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Quaternary Sedimentation on the Inner Atlantic Shelf Between Cape Henry and Cape Hatteras: A Preliminary Report*

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Introduction

The coast of the Middle Atlantic Bight of North America's Atlantic shelf consists of a series of spit - barrier island systems attached on their northern ends to eroding headlands. It has been suggested that these barriers were generated as coastwise-prograding spits (Fisher, 1967) or alternatively as mainland beaches detached by the Holocene rise of sea level (Hoyt, 1967). The shore face before the barriers consists of fine, seaward-fining sand. Locally, it is corrugated by oblique-trending ridges with up to 8 metres of relief -- see for instance C&GS Chart 1109. Beyond the shore face lies a vast submarine sand plain with a subdued ridge and swale topography. The sand has faunal and petrographic characteristics indicative of subaerial deposition during Pleistocene low stands of the sea (Emery, 1965). Its ridge and swale topography has been described as a relict strand plain (Shepard, 1963, p. 213), and as a modern, hydraulically maintained topography (Uchupi, 1968). At present we are engaged in a study of the Cape Hatteras to Cape Henry sector, North Carolina - Virginia, in order to further investigate these various features and determine their geneses. Our study is supported by the Coastal Engineering Research Centre, Geology Branch; by the United States Geological Survey, and by the National Science Foundation. Some of our preliminary findings are presented below.

Regional Reconnaissance

Sample Plan:

Our first step has been to reconnoitre the inner shelf along a series of transects from Cape Henry to Cape Hatteras (Fig. 1). Primary transects were occupied every 20-km. Grab samples were collected at the beach, and across the shore face at 2-metre depth intervals until the horizontal spacing between stations exceeded two km. Grab samples were then collected every two km until two consecutive samples of medium to coarse "relict" sand were obtained. Beach, 14-metre and 8-km stations were sampled in triplicate for purposes of heavy mineral analysis. Supplementary transects, consisting only of beach, 14-metre, and 8-km stations were sampled between each set of primary transects. An additional beach sample was collected between each primary and supplementary transect. Bottom profiles were recorded for some of the transects. Finally, 14 samples were collected from the Pleistocene of the adjacent mainland.

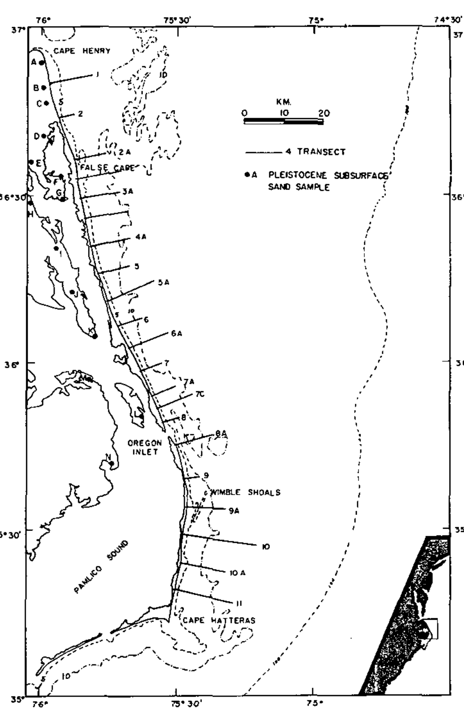

Figure 1 – Sampling transects for coastal reconnaisance.

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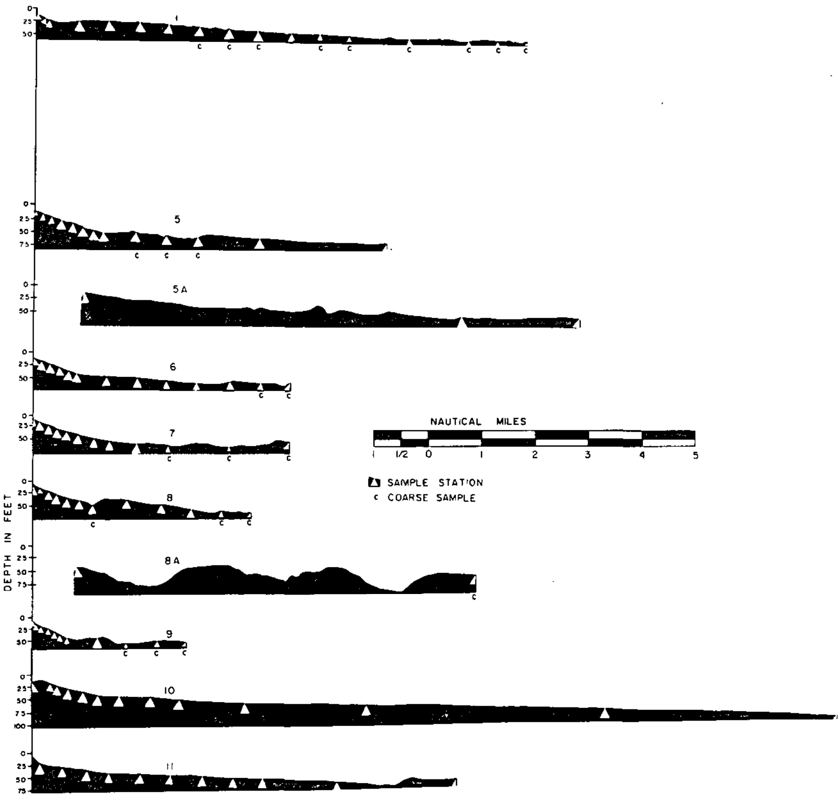

Figure 2 – Bottom profiles of selected coastal transects.

Grain Size and Bathymetry:

The bottom profiles (Fig. 2) indicate that at most transects two well-defined geomorphic provinces are present. A nearly planar shore face has a gradient of 8 m/km (approximately 50 ft/mi). Seaward of the shore face an undulating shelf floor slopes seaward at 1 m/km (approximately 5 ft/mi) with a relief of up to seven m. Preliminary examination of the samples indicates that the shore face is floored with fine- to very fine-grained, grayish sand, while the shelf surface consists of patches of both fine- to very fine-grained, medium gray sand and medium- to very coarse-grained, gravelly, orange-brown sand.

Such sharply angulated profiles appear to be characteristic of sandy coasts undergoing erosion (Zenkovich, 1967, p. 205) and most of this sector is in fact retreating. The rate for the Virginia sector, averaged over a century, is 22 cm/yr (Felton, unpublished report, Norfolk District Corps of Engineers). Profiles 1, 10, and 11 are anomalously flat and shoal, indicating accretion. At Cape Henry the accretion may be associated with a clockwise residual current gyre (Harrison and others, 1964) resulting from the interaction of the tidal vet of Chesapeake Bay mouth and the shelf tide. Profiles 10 and 11 cross the north flank of Diamond Shoals, generated by seaward diversion of littoral drift off Cape Hatteras (Tanner, 1960, El Ashry and Wanless, 1968).

Heavy Mineral Analysis:

Heavy mineral content of the Pleistocene, beach, 14-metre, and 4-kilometre stations was determined as follows: five gram cuts from each subsample were combined in order to reduce sampling error at each station (Krumbein and Rasmussen, 1941). The 88-177 micron fractions of each composite sample were placed in separatory funnels containing tetrabromoethane, (S.G. of 2.9). The heavy mineral fraction thus obtained was split where necessary with a microsplitter, and about one gram was mounted on gridded slides, in arochlor (n = 1.665). One hundred heavy minerals were counted on each slide, using a Swift mechanical stage and point counter. First the percentage of opaque heavy minerals was determined in this manner, then in the course of a separate, 100-grain count, the percentages of garnet, epidote, hyanite, tourmaline, zircon, apatite, hypersthene, sillimanite, staurolite, amphibole, and miscellaneous minerals were determined.

The percent of non-opaque heavy minerals at each station is shown in Fig. 3, and is compared with the modal grain size of the whole sample estimated visually in Wentworth classes. Samples of "anomalous" grain size (fine samples in the offshore province, medium or coarse samples in the nearshore province) are indicated by exclusion from the trend line. The most consistent trends occur in the beach and nearshore stations. The percentages of garnet and opaque heavy minerals (not shown) increase toward Hatteras as does grain size, while the percentage of amphibole decreases. In the nearshore zone the percentage of epidote increases toward Hatteras, while the percent of staurolite and kyanite decrease. The trends become more distinct if only the major littoral drift cell, Cape Henry to Oregon Inlet, is considered (Fig. 4).

Fisher (1967, personal communication) and Pierce and Colquhoun (1969, personal communication) have suggested that Currituck Spit, north of Oregon Inlet, formed as a coastwise-prograding spit. These workers also suggest that Hatteras Island to the south of the inlet formed as a coastwise-prograding spit. Fisher (1967) has presented geomorphic evidence for such progradation of Hatteras Island in the form of oblique trending beach ridges (Fig. 5). These workers suggest that the area around Oregon Inlet was formerly a headland (Bodie Island Headland of Fisher). Pierce and Colquhoun have presented as evidence for this a buried soil profile (Fig. 5), indicating that here the barrier formed from the detachment of a mainland beach by rising sea level, in the manner that has been described by Hoyt (1967).

Statistical analysis of our heavy mineral data may shed some light on the genesis of this coast. We plan to subject each heavy mineral species to multiple linear regression, with the percentage as the dependent variable, and grain size of the whole sample and distance from the head of the relevant littoral drift cell as the independent variables. If these variables account for most of the variance, then the littoral drift systems may be considered as essentially closed systems with sediment input via substrate erosion at the cell heads, and mineralogic gradients determined by progressive down-drift sorting. This model would support barrier construction by the coastwise prograding of spits. If, however, only a small amount of variance is attributable to distance and grain size, then an open system may be suspected, with sediment supplied by a variable substrate along the length of each littoral drift cell. Such a model would be compatible with barrier construction by detachment of a mainland beach.

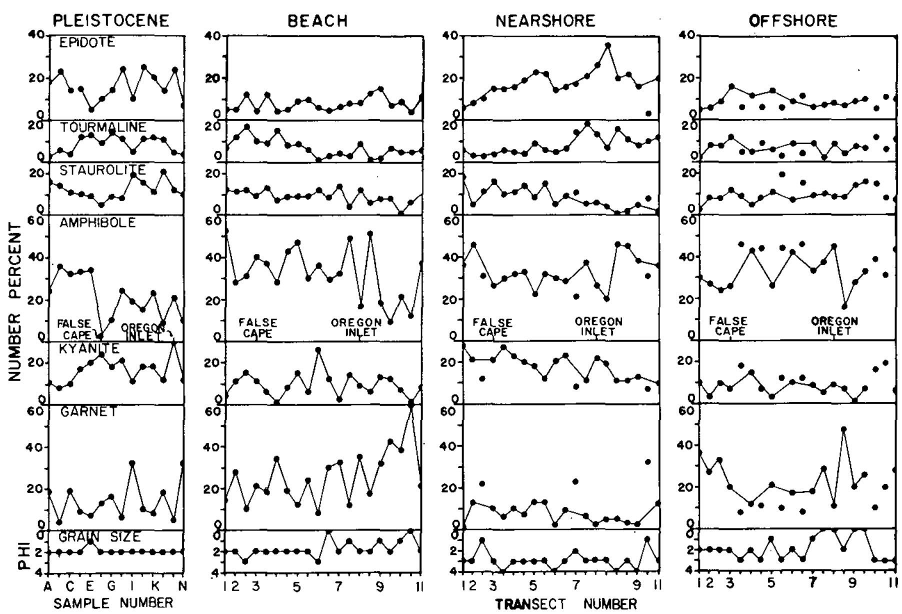

Figure 3 – Percent of Non-opaque heavy minerals. See text for explanation.

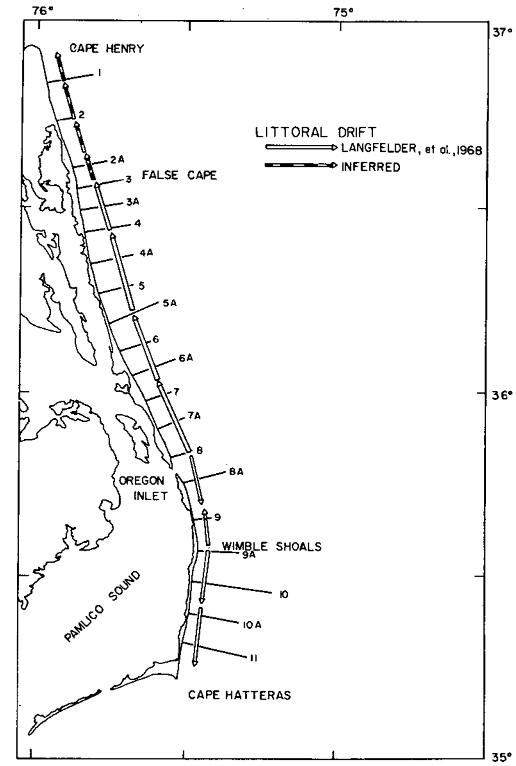

Figure 4 – Directions of littoral drift between Cape Henry and Cape Hatteras.

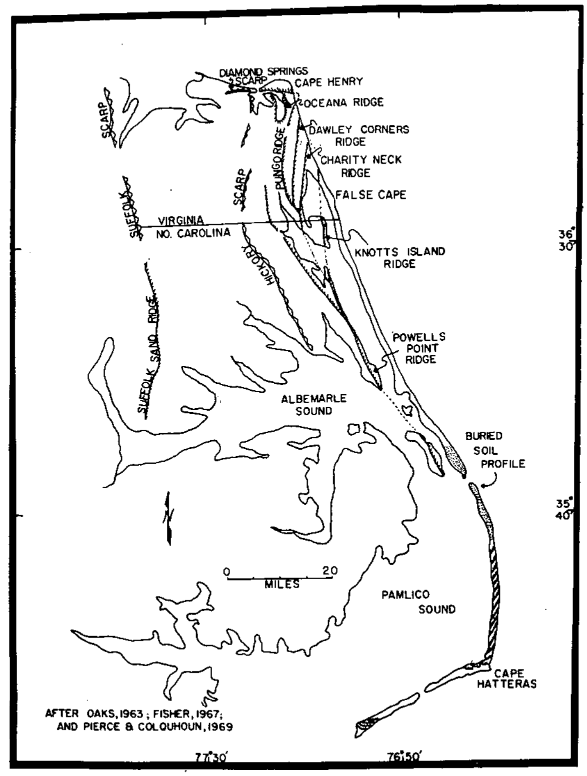

Figure 5 – Quaternary framework of the Virginia-North Carolina Coast.

Ridge System at False Cape

At several points along the Virginia - North Carolina coast, the shore face broadens and deforms into a series of oblique-trending sand ridges, with wave-lengths of two to six km, and amplitudes up to eight metres, tied to the shore face at depths of three to five metres. A portion of such a ridge system at False Cape, near the Virginia - North Carolina line is shown in Figure 6. The map is based on a 1922 Coast and Geodetic survey. This survey was accomplished by means of lead line sounding, with navigation carried out with the aid of horizontal sextant angles and shore towers. Probable vertical accuracies for this method are ± 30 cms; horizontal accuracies are ± 10 metres within six km of shore, and somewhat less further offshore. During the summer of 1969, we resurveyed this area, using an Edo Bottom Profiler and a Cubic Autotape Radio-Navigation System. Our survey methods were more accurate, but our survey lines were two km apart, as compared with those for the 1922 survey which were as close as .5 km apart. Hence our map (Fig. 7) is somewhat smoother.

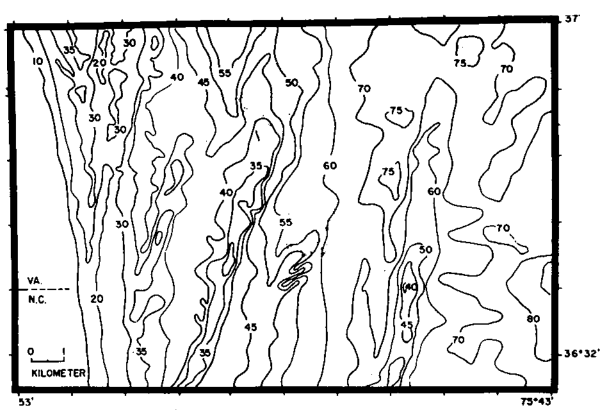

Figure 6 – Bathymetry of False Cape Study area, from 1922 US C&GS survey. Depth in feet.

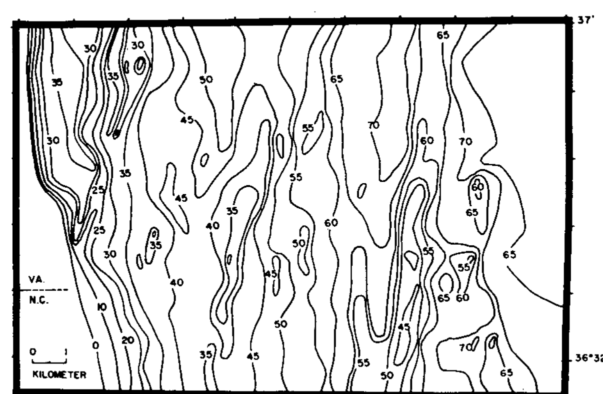

Figure 7 – Bathymetry of False Cape Study area, from 1969 survey. Depth in feet.

Profiles (Fig. 8) based on the two maps reveal the following changes:

1. The shoreline has retreated approximately 500 metres in the north and 600 metres in the centre, but has advanced 500 metres in the south.

2. Most ridge crests have advanced shorewards, for up to 300 metres. The southern portion of the central ridge, however, has become more northsouth in orientation, moving up to 400 metres seaward in the process.

3. The inshore and northern portions of the map area have undergone up to three metres of erosion. The southeast quadrant has undergone up to two metres of accretion mainly through the appearance of a new offshore ridge.

Grain size varies systematically across the ridge system (Fig. 9), as determined by visual estimation of Wentworth size classes. Medium- to very coarse-grained sand occurs on ridges, with fine-grained sand in the swales. Second order tongues of coarse grained sand extending from the main bodies in Figure 9 correspond to smaller ridges in Figure 7.

Sub-bottom continuous seismic reflection profiles recorded over the outer ridge with a high resolution boomer were unable to resolve internal structure, but did reveal that the ridge has a plano-convex configuration, and that it rests on a prominent reflector which is exposed in the swale to the seaward of the ridge (Fig. 10). A scuba dive in the trough between the two branches of this ridge revealed 15 centimetres of coarse, shelly sand overlying stiff clay. The clay is tentatively correlated with the sand ridge and mud flat complex of the Sandbridge

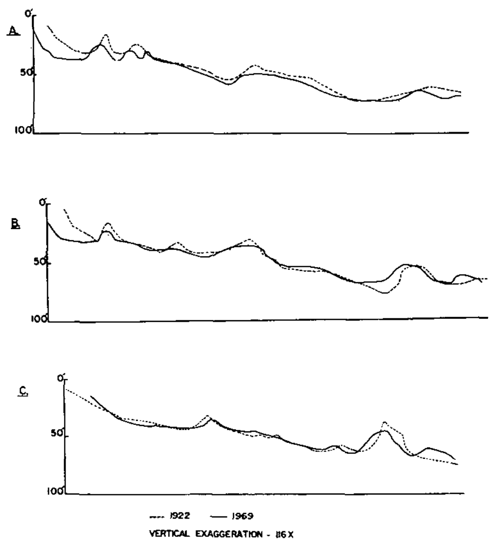

Figure 8 – Profiles through the False Cape Study area. Horizontal scale same as in Figure 7.

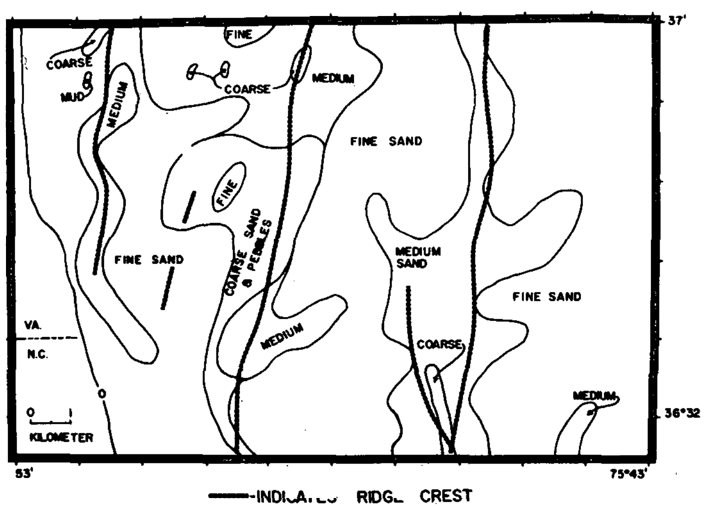

Figure 9 – Preliminary grain size map of the Flase Cape Study area, based on visual estimation of Wentworth size classes.

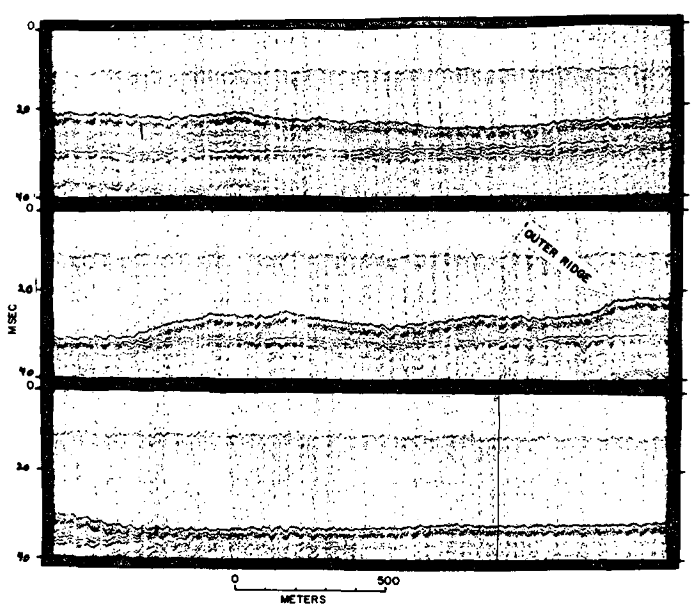

Figure 10 – High Resolution Boomer Profile through the outer ridge. Left margin of each profile continues as right margin of subjacent profile.

Formation (Fig. 5) ascribed to the late Sangamon regression by Oaks (1964). Three cores taken with a hydraulic coring system to the north of the study area appear to have nearly penetrated to this surface. They consist of 20 centimetres to one metre of sand that appears to fine downward. In two cases there is a coarse, shelly gravel at the base of the core and in the third case, a coarse coquina. The thickness of the basal layer is unknown since it was sufficiently coarse to stop the corer. Two cores contained large clay fragments near the base. Powers and Kinsman (1953) have reported taking 37 similarly graded cores up to two metres long to the north of the study area, off the mouth of Chesapeake Bay.

We suspect that the surface is a compound one, formed in part by subaerial weathering during Wisconsin low stands of the sea, and in part by surf erosion during the Holocene transgression. At one point our ship's anchor brought up a mottled clay, suggestive of subaerial weathering, and similar to that reported by Pierce and Colquhoun as underlying parts of Hatteras Island. The role of surf erosion is supported by the basal gravel observed in cores, and by the geologic cross sections of Oaks (1964) which indicate that the shore face at False Cape has cut deeply into the underlying Pleistocene. Thus the discontinuous sand sheet over the surface appears to have been generated by shore face and sea floor erosion since the return of the Holocene Sea.

The ridge and swale topography seen at False Cape and elsewhere on the inner shelf of the Atlantic Bight is problematic. Sanders (1963) has suggested that the False Cape ridges are relict Pleistocene beach ridges. They unquestionably parallel the beach ridges of the Sandbridge Formation (Fig. 5) but we nevertheless suspect that they are maintained by the modern hydraulic regime, for the following reasons: (1) They have moved inland with the beach face since 1922. (2) Oaks (1964) study indicates that the shore face has cut deeply into the Sandbridge Formation, destroying its upper surface.

If hydraulically maintained, a further problem is the general category of bedforms to which the ridges belong, whether transverse or longitudinal to the major direction of flow. Large-scale, submarine sand ridges described from the North Sea (Houbolt, 1968) and Georges Bank (Stewart and Jordan, 1964) are longitudinal forms. Houbolt (1968) has proposed horizontal helical flow cells of tidal origin as the generating mechanism for sand ridges in the North Sea and has presented field evidence for it. Smith (1969) has studied a sand ridge in Vinyard Sound, Massachusetts. The ridge is oriented parallel to the long axis of the tidal current ellipse. Smith concluded that the ridge was maintained by alternating cross-ridge flow, parallel to the short axis of the tidal ellipse. Smith's ridge is thus morphologically a longitudinal form, but is dynamically a transverse form. Smith's and Houbolt's generating mechanisms need not be mutually exclusive.

Moody (1964) has described nearshore, oblique-trending sand ridges, similar to the False Cape system, from the Delaware coast. They appear to be moving to the southeast as asymmetrical transverse forms, mainly during storms. Moody showed that the ridges are growing at the same rate as the shore face is receding. He believed that as his ridges advance and sea level rises, slow ones are overtaken by larger ones, thus initiating the larger offshore ridge systems. In this way, the offshore ridge and swale topography of the Atlantic shelf may have been generated as inner shelf topography rather than as shoreline topography. It is not necessarily relict, either, since as Uchupi (1968) has indicated, the offshore ridges may still be active during storms.

Detailed knowledge of the hydraulic regime associated with the False Cape ridge system must await the results of our current-metre study. However, a bathymetric map of the inner Virginia shelf is compatible with the sort of evolution suggested by Moody (Fig. 11). Here the False Cape ridge system can be seen to have a more weakly developed northern extension. The False Cape system of beach-tied ridges is part of the shore face as defined by the 55-foot contour; offshore on the flatter sea floor are other extensive ridge systems. The four major False Cape ridges here appear to represent a sequence of evolution from shore face ridges to offshore ridges. The changes between the two surveys are compatible with such evolution. In particular the straightening of the most seaward of the beach-tied ridges between 1922 and 1969 would be necessary for it to become an offshore ridge. Unfortunately limitations of funds prevented our extending our survey far enough south to determine whether or not it has actually severed its connection with the shore face.

We plan a coring program to resolve the late Holocene history of the ridge system. We are presently undertaking current-metre studies, financially supported by the National Science Foundation, to shed further light on the hydraulic regime that maintains the sand ridge systems.

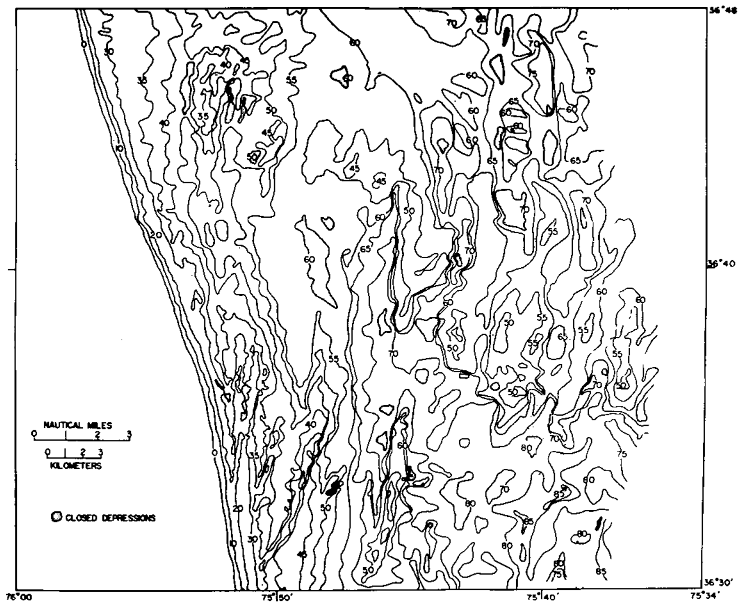

Figure 11 – Bathymetry of the Inner Virginia Shelf, from contouring of C and GS smooth sheet 1227.

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