.2 miles distance between profiles 1-18

Average of 1.54 miles distance between each profile

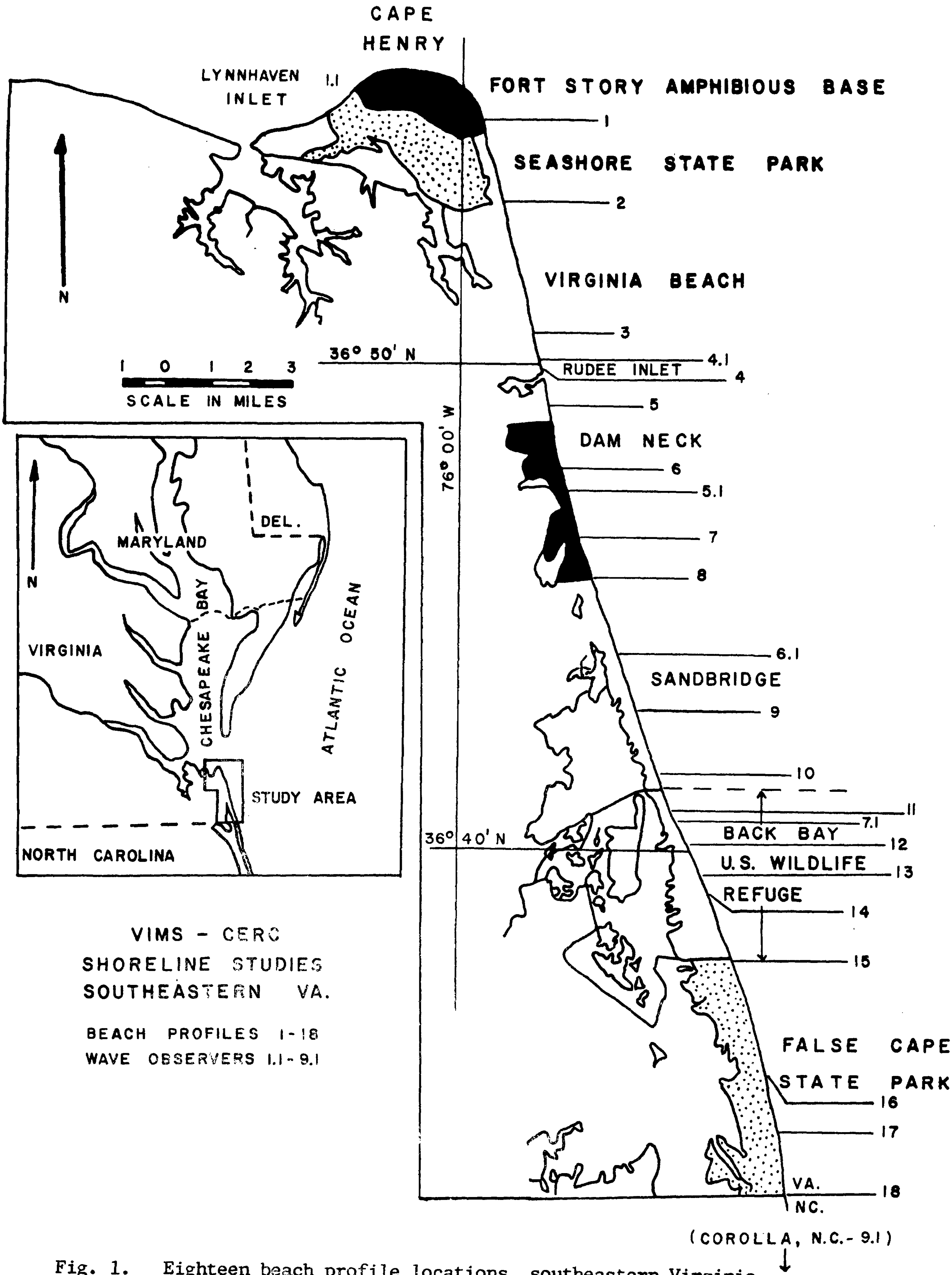


Fig. 1. Eighteen beach profile locations, southeastern Virginia.

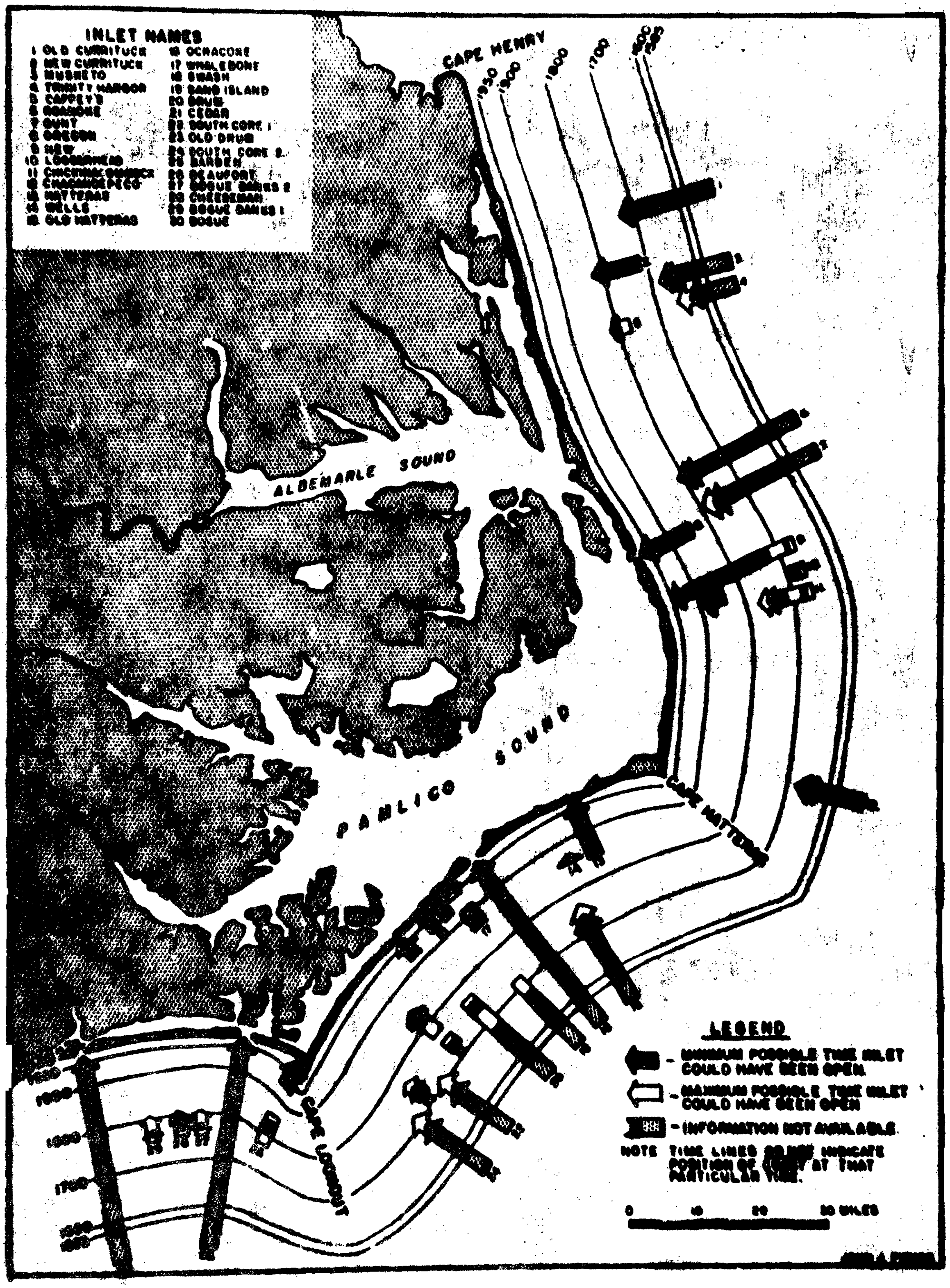


Fig. 2a. Temporal-spatial distribution of historic inlets along the Outer Banks coast (from Fisher, 1967).

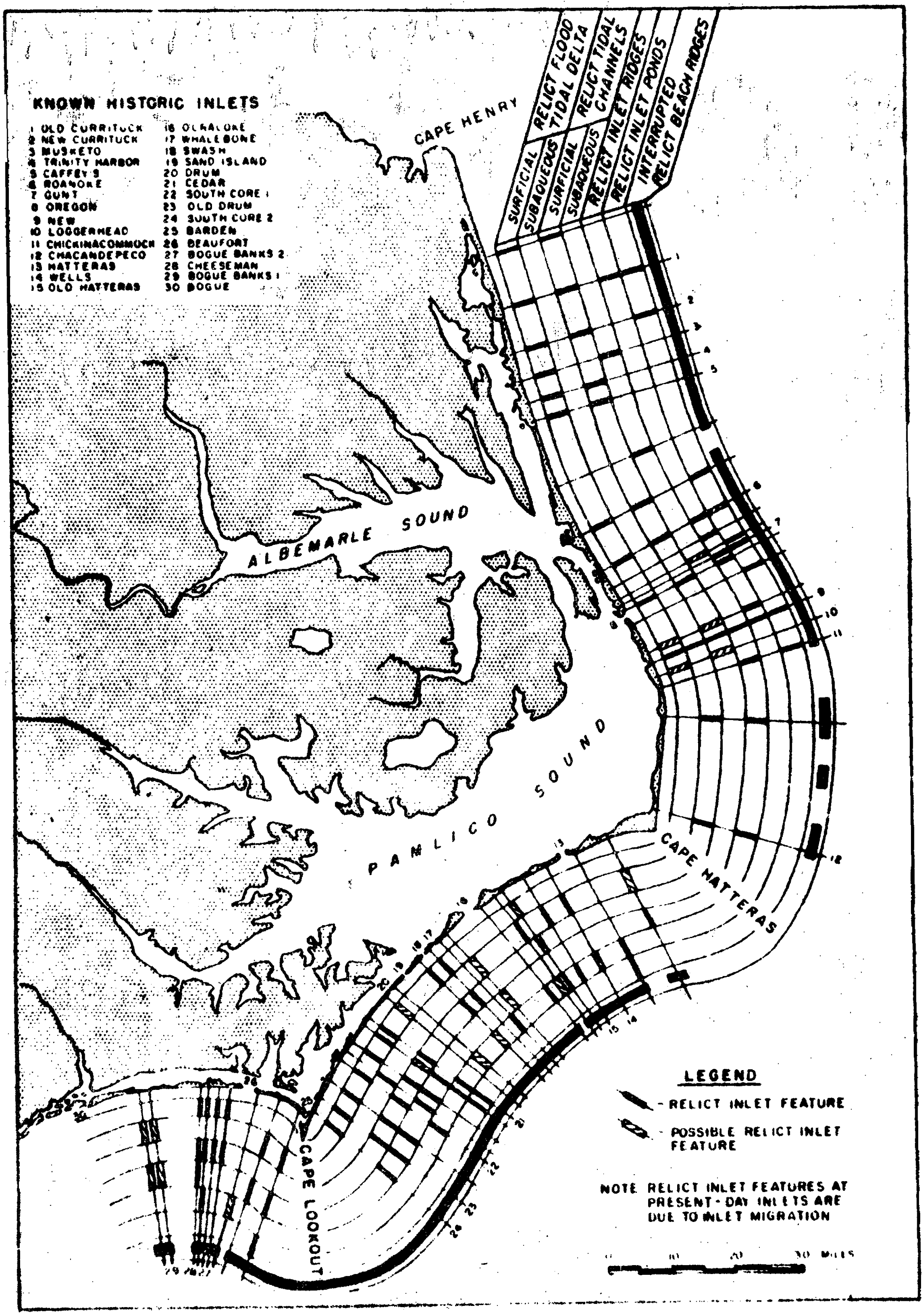


Fig. 2b. Distribution of relict inlet features along the Outer Banks (from Fisher, 1967).

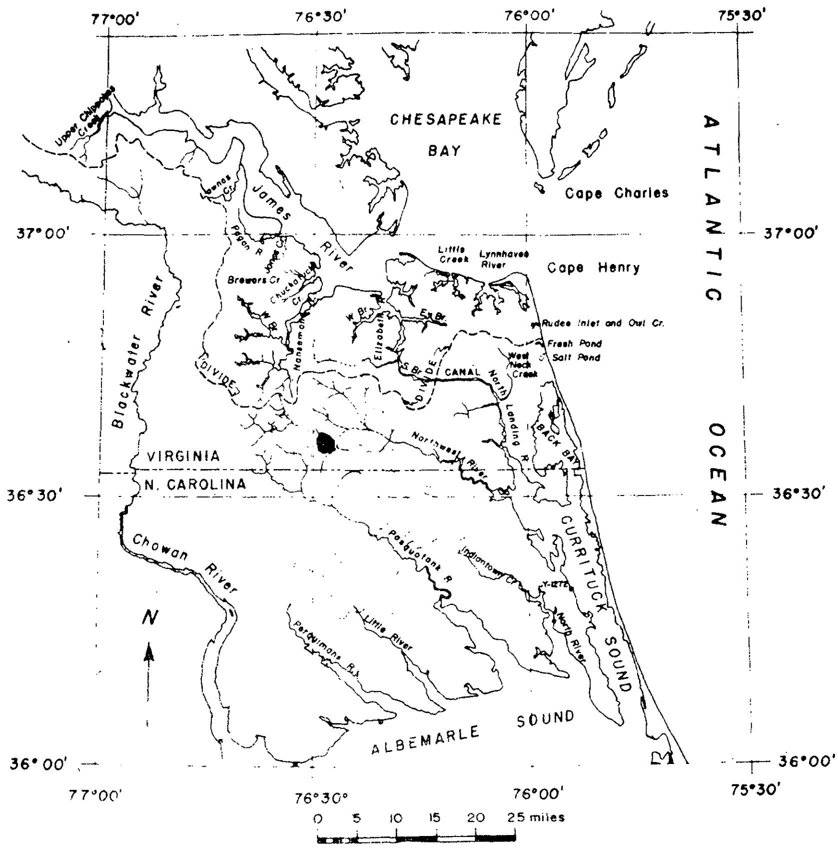


Fig. 3. Drainage of southeastern Virginia and adjacent North Carolina (from Oaks and Coch, 1963).

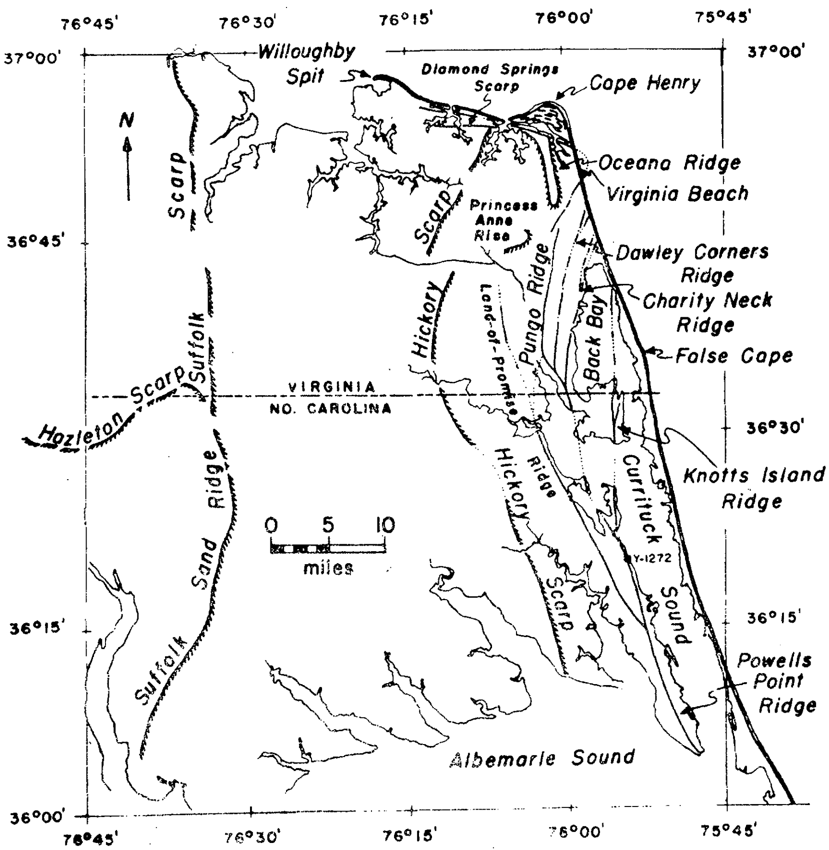


Fig. 4. Scarps and ridges in southeastern Virginia and adjacent North Carolina (from Oaks and Coch, 1963).

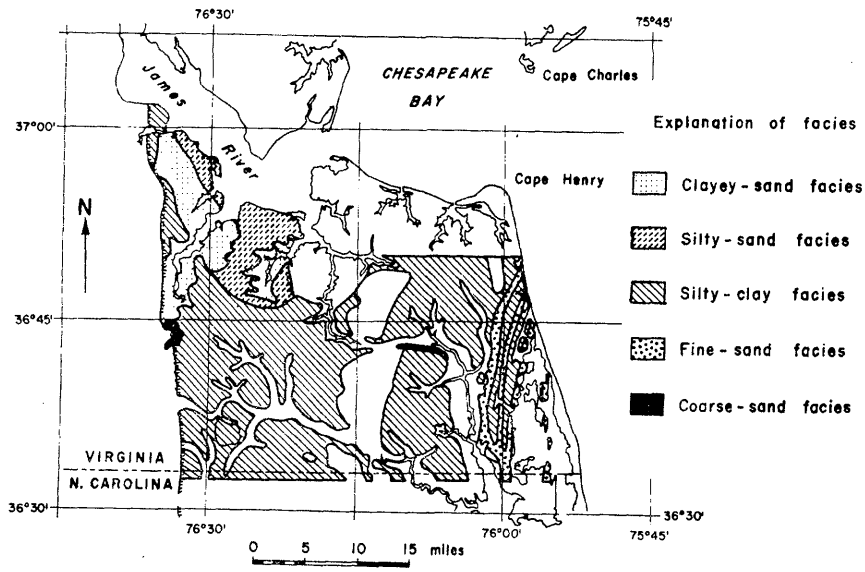


Fig. 5. Distribution of major sediment facies of upper member of Sandbridge Formation, southeastern Virginia (from Oaks and Coch, 1973).

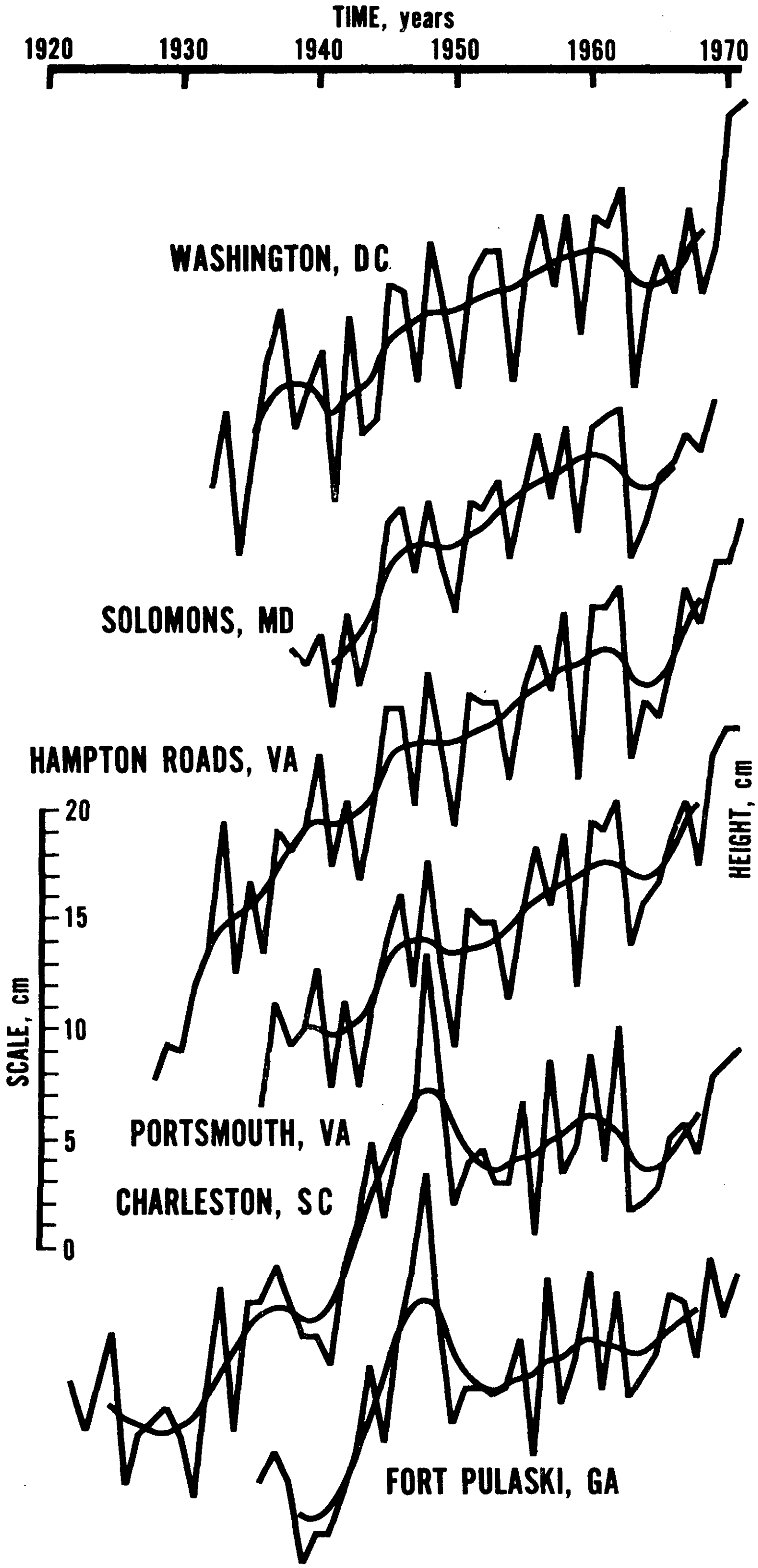


Fig. 6. Historical sea level changes at Hampton Roads, Virginia (from Hicks, 1973).

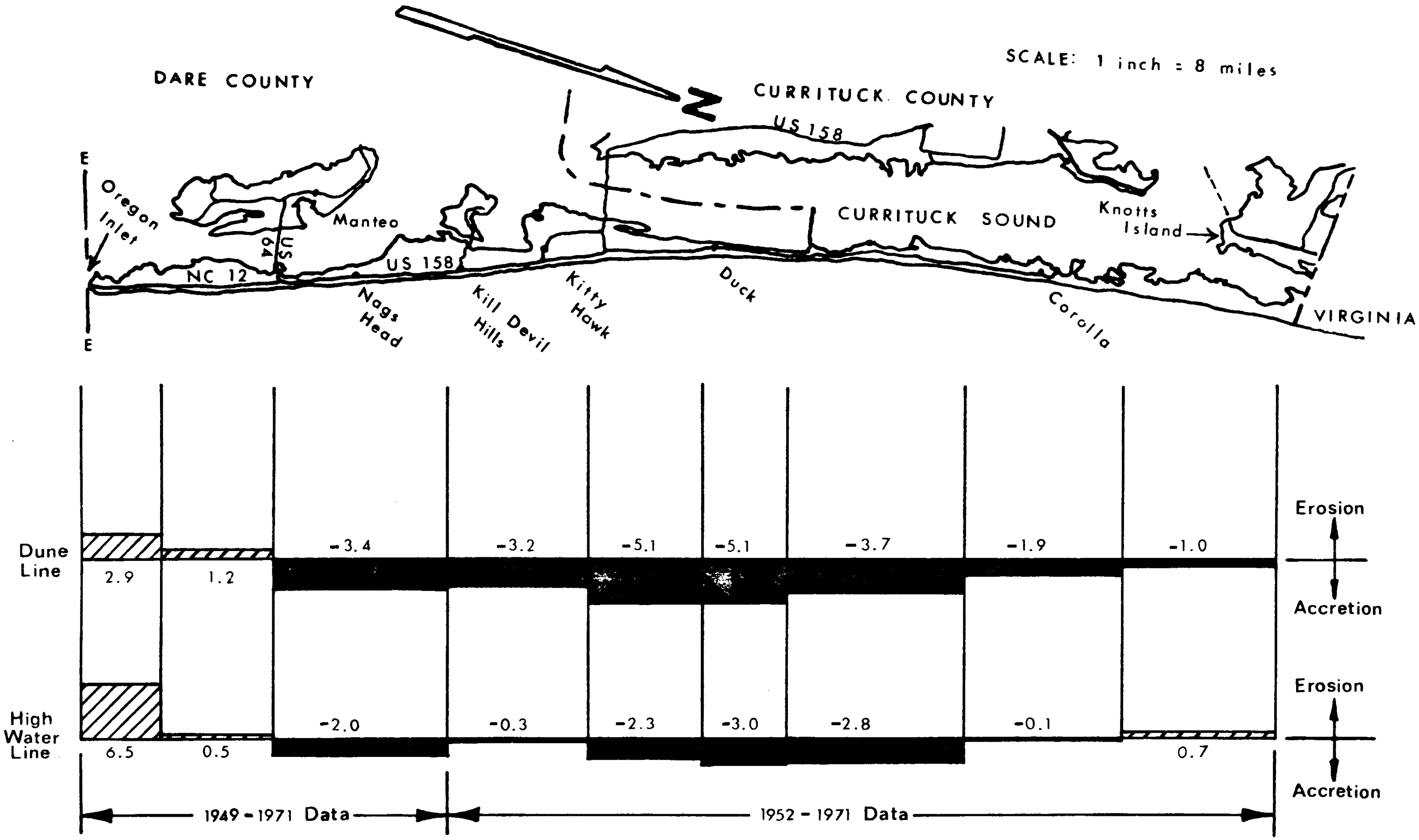
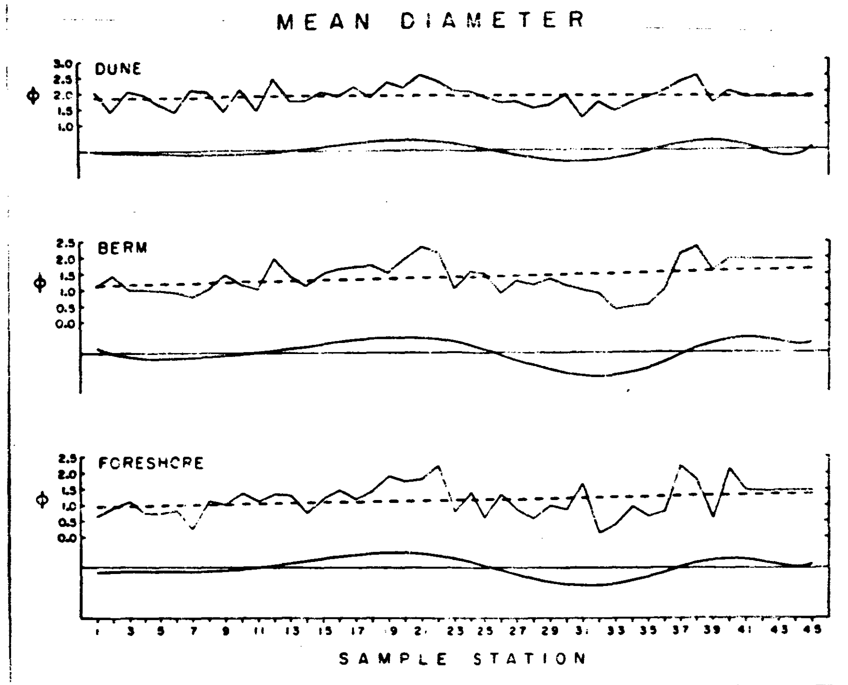
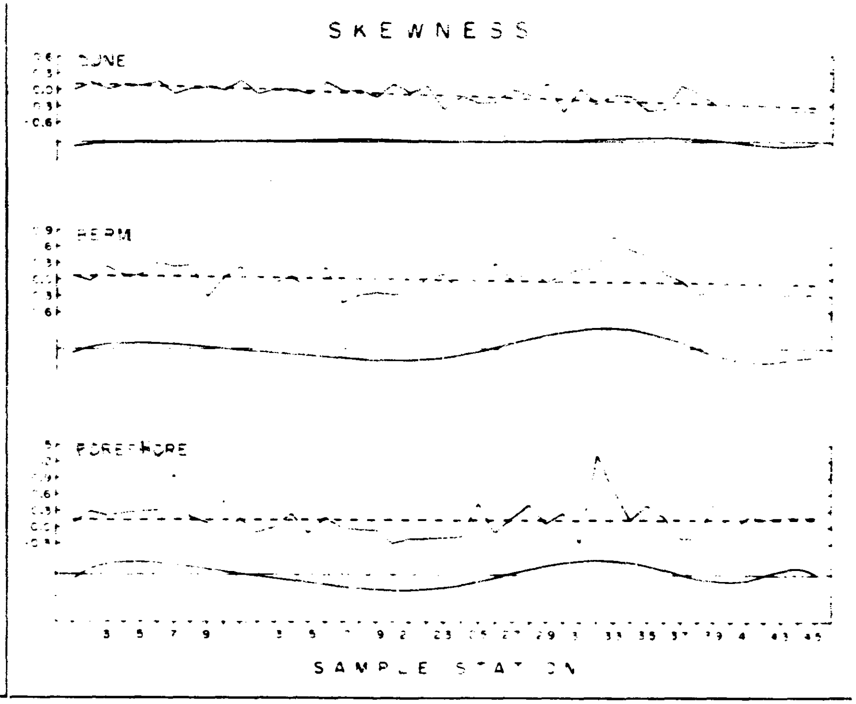


Fig. 7. Northern Dare and Currituck Counties - dune line and high water line. Composite mean annual rates of change (feet per year), 1949-1971 (from Wahls, 1973).

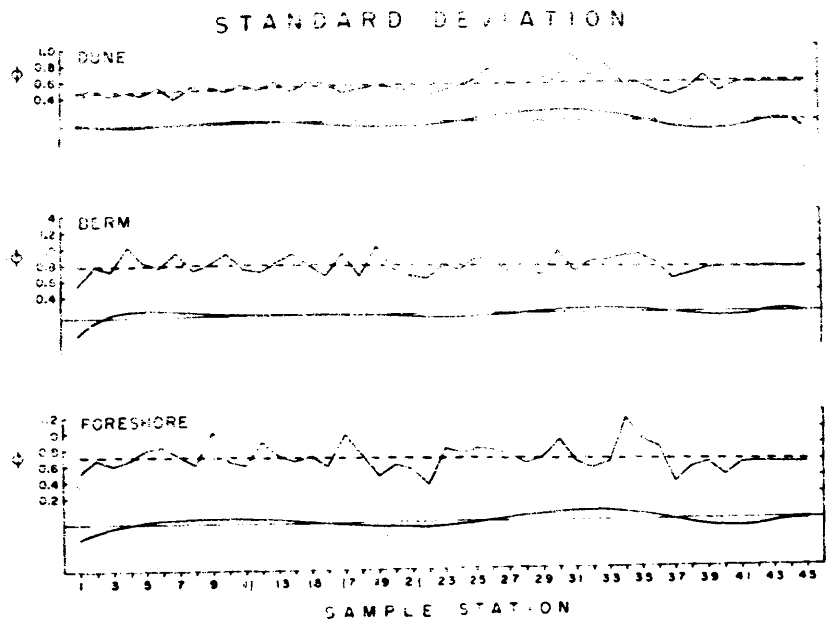
Fig. 8. Interpretation of coastal processes from grain size (from Shideler, 1973)



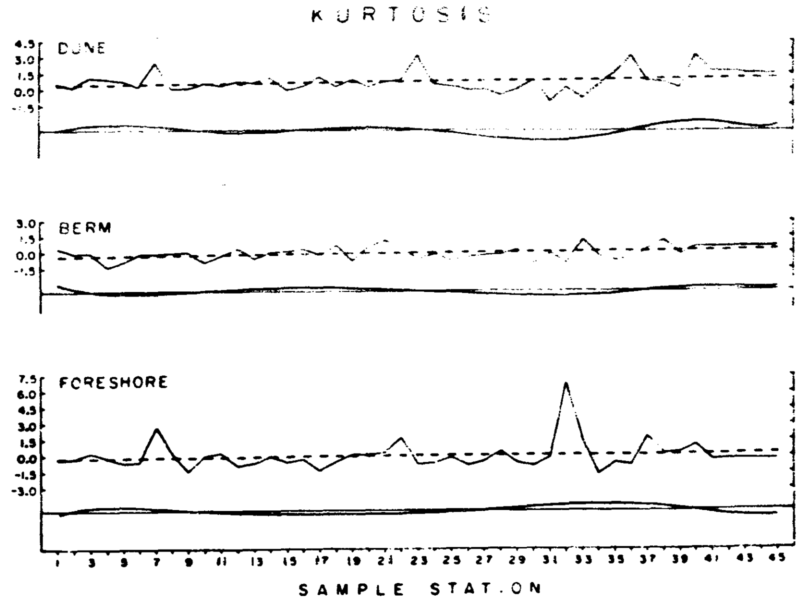
Comparative trend-analysis graphs of the mean diameter.



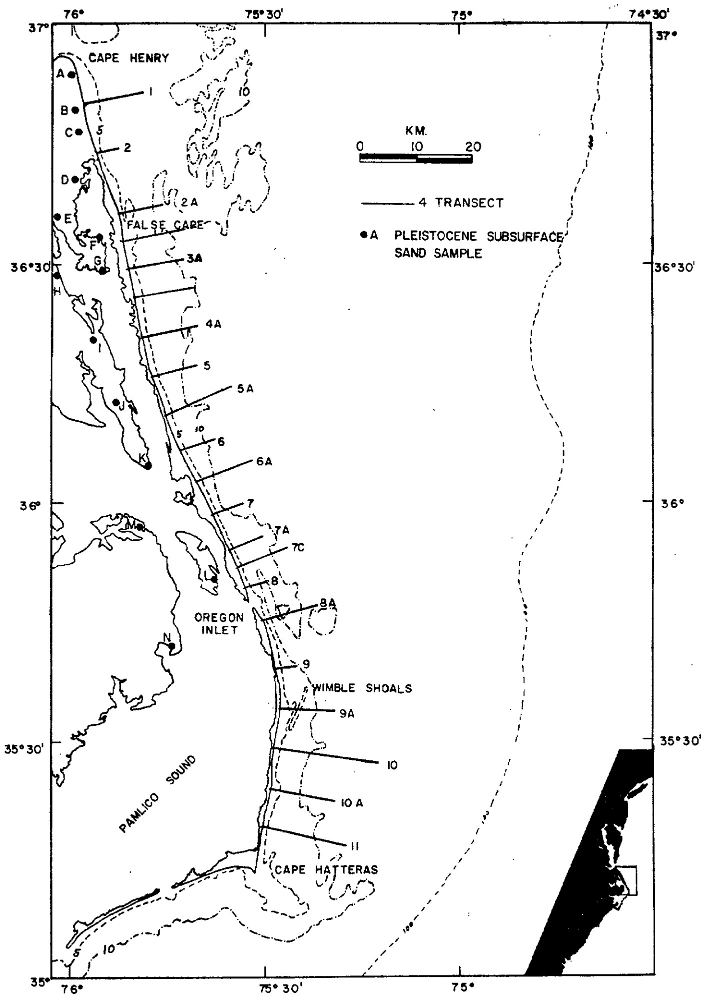
Comparative trend-analysis graphs of skewness.



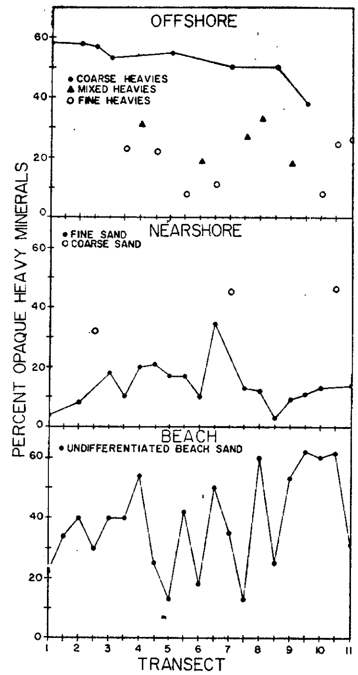
Comparative trend-analysis graphs of the standard deviation.



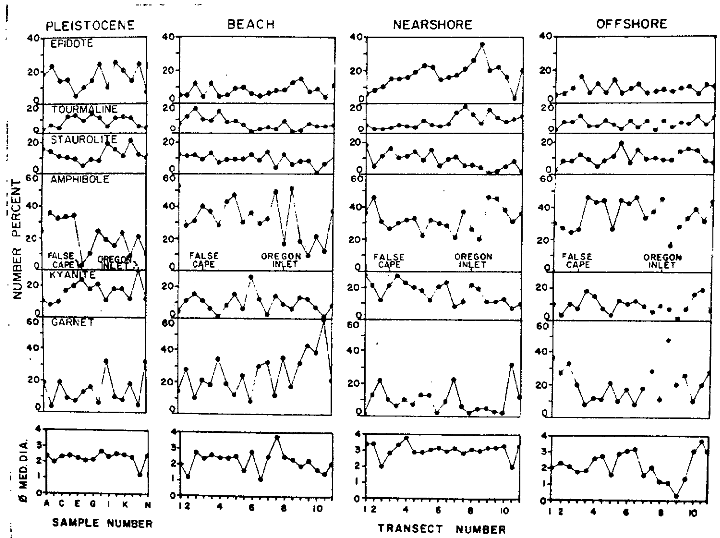
Comparative trend-analysis graphs of kurtosis.



Study area and sample net. Each transect was sampled on the berm, at 15 meters, and 8 kilometers. Depths in fathoms.



Coastwise trends of opaque heavy minerals.



Coastwise trends of translucent heavy minerals.

Fig. 9. Mineralogical data (from Swift, Dill, and McHone, 1971).

Shore-line changes along unbroken reaches of the coast

Location mile No.[1]	Number of miles	Period in years	Dates of surveys	Net change in feet: Accretion	Net change in feet: Erosion	Average annual change in feet: Accretion	Average annual change in feet: Erosion	Remarks
0-4	4	67	1858-1925	239		3.56		
4-32			1857					Only 1 survey.
32-34	2	67	1848-1915		63		0.94	
34-43	9	65.7	1849-1915	312		4.78		
43-45	2	64	1851-1915		131		2.05	
45-46	1	64	1851-1915	10		.15		
46-55	9	66	1849-1915		249		3.77	
55-59			1849-1915					Oregon Inlet.
59-62	3	65	1852-1917		148		2.24	
62-64	2	65	1852-1917	105		1.60		
64-69			1852-1917					New Inlet.
69-74	5	65	1852-1917		395		6.07	
74-75	1	65	1852-1917	119		1.84		
75-77	2	65	1852-1917		118		1.81	
77-89	12	65	1852-1917	379		5.83		
89-90	1	65	1852-1917		15		.23	
90-91	1	65	1852-1917	63		.96		
91-93	2	65	1852-1917		160		2.46	
0-93	56	65.6		55		.84		
93-100			1852-1917					Cape Hatteras.
100-102	2	57	1860-1917	348		6.10		
102-110	8	57	1860-1917		588		10.32	
110-112			1860-1917					Hatteras Inlet.
112-119	7	56	1860-1916		563		10.05	
119-124	5	50	1866-1916	171		3.42		
124-125	1	64	1852-1916		87		1.36	
125-127	2	64	1852-1916	353		5.51		
127-130			1852-1916					Ocracoke Inlet.
130-139	9	50	1866-1916	182		3.64		
139-142	3	50	1866-1916		91		1.82	
142-144		50	1866-1916					Sand Inlet.
144-148	4	70	1866-1936	302		4.31		
148-149			1866-1936					Drum Inlet.
149-157	8	70	1866-1936				1.88	
157-158			1866-1936					Only 1 survey.
158-159	1	70	1866-1936		241		3.44	
159-161		70	1866-1936					Only 1 survey.
161-163	2	70	1866-1936		101		1.44	
163-164	1	70	1866-1936	38		.54		
164-171	7	60	1853-1913		354		6.26	
93-171	60	59			131		2.22	
171-179			1853-1913					Cape Lookout.
179-185	6	60	1853-1913		93		1.55	
185-186	1	62	1851-1913	15		.24		
186-190			1851-1913					Beaufort Inlet.
190-191	1	79	1854-1933				.14	
191-193	2	79	1854-1933	70		.90		
193-200	7	66	1867-1933		77		1.14	
200-213	13	62	1871-1933	165		2.66		
213-216			1871-1933					Bogue Inlet.
216-217	1	61	1872-1933	125		2.06		
217-219			1872-1933					Bear Inlet.
219-221	2	61	1872-1933		62		1.02	
221-222			1872-1933					Brown's Inlet.
222-223	1	61	1872-1933	47		.78		
223-228	5	61	1872-1933		67		1.10	
228-230			1856-1933					New River Inlet.
230-242	12	77	1856-1933		100		1.31	
242-244	2	75	1858-1933	125		1.66		
244-246	2	75	1858-1933		36		.48	
246-247	1	75	1858-1933	40		.53		
247-248	1	75	1858-1933		25		.33	
248-249	1	75	1858-1933	31		.41		
249-251			1858-1933					New Topsail Inlet.
251-252	1	75	1858-1933		669		8.92	
252-253			1858-1933					Old Topsail Inlet.
253-254	1	75	1858-1933		110		1.47	
254-256	2	76	1857-1933	148		1.95		
256-257			1857-1933					Rich Inlet.
257-260	3	76	1857-1933		409		5.38	
260-261			1857-1933					Mason Inlet.
261-262	1	76	1857-1933		630		8.30	

[1] Measured from Virginia State line.

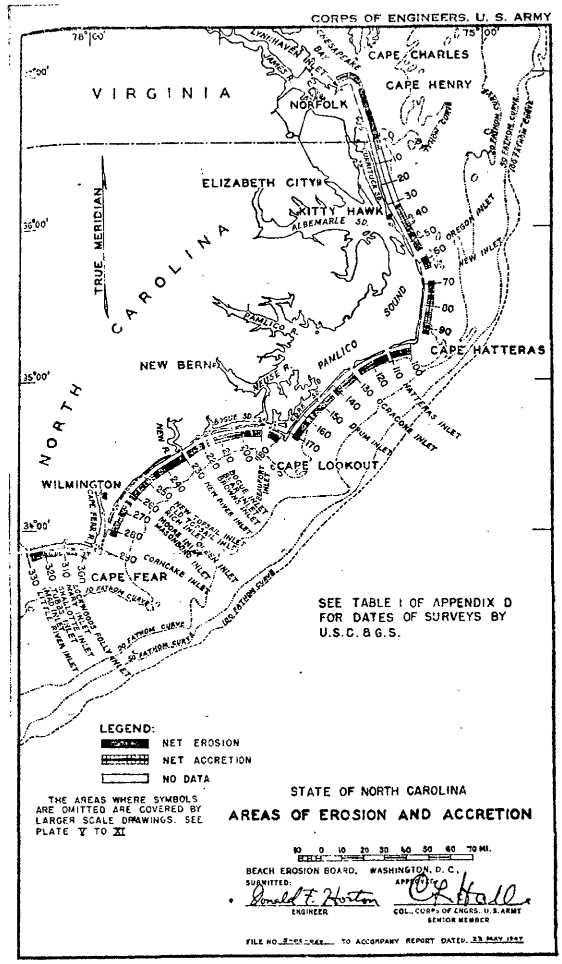
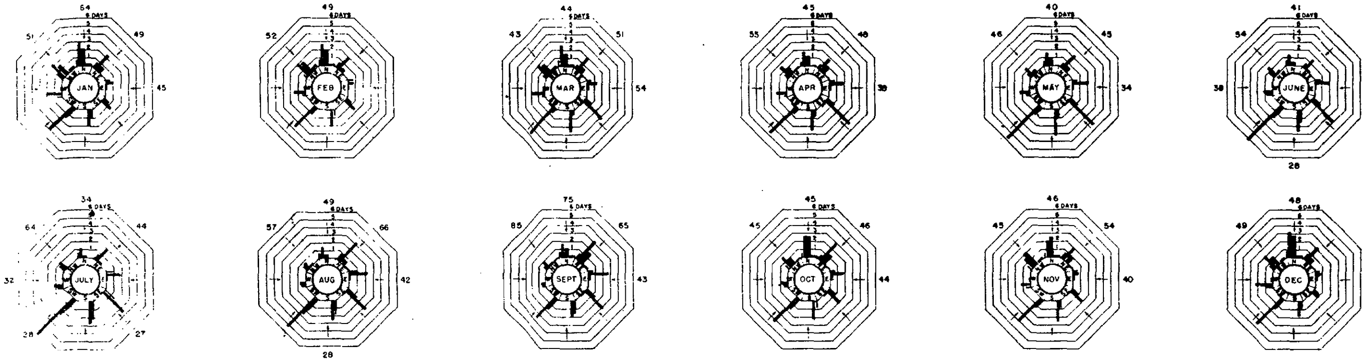


Fig. 10. Shore-line changes (1858-1933) along unbroken reaches of coast (from U.S. Army Corps of Engineers, 1948).



DIRECTION AND VELOCITY OF WINDS

Direction is indicated by arrows, velocity by widths, and frequency by length of shaded lines.

Length of shaded lines indicates number of days duration in an average month

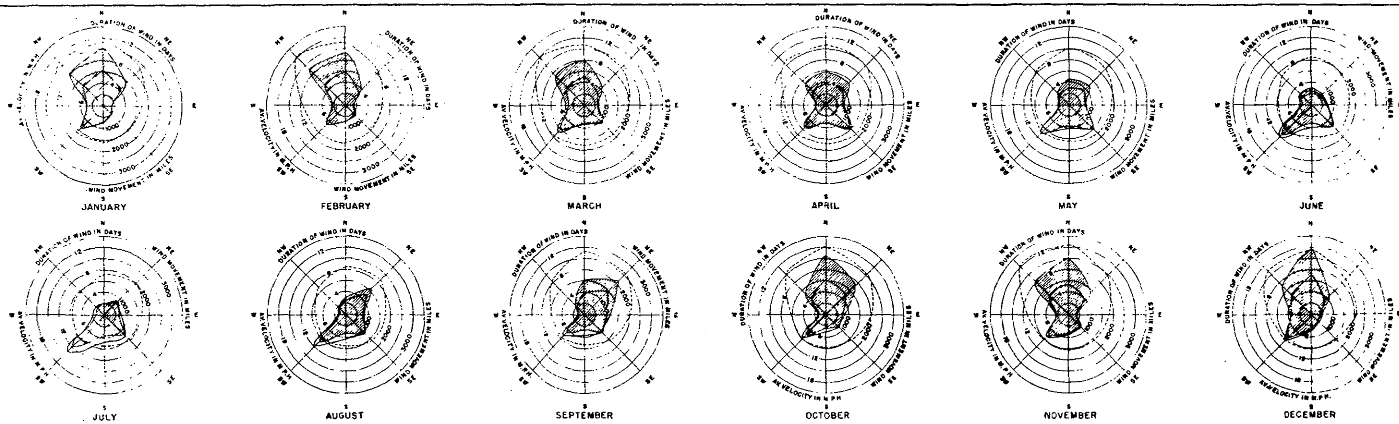
Data obtained from U.S. Weather Bureau, Cape Henry, Va.

Figures outside diagrams denote maximum wind velocities recorded during period 1930-1945.

LEGEND

Velocity Range M.P.H.	Force Beaufort Scale
0 to 7	0 to 2
8 to 18	3 & 4
19 to 31	5 & 6
over 31	7 & over

DIRECTIONAL-DURATION WIND ROSES
MONTHLY LONG-TERM AVERAGE
16 YEARS: 1930-1945



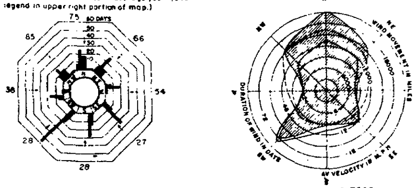
Dynamic wind roses shown hereon represent average monthly values based on 16 years of record of the U S Weather Bureau's Cape Henry Station for the period 1930-1945

LEGEND

Average velocity in M P H
Duration of wind in days
Wind movement in miles

DYNAMIC WIND ROSES
MONTHLY LONG-TERM AVERAGE
16 YEARS 1930-1945

Length of shaded lines indicates number of days duration of winds in average year (See legend in upper right portion of map.)



DIRECTIONAL-DURATION WIND ROSE
AVERAGE YEAR
16-YEAR PERIOD: 1930-1945

DYNAMIC WIND ROSE
AVERAGE YEAR
16-YR PERIOD: 1930-1945

FREQUENCY IN DAYS PER 100 YEARS OF WINDS OVER 45 M P H.

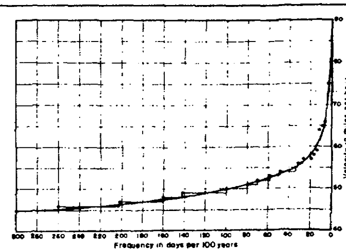
Velocity in M.P.H	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	64	65	66	75	85
Number of observed days	17	22	19	6	17	7	4	5	4	6	1	2	4	[illegible]	1	1	1	1	1	1
Number of days wind velocity equalled or exceeded velocity shown on top line	12[illegible]	104	82	63	57	40	33	29	24	20	4	13	11	7	6	5	4	3	2	1
Frequency in days per 100 years	297	228	184	142	120	98	78	62	50	42	33	27	23	20	16	9	8	7	3	1

FREQUENCY BY MONTHS OF WINDS OVER 45 M P H

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of observed days	21	17	16	8	3	6	6	11	10	6	7	10
Frequency in days per 100 years	53	41	37	20	7	15	15	27	25	16	17	25

FREQUENCY BY DIRECTIONS OF WINDS OVER 45 M P H

Direction	N	NE	E	SE	S	SW	W	NW
Number of observed days	36	28	5	0	0	0	0	52
Frequency in days per 100 years	88	69	12	0	0	0	0	128



NOTE.

Wind frequencies shown hereon were developed from 40 years of record covering the period 1906-1945, incl.

VIRGINIA BEACH, VIRGINIA

WIND ROSE DATA

NORFOLK DISTRICT, CORPS OF ENGINEERS

JUNE 1969

FILE. H-31-10-40

Fig. 11. Wind rose data (from U.S. Army Corps of Engineers, 1971).

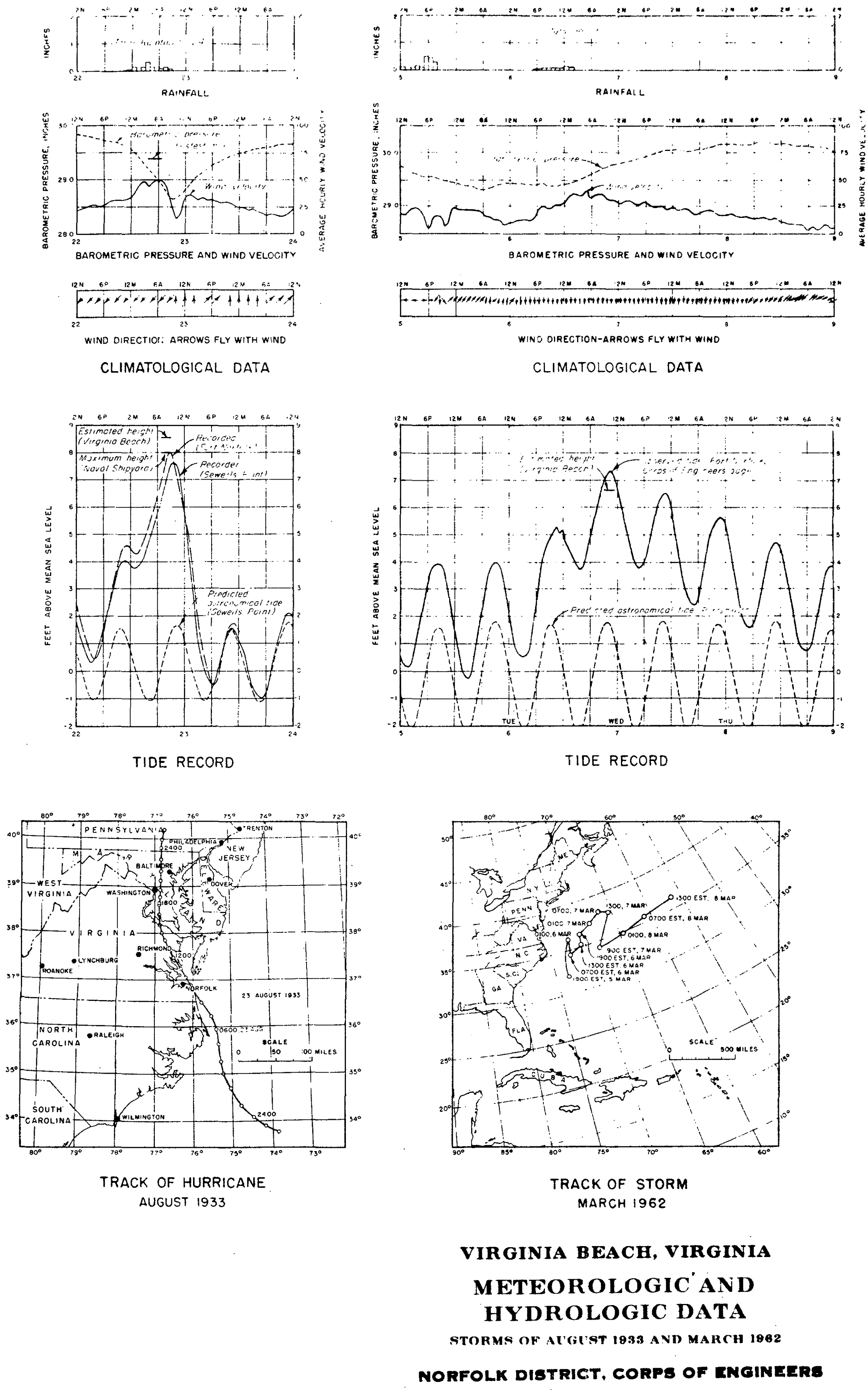


Fig. 12. Storms of August 1933 and March 1962 (from U.S. Army Corps of Engineers, 1971).

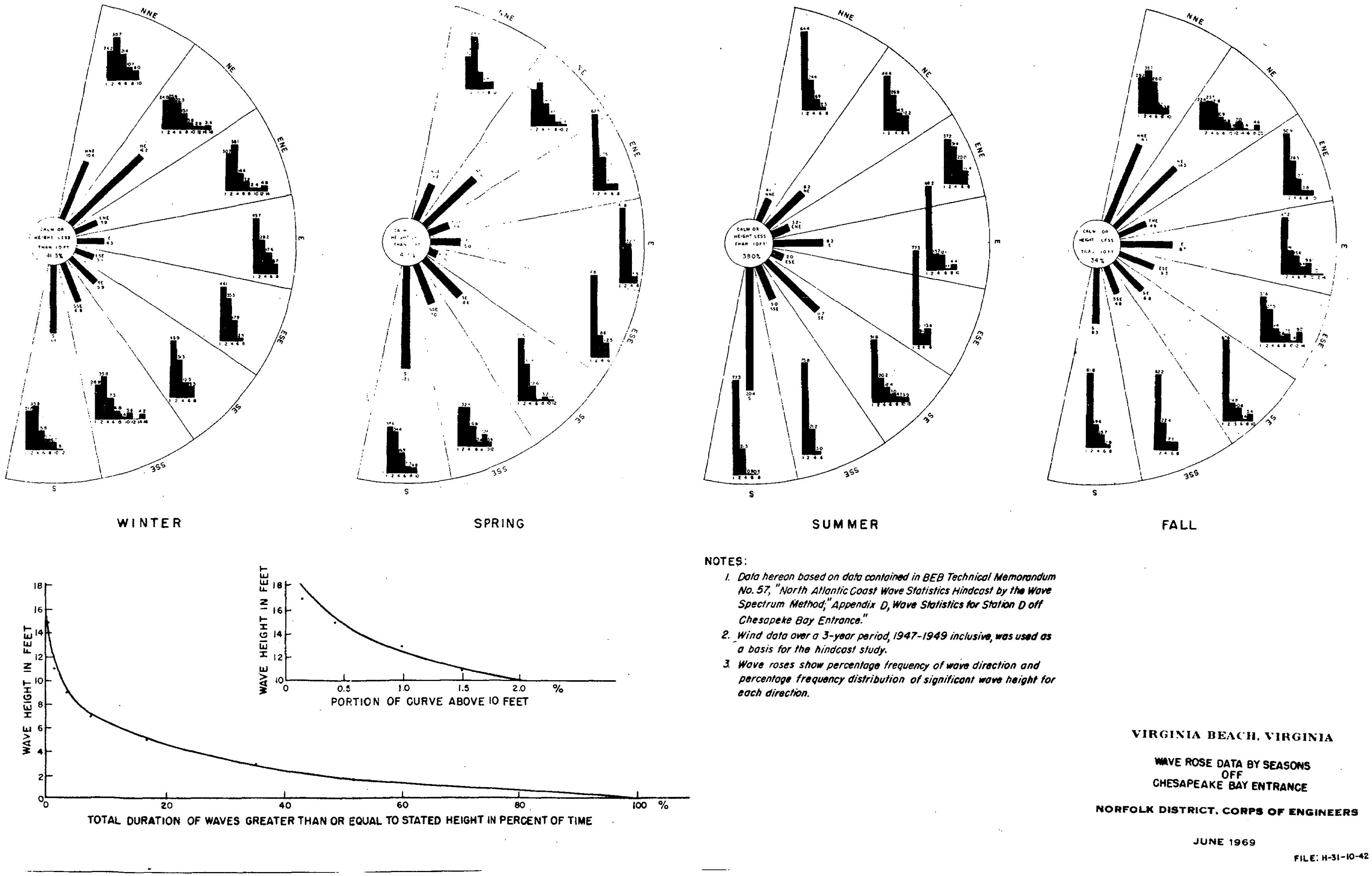
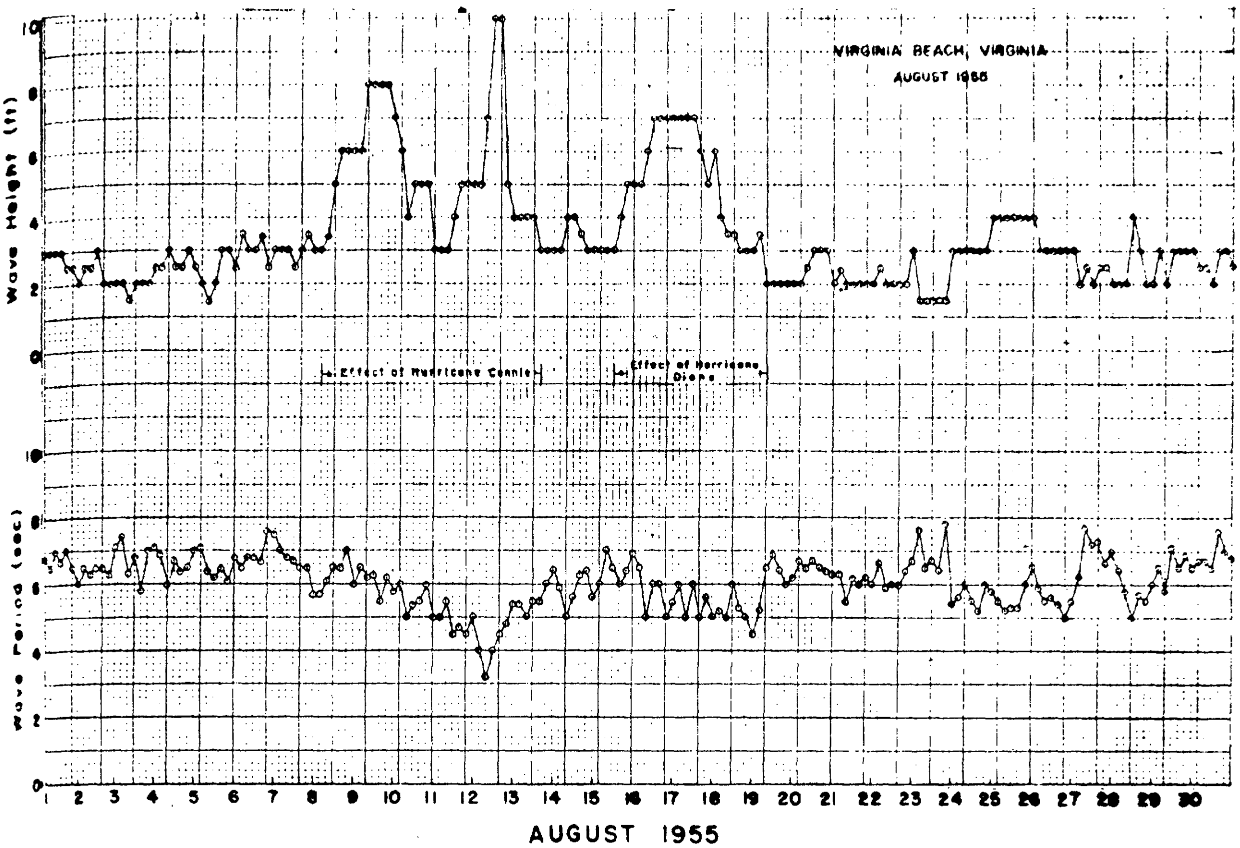
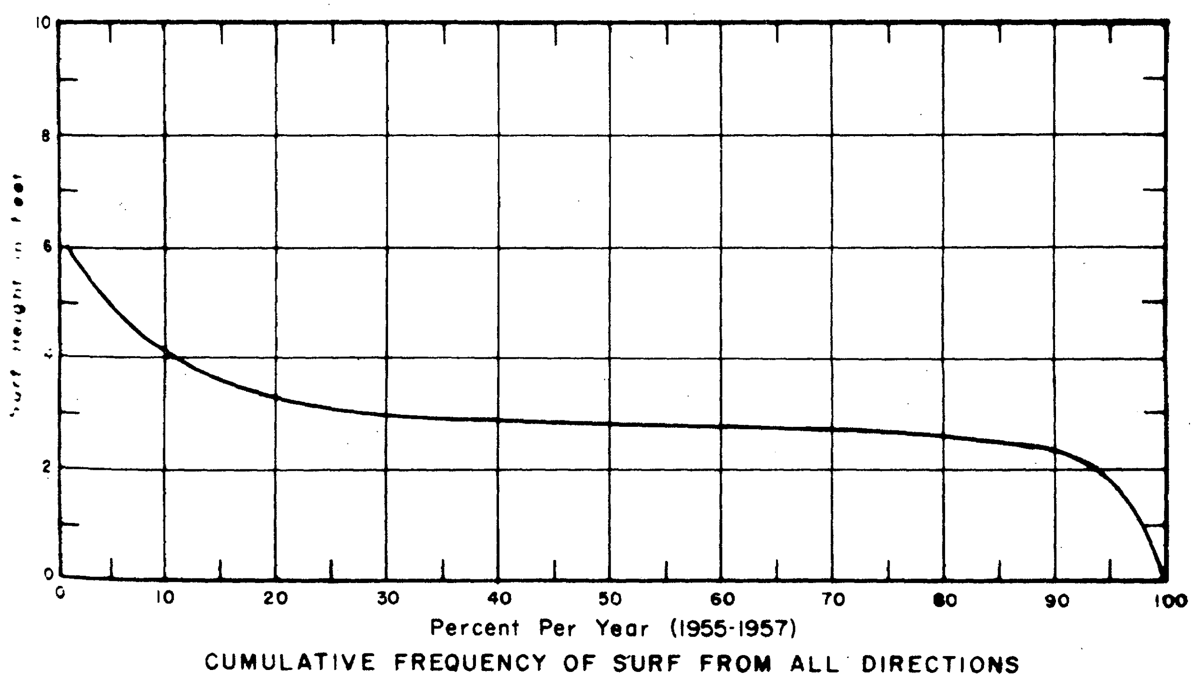


Fig. 13. Wave rose data by seasons off Chesapeake Bay entrance (from U.S. Army Corps of Engineers, 1971).





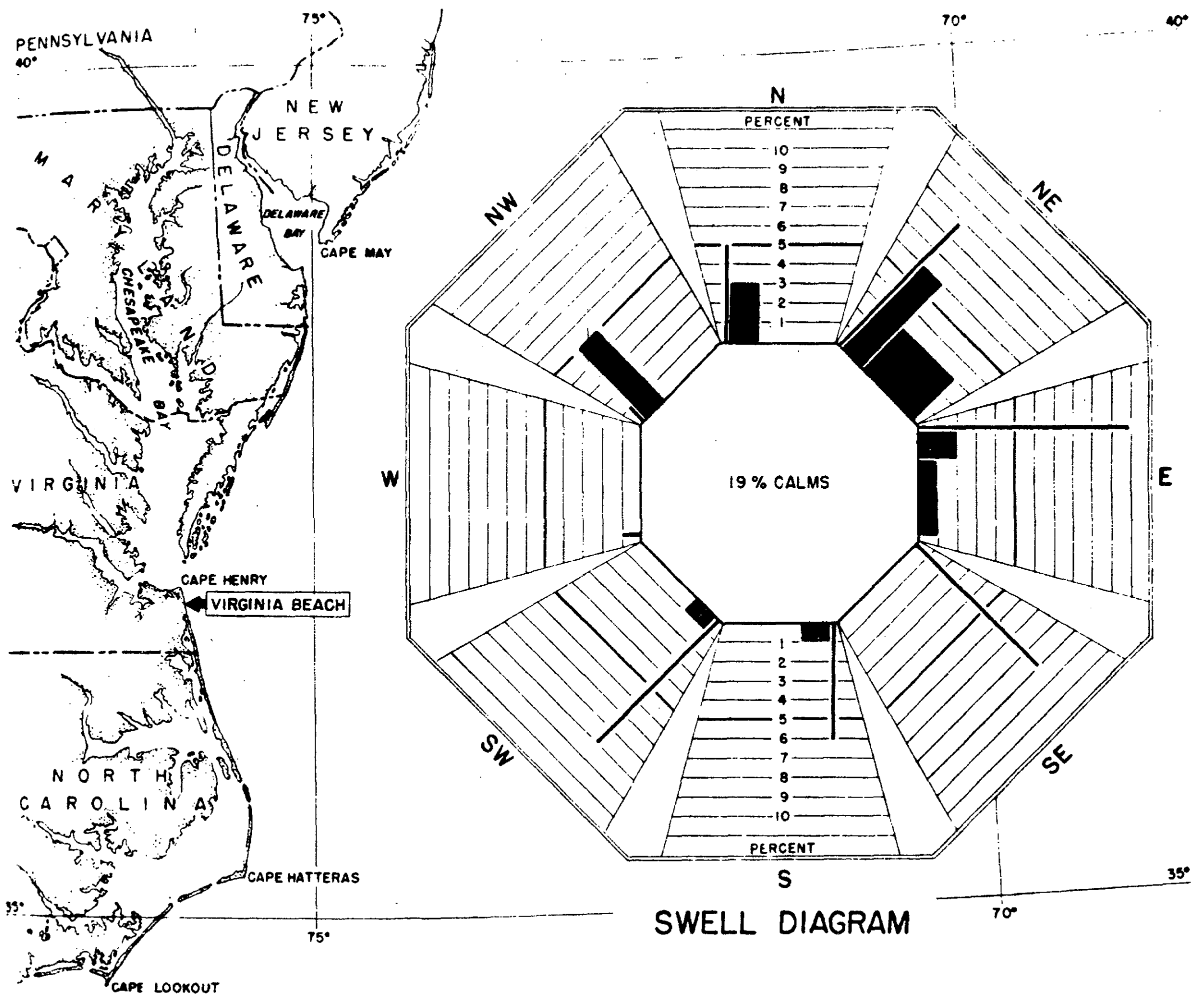
NOTE:
Data obtained from B.E.B. Technical Memorandum No. 108, "Surf Statistics for the Coasts of the United States."

VIRGINIA BEACH, VIRGINIA

SURF DATA

NORFOLK DISTRICT, CORPS OF ENGINEERS

Fig. 14. Surf data (from U.S. Army Corps of Engineers, 1971).



IN THE SWELL DIAGRAM THE LENGTH OF THE BAR DENOTES THE PERCENT OF THE TIME THAT SWELLS OF EACH TYPE HAVE BEEN MOVING FROM OR NEAR THE GIVEN DIRECTION. THE FIGURE IN THE CENTER OF THE DIAGRAM INDICATES THE PERCENT OF CALMS.

WIDTH OF BARS HAVE BEEN WEIGHTED IN PROPORTION TO THE SWELL HEIGHT SQUARED.

THE SWELL DIAGRAM SHOWN ABOVE APPLIES TO THAT PORTION OF THE ATLANTIC OCEAN BETWEEN LATITUDE 35° AND 39° NORTH AND FROM THE SHORE EASTWARD TO THE 70 TH. MERIDIAN WEST.

VIRGINIA BEACH, VIRGINIA

SWELL DIAGRAM

NORFOLK DISTRICT, CORPS OF ENGINEERS

JUNE 1969

Fig. 15. Swell diagram (from U.S. Army Corps of Engineers, 1971).

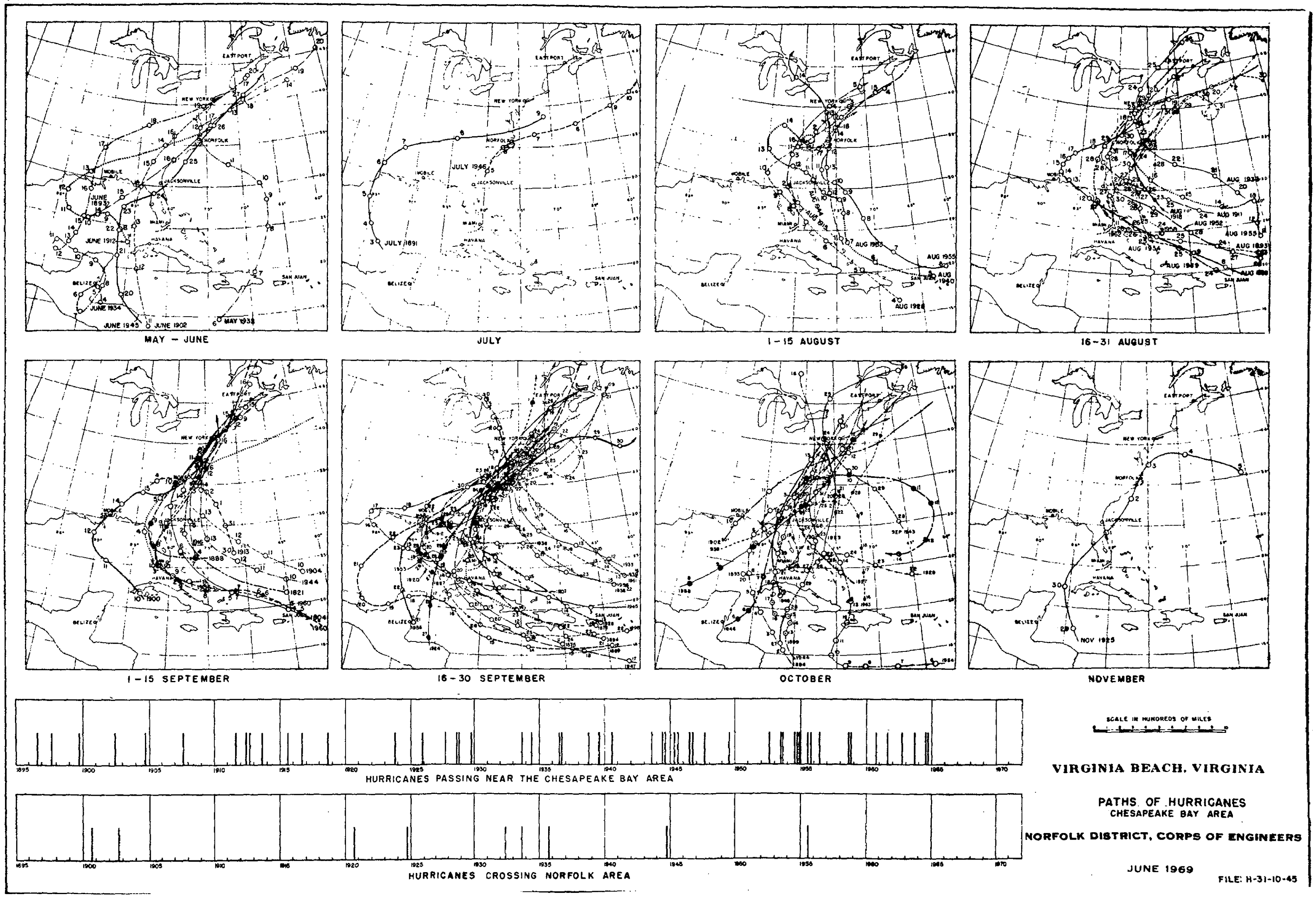


Fig. 16. Paths of hurricanes, Chesapeake Bay area (from U.S. Army Corps of Engineers, 1971).

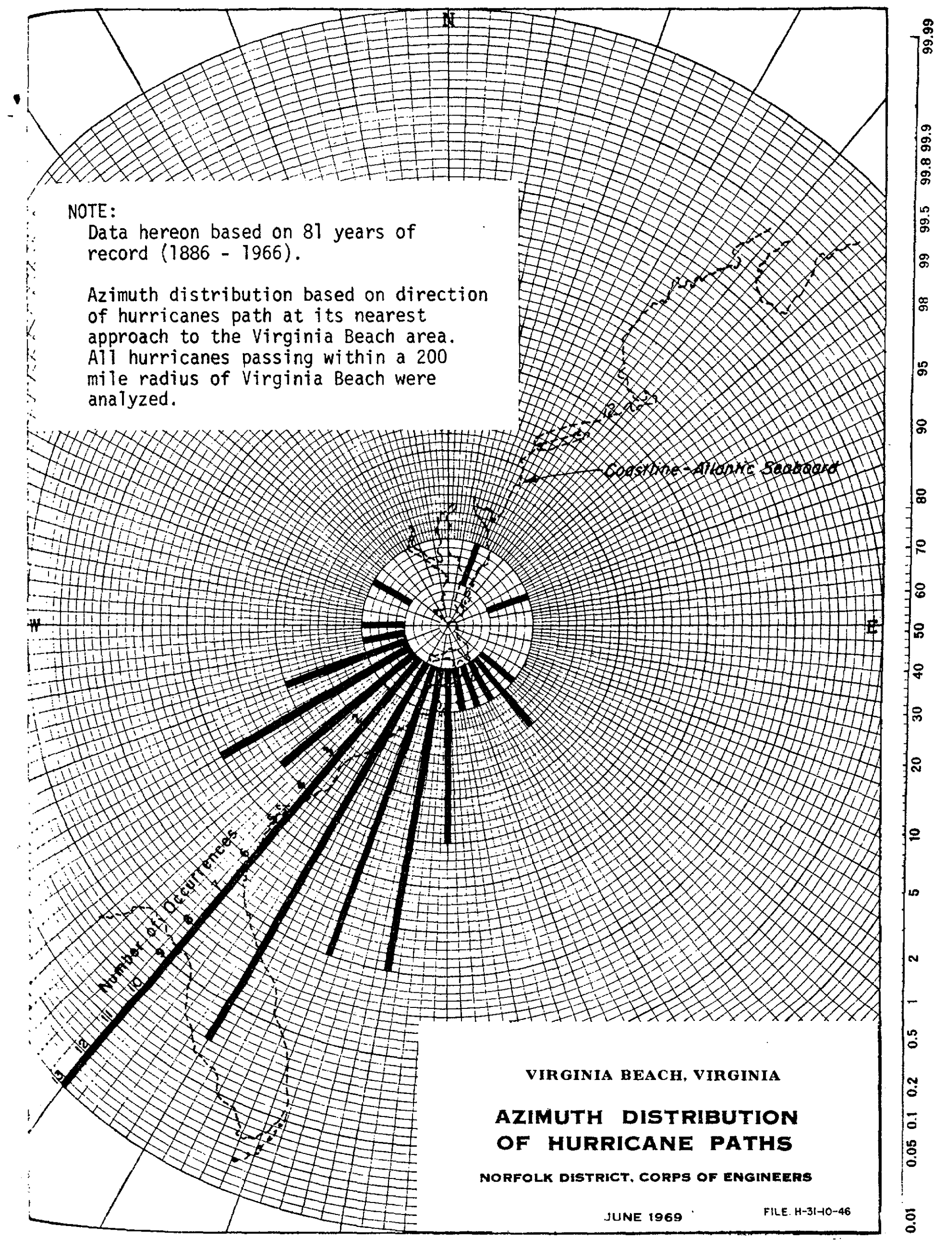


Fig. 17. Azimuth distribution of hurricane paths (from U.S. Army Corps of Engineers, 1971).

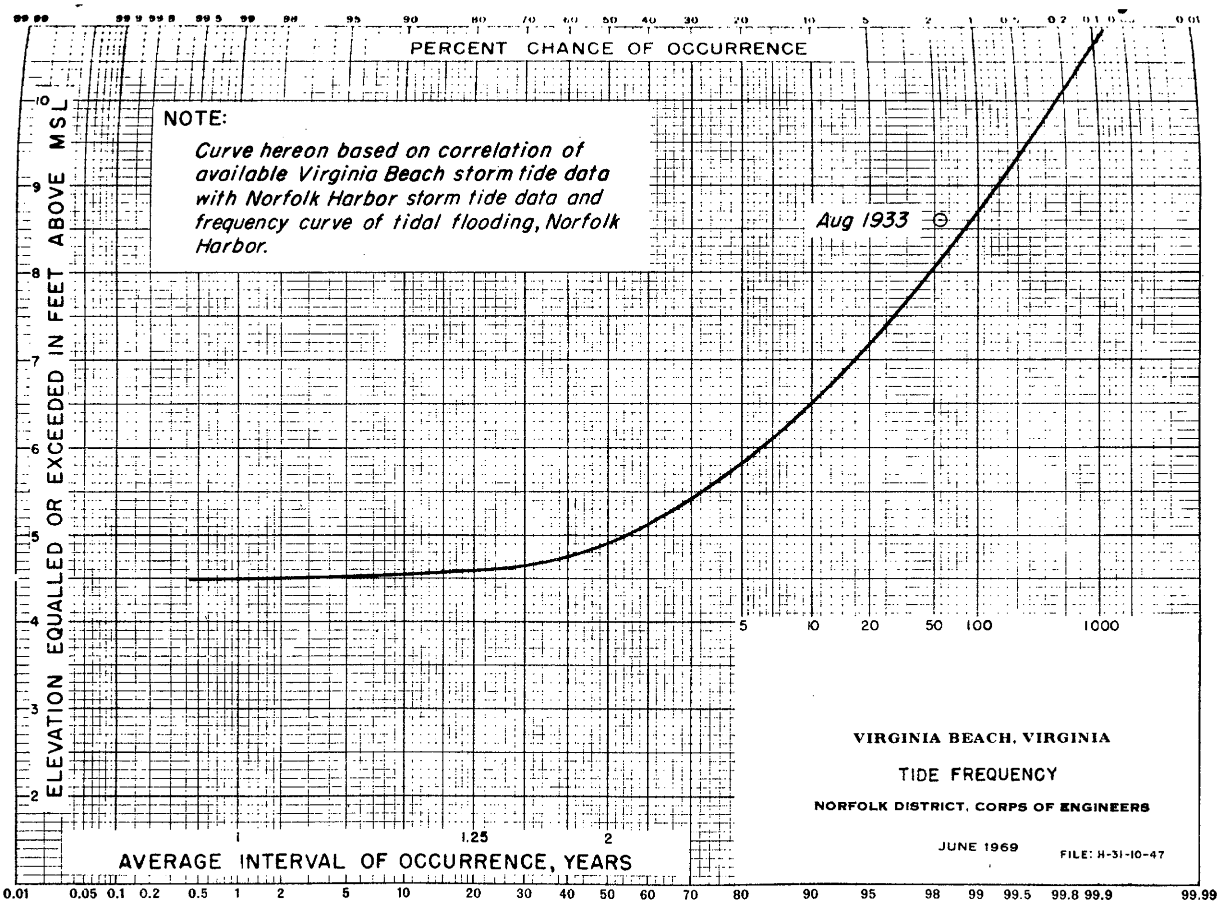


Fig. 18. Tide frequency (from U.S. Army Corps of Engineers, 1971).

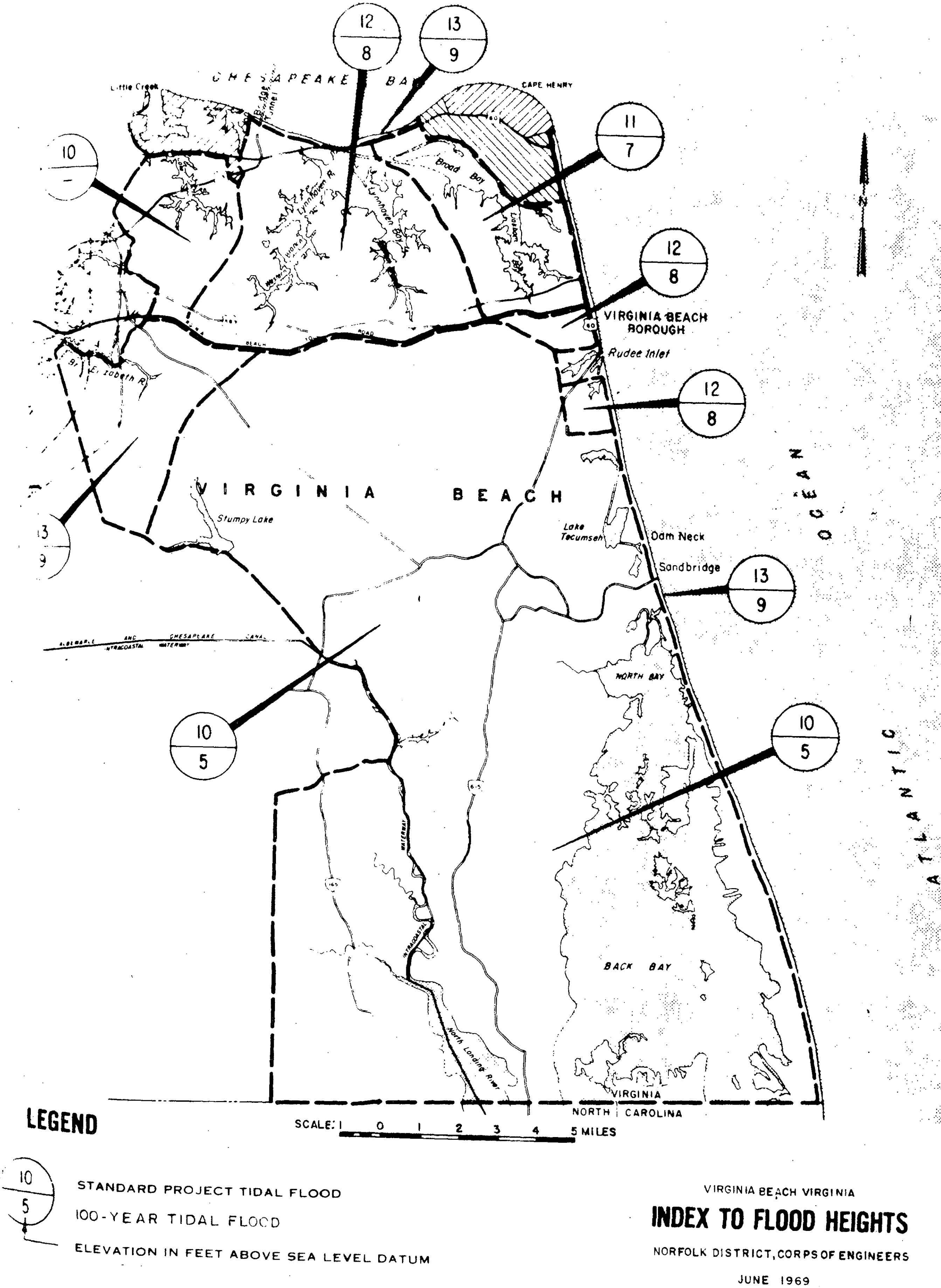


Fig. 19. Index to flood heights (from U.S. Army Corps of Engineers, 1971).

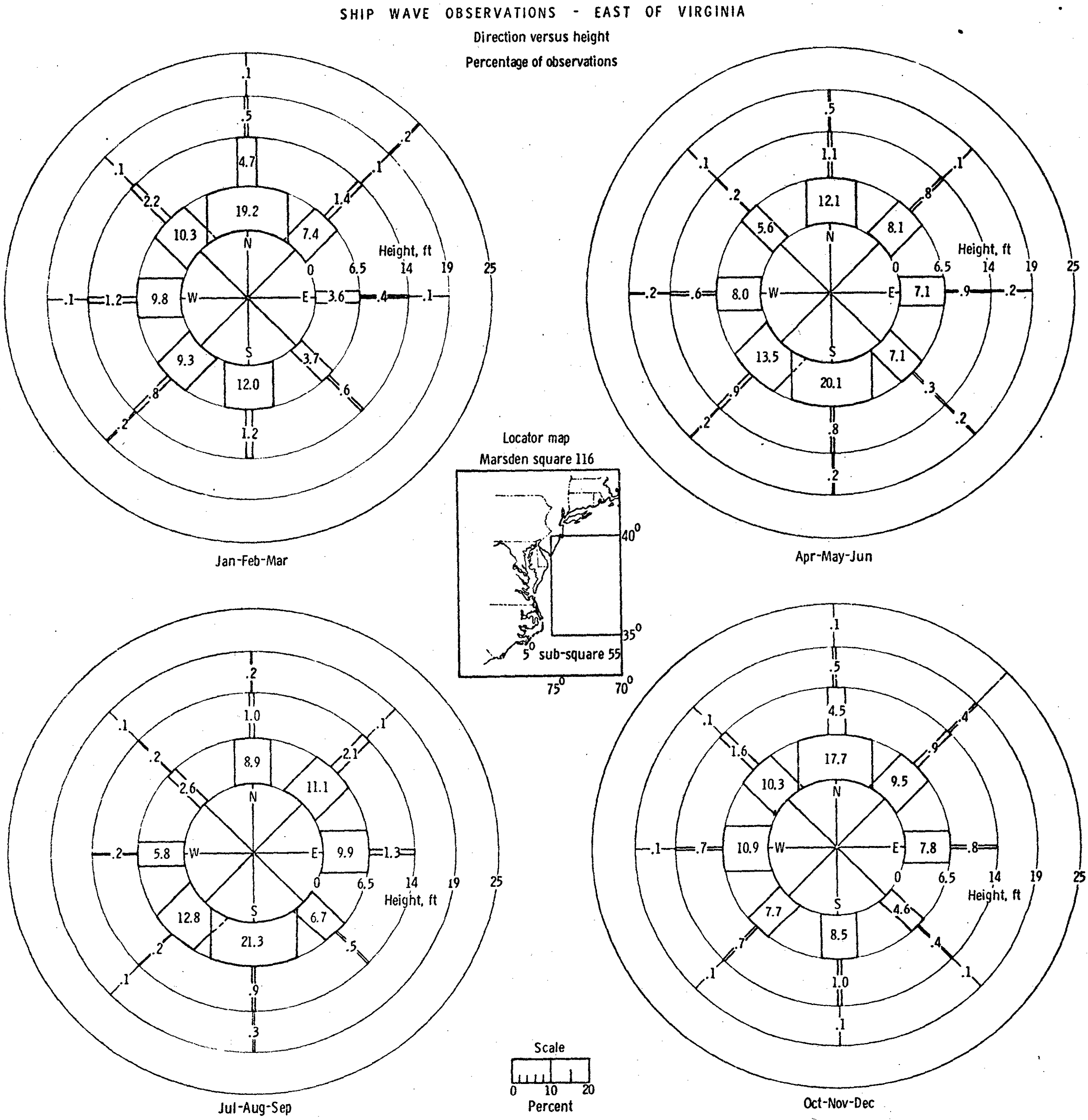


Fig. 20. Ship wave observations, east of Virginia; direction versus height (from Goldsmith, et al., 1974).

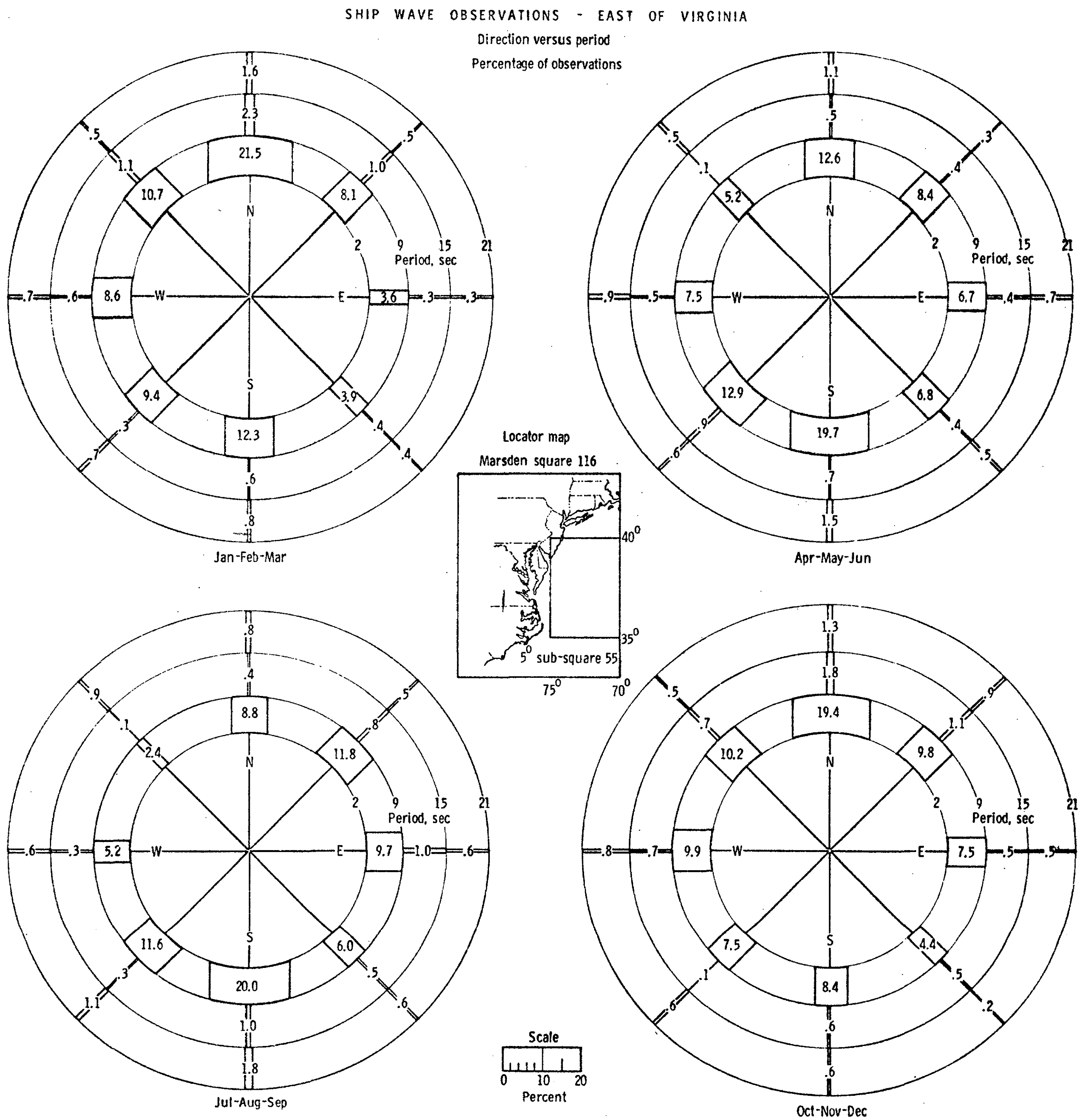


Fig. 21. Ship wave observations, east of Virginia; direction versus period (from Goldsmith, et al., 1974).