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Potential Offshore Sand Resources in Southern Maryland Shoal Fields

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Executive Summary

Extensive beach restoration projects on the Maryland coast are placing increased pressure on known offshore sand resources within State waters. Assessment of potential sand resources in Federal waters will encourage both the development of new resources, and further restoration projects. Previous studies suggest that most usable sand deposits will occur within linear shoals on the inner continental shelf. A shoal field in waters off Assateague Island, containing eight linear shoals, was examined for potential sand resources. This field, designated Shoal Field III, is located approximately ¾ of a nautical mile off Assateague Island, and extends eastward 14 miles. Seismic surveys and vibracore samples were used to estimate the quality and quantity of sediments contained within the shoals. Shoals K and F have a high potential for containing sands with desirable grain size parameters, and are in sufficiently shallow waters. Five other shoals have moderate potentials, limited by finer sediments and, in some cases, deeper waters. Shoal G, within two miles of the shore, appears to contain sediments too fine and thinly distributed to be of potential use for beach restoration.

INTRODUCTION

Atlantic coast beaches are primary economic and recreational resources in Maryland. Two barrier islands separated by the Ocean City Inlet comprise Maryland's coastline. Fenwick Island, to the north of the inlet, is highly developed, and is the site of the State's only coastal resort, Ocean City. The 8 miles of Fenwick Island within Maryland consist of public beaches fronting commercial and private real estate. South of the inlet, the 32 miles of Assateague Island in Maryland are undeveloped state and Federal park lands. These islands and their coastal lagoons are readily accessible to nearly thirty-million people.

Although coastal lands are immensely valuable resources, they are also potentially an expensive liability. While barrier islands are ephemeral land forms, they are often developed as though they were permanent features. Urbanization of these fragile islands may enhance their inherent instability. The natural migration of barrier island/inlet systems, exaggerated by development, poses a threat to regional economic and cultural commitments. In Maryland, rapid shoreward erosion of these islands jeopardizes both property and economy. A variety of shoreline stabilization and remediation schemes are available to protect established communities and investments. Beach nourishment is currently one of the most attractive options for barrier island protection.

Studies conducted by the U.S. Army Corps of Engineers in the 1980's indicated an immediate need for beach replenishment along the Ocean City shoreline (U.S. Army Corps of Engineers, 1980). The Army Corps study also examined potential sand sources during the planning phase of Delmarva beach restoration projects north of the Ocean City Inlet. A subsequent Army Corps study projected the need for beach replenishment on Assateague Island (U.S. Army Corps of Engineers, 1994). Beach nourishment projects demand that sand resources meet certain physical, economic, and environmental criteria. Sand used for replenishment must be of an optimum grain size, which is determined by kinetic factors specific for each region. The volume of sand required for restoration is also dependent on these factors. Sand source proximity to the target beach is an important economic factor. The Army Corps studies concluded that offshore sands are the most desirable materials for beach nourishment projects in Maryland.

Currently utilized resources are found north of Ocean City Inlet, within the three-mile limit of state jurisdiction. These sands are committed to the reconstruction and periodic nourishment of Ocean City beaches. Demand for offshore sands is increasing as more shore communities opt for shoreline replenishment. An increase in the frequency of strong storms has accelerated erosion of the restored beaches. These factors place increasing demands on the sand resources within state waters. It is conceivable that sand resources identified within state waters could be depleted within a decade. New sand sources must be found to meet increased demand. Access to aggregate resources in Federal waters would encourage the continuation of shoreline restoration projects. While the general distribution of offshore sand is understood, detailed information on potential resources is sparse. Site-specific data will encourage development of these resources.

The Maryland Geological Survey/Delaware Geological Survey/Minerals Management Service Cooperative agreement was created to encourage and expedite an inventory of potential offshore sand resources for beach nourishment in the Delmarva region. Specifically, the cooperative agreement seeks to exchange field, laboratory, financial, and data resources for efficient production this information.

In Maryland, the objective of the third year of the cooperative was to identify potential sand resources for proposed beach restoration projects on Assateague Island, MD. We confined the sand resource study to an area south of Shoal Field II, which was examined during the second year of the cooperative.

Acknowledgments

The cooperative was funded by a grant from the U.S. Minerals Management Service, and contributions from Maryland Department of Natural Resources, and Delaware Geological Survey. Kelvin Ramsey, Delaware Geological Survey's principal investigator in the cooperative, was of invaluable assistance. We are grateful to Darlene Wells for her assistance in background preparation for this study. Special thanks to R.V. Discovery's Captain Richard Younger for his technical expertise in field data collection techniques. We also extend thanks to Randall Kerhin and Dr. Emery Cleaves for their suggestions and comments.

THIRD YEAR GEOLOGICAL INVESTIGATIONS

Previous Studies

Numerous scientists have investigated the Atlantic inner shelf. Comprehensive reviews of these works have been published by Duane and others (1972), Field (1976, 1980), Toscano (1989), McBride and Moslow (1990), and Wells (1994). Of primary interest to this study are the origins and morphology of linear shoals on the Atlantic inner shelf. Linear shoals have long been recognized as important sand reservoirs on the Atlantic shelf. As a group, linear shoals share several common features. Duane and others (1972) characterized these features:

1) Linear shoal fields occur in clusters, or fields, from Long Island, New York to Florida.
2) Shoals exhibit relief up to 30 ft, side slopes of a few degrees, and extend for tens of miles.
3) The long axes of linear shoals trend to the northeast and form an angle of less than 35° with the shoreline.
4) Shoals may be shoreface-attached, or detached. Shoreface-attached shoals may be associated with barrier island inlets.
5) Shoal sediments are markedly different from underlying sediments. Shoals are composed of sands and generally overlay fine, occasionally peaty, sediments.

With so many common characteristics, early researchers assumed a common origin for these features. Generally, it was assumed that linear ridges represented relict barriers or subaerial beaches, developed at a lower sea level stand, and preserved with sea level rise. (Veatch and Smith, 1939; Shepard, 1963; Emery, 1966; Kraft, 1971; and many others). Improvements in seismic data collection and reexamination of earlier data led to a new hypothesis of shoal evolution: linear shoals are post-transgressive expressions of modern shelf processes. In particular, Field's (1976, 1980) work on the Delmarva shelf could find no support for the theory of relict, submerged shorelines. Many investigators (including Field 1980; Swift and Field, 1981) concluded that ridge and swale topography developed by the interaction of storm-induced currents and sediments at the base of the shoreface. As the shoreface retreated during transgression, shoreface-attached shoals became detached, and isolated from their sand source. Once detached, the shoals continued to evolve within the modern hydraulic regime.

McBride and Moslow (1991) employed a statistical approach to analyze existing geomorphic and sedimentologic data on linear shoals. They found a correlation between the distribution of shore-attached and detached shoals and the locations of historical and active inlets along the Atlantic coast. They provided a model for the genesis and development of shoal fields, based on the formation and migration of ebb-tidal deltas. This model describes a source of sediment for linear shoal formation, and explains the orientation, shape, evolution and distribution of linear shoals. While these authors recognized that diverse mechanisms can account for shoal formation, the ebb-tidal shoal model provides the first field-tested explanation for the formation of shoal fields.

A model of late Tertiary and Quaternary stratigraphy on the Maryland shelf has been published by and Toscano *et al.* (1989). The model uses Field's (1976, 1980) framework, and clarifies spatial, temporal, and climatic relationships through extensive seismic, sedimentologic, and paleontologic investigations. Application of the model to field investigations led Kerhin (1989) and Wells (1994) to conclude that sand resources off the Maryland coast are confined mainly to the linear shoal fields. It was Kerhin's (1989) preliminary assessment that any non-shoal sand resources within the explored Maryland shelf were limited to an area nineteen to twenty-four miles east of the Maryland-Virginia boundary. Wells (1994) found that significant sand sources within her study area, east of Ocean City, were confined to shoals. Furthermore, she found that shore-attached shoals contained fine sands and muds, unsuitable for beach fill. Coarser sands were generally found in shore-detached shoals.

The Offshore Sand Resources Study employs the Toscano-Kerhin model of the Maryland Quaternary shelf to define shoal field structures. The McBride-Moslow shoal model is used here to classify the shoals as either ebb-tidal or non ebb-tidal in origin.

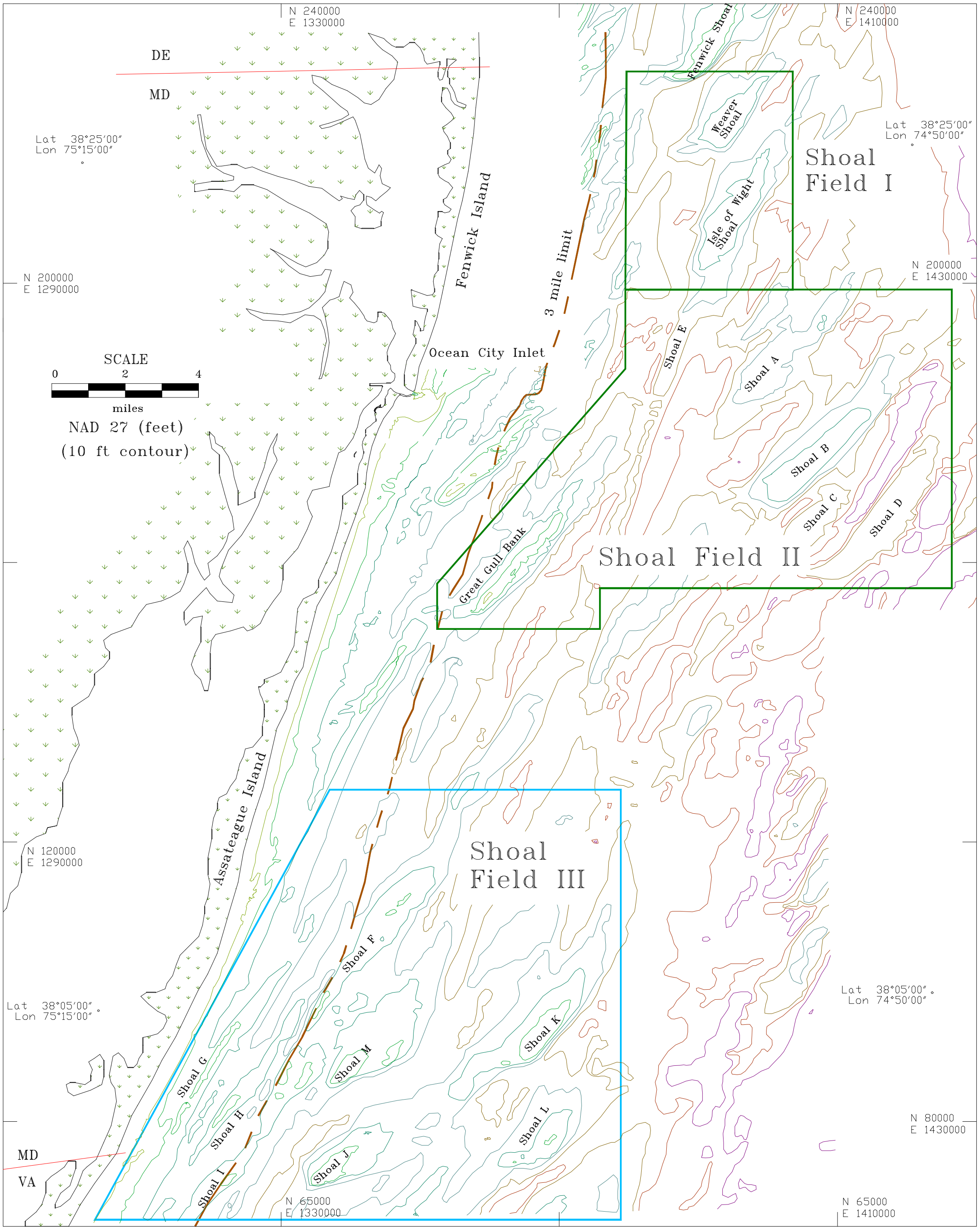
Study Area

The Offshore Sand Resources Study's third year field area was selected for its proximity to Assateague Island, MD. A beach nourishment project to restore the northern Assateague Island shoreline was proposed by the U.S. Army Corps of Engineers in 1994 (U.S. Army Corps of Engineers, 1994). This project is an integral part of a comprehensive water resources management plan for the Ocean City region. Identification of potential sand resources for Assateague beach nourishment projects was the primary goal of our third year study.

A target shoal field was selected by examining NOS Bathymetric Map NJ 18-5. This field is found approximately ten nautical miles south of Ocean City Inlet, south of Shoal Field II. The shoal field extends from approximately ¾ of a nautical mile off Assateague Island out to 14 miles. Designated Shoal Field III, the study region encompasses eight unnamed shoals. Shoal Field III encloses 108 square miles of ocean floor, from depths of -19 ft to -109 ft feet below NGVD.

The Maryland Department of Natural Resources has suggested some practical limits for offshore sand resource locations (J. Loran, pers. comm., 1992). Economic and mechanical limitations imply that resources should be located within a 15-mile radius from the point they are needed, and in waters less than 50 feet deep. Portions of Shoal Field III conform to these suggested parameters. Figure 1 details the location of Shoal Field III.

Figure 1


N 240000
E 1330000
N 240000
E 1410000
DE
MD
Lat 38°25'00"
Lon 75°15'00"
Fenwick Shoal
Weaver Shoal
Isle of Wight Shoal
Shoal Field I
Lat 38°25'00"
Lon 74°50'00"
Fenwick Island
3 mile limit
N 200000
E 1290000
N 200000
E 1430000
SCALE
0
2
4
miles
NAD 27 (feet)
(10 ft contour)
Ocean City Inlet
Shoal E
Shoal A
Shoal B
Shoal C
Shoal D
Great Gull Bank
Shoal Field II
N 120000
E 1290000
Assateague Island
Shoal Field III
Shoal F
Lat 38°05'00"
Lon 75°15'00"
Lat 38°05'00"
Lon 74°50'00"
Shoal K
Shoal M
Shoal G
Shoal H
Shoal L
N 80000
E 1430000
MD
VA
Shoal J
Shoal I
N 65000
E 1330000
N 65000
E 1410000

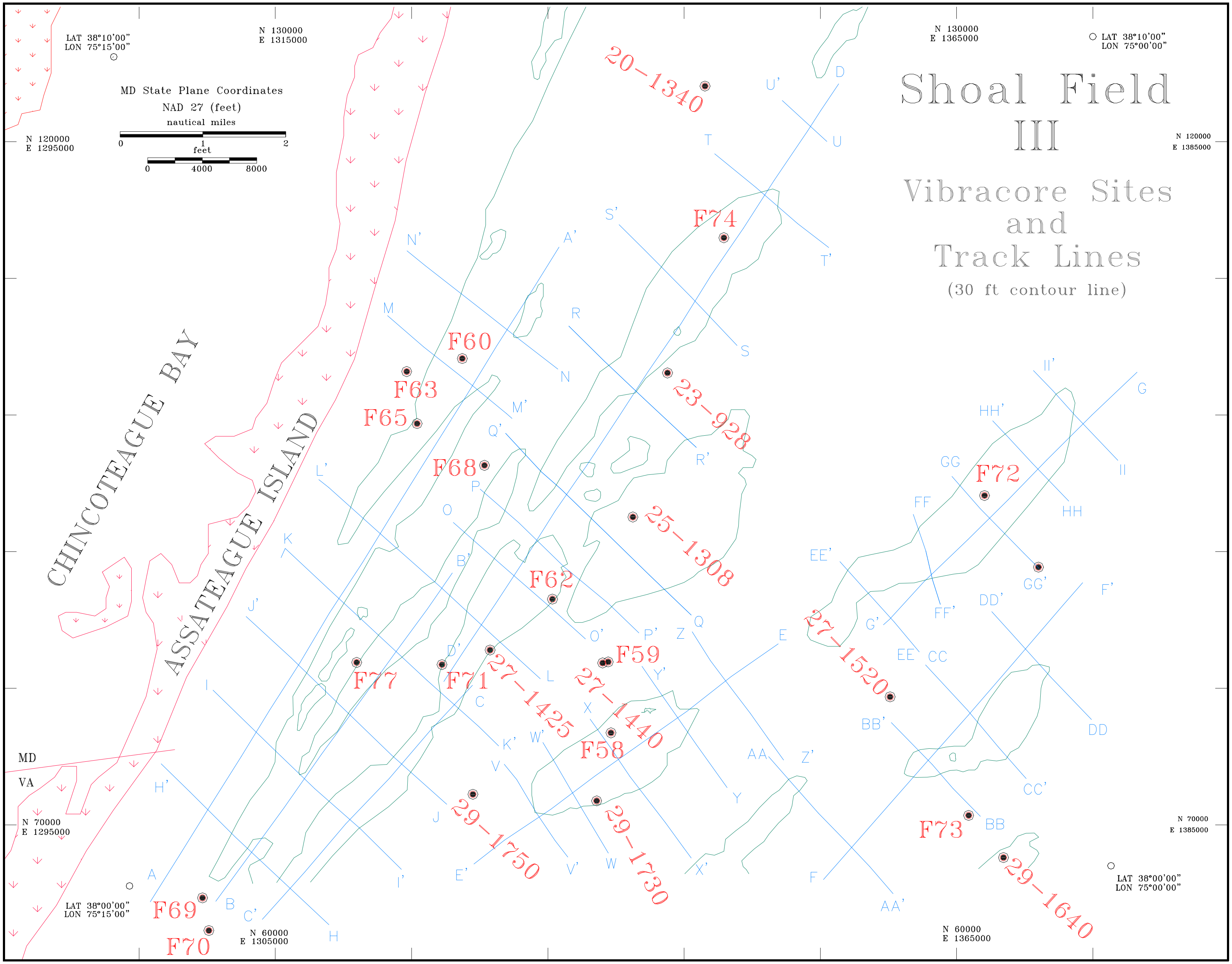
Study Methodology

Our goal in the third year of the Cooperative was to locate and evaluate potential sand resources within Shoal Field III. To achieve this goal, we developed a study plan of seismic surveying and digital analysis of field data. Seismic data provided a basis for stratigraphic and volumetric analysis of the shoals. Textural parameters of shoal sediments are based on seismic records and existing vibracores. Because sufficient funding for vibracore sampling was unavailable in the Cooperative's third year, we chose to concentrate on the structural aspects of Shoal Field III. Data from vibracores obtained by Field (1976), and Toscano *et al.* (1989) are available for this region. Based on this information, the shoals were classified according to their resource potential. The data also contribute to a model of regional shoal classification.

Previous studies by McBride and Moslow (1991), Toscano *et al.* (1989), Kerhin (1989), and Wells (1994) show that significant sand deposits will most likely be found in linear shoals. We therefore concentrated our data collection to the shoals. Seismic lines were arrayed to provide cross-sections and axial profiles of the linear shoals, and the perimeter of the shoal field. Sediment samples previously collected from this area provide ground truthing for seismic interpretations.

Bathymetry and Subbottom Profiling

Bathymetry and subbottom structures were determined by high-resolution seismic profiling. We carried out the seismic survey on board Maryland Department of Natural Resources' *R.V. Discovery*. The survey took place in August 1994. More than 115 miles of seismic lines were recorded off the Maryland coast. We used a Datasonics acoustic profiling system for data collection. The best subbottom acoustic records were obtained at 3.5 kHz. While the Datasonics system can provide penetrations greater than 300 feet, shallow water depths and a generally hard, sandy sea floor limited penetration to less than 90 feet in shoal areas. However, this limitation was not significant for the study because our interests were in surficial sediments. Better penetration was obtained in inter-shoal regions, due to the presence of more acoustically transparent, fine sediments. Bathymetry was recorded at a frequency of 200 kHz. Trackline positioning was determined by an onboard geographical positioning system, which provided fix marks at five minute intervals (Figure 2). Horizontal data are reported in Maryland State Plane Coordinates (NAD 27, feet). Conversion between Maryland State Plane Coordinates and geographic coordinates was performed by *CORPSCON* software.


Shoal Field III
Vibracore Sites and Track Lines
(30 ft contour line)
MD State Plane Coordinates
NAD 27 (feet)
nautical miles
0
1
2
feet
0
4000
8000
LAT 38°10'00"
LON 75°15'00"
N 130000
E 1315000
N 130000
E 1365000
LAT 38°10'00"
LON 75°00'00"
N 120000
E 1295000
N 120000
E 1385000
N 70000
E 1295000
N 70000
E 1385000
LAT 38°00'00"
LON 75°15'00"
N 60000
E 1305000
N 60000
E 1365000
LAT 38°00'00"
LON 75°00'00"
CHINCOTEAGUE BAY
ASSATEAGUE ISLAND
MD
VA
20-1340
F74
F60
F63
F65
F68
23-928
25-1308
F62
F72
27-1520
F59
F77
F71
27-1425
27-1440
F58
29-1750
29-1730
F73
29-1640
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F70
A
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B'
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E
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P
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Q
Q'
R
R'
S
S'
T
T'
U
U'
V
V'
W
W'
X
X'
Y
Y'
Z
Z'
AA
AA'
BB
BB'
CC
CC'
DD
DD'
EE
EE'
FF
FF'
GG
GG'
HH
HH'
II
II'

Figure 2

Sediment data

Data for vibracores were derived from Field (1976), and Toscano *et al.* (1989). Vibracore station locations are shown in Figure 2. Station locations for Field's vibracores are not available, and were therefore estimated from location maps in the 1976 publication. Grain size parameters for the Toscano *et al.* vibracores were estimated from core log descriptions.

Digital analysis of Bathymetric and Subbottom Data

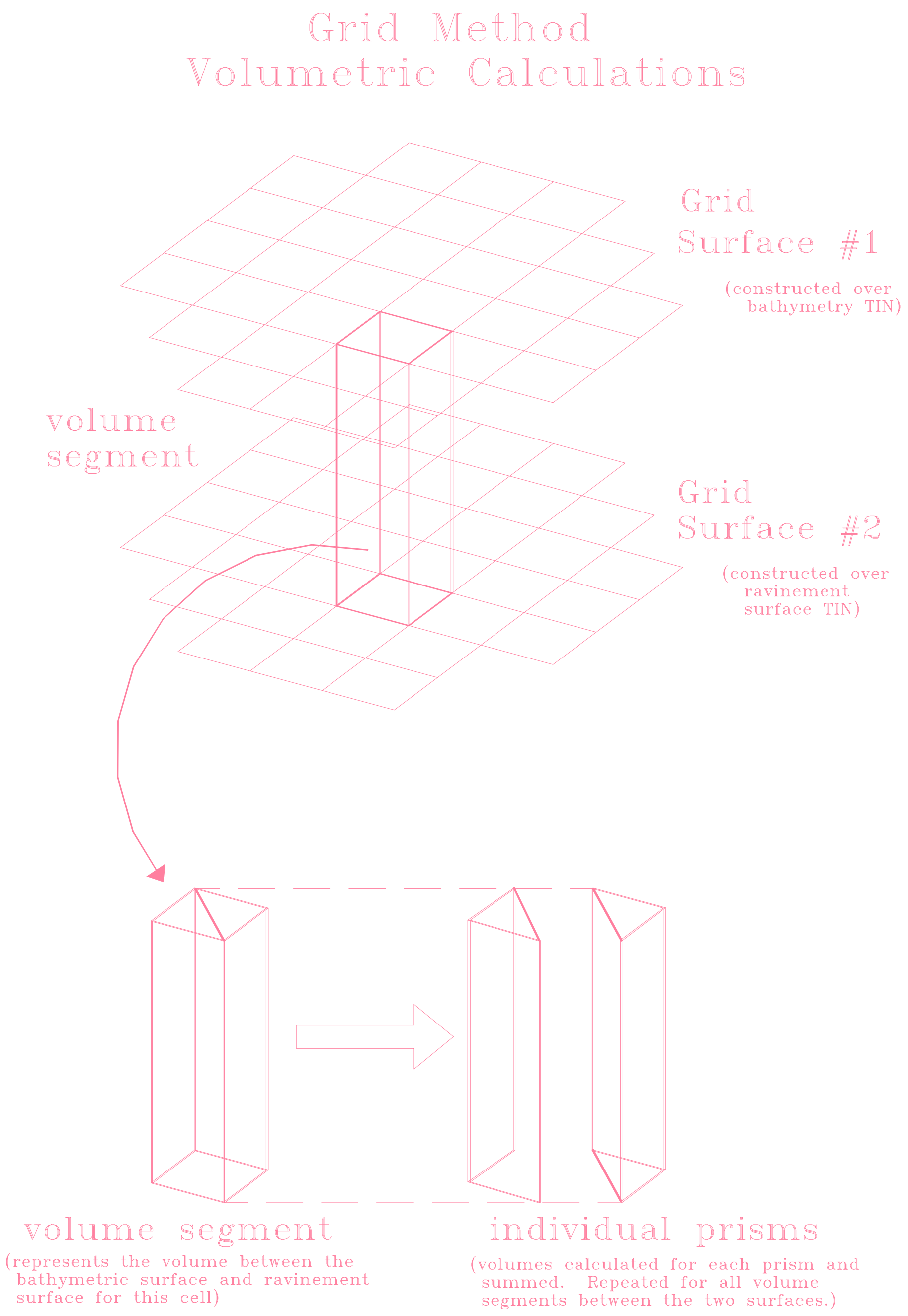
Seismic data were collected on an analog strip chart recorder but were required in digital form. We developed a method of transferring the two-dimensional, graphic information collected in the field into a three-dimensional, digital model. We used a Calcomp 9800, large format digitizer to enter the seismic data into *AutoCAD 13 (DOS)*. A program was developed for *AutoCAD* that calculates the grid coordinates and depths for each digitized point. Bathymetric and subbottom reflectors were digitized along each trackline to produce three-dimensional profiles of the bottom and subbottom.

We used a third party program, *Civil/Survey* (Softdesk), within the *AutoCAD* environment to generate surface models of the ocean floor and seismic reflectors, based on the digitized data. *Civil/Survey* uses triangular irregular networks, or TINs, to construct surface models. This is the most commonly employed method for constructing elevation models. TINs are generated by connecting elevation points with lines to form triangles. The network of interconnected triangles forms an interpolated surface model. These models can be represented in several forms, including contour maps, cross-sections, and a variety of gridded and rendered surfaces. Separate TINs are generated for bathymetric data and each digitized subottom horizon. The TIN surfaces derived from these data are then used to calculate parameters such as volume, slope, intersecting surfaces and elevations.

Our bathymetric model was constructed from a digital bathymetric database of the Delmarva Atlantic shelf, compiled by the National Ocean Service. The bathymetric model generated from this database is accurate and highly detailed. The surface models of subbottom reflectors are less detailed due to the limited amount of data points available from the digitized data. Because the shoals are usually acoustically opaque several feet below their surface, few data points for surfaces under the shoals were obtained. Contours depicted under the shoals are extrapolated by the contouring program from data surrounding and under the thinner, more acoustically transparent margins of the shoals. Seismic reflectors are subject to the phenomenon of 'pull-up'. This effect is seen as a change in depth of the reflector as it passes under a shoal. The density and thickness of shoal sediments change the two-way travel time of the acoustic signal and artificially warp the underlying seismic signatures. This causes anomalous contour highs or lows on reflector surfaces under ridges and swales. Predicting the net effect of this phenomenon on the seismic reflectors is difficult. Although the pull-up effect causes inaccuracies in portions of the surface models, it is limited to a tolerance of several feet and has minimum influence on volumetric calculations. We assume that, while the contours under the shoals may not accurately reflect the detailed surface geometry, they are a reasonable representation of the mean depth of these reflectors.

Volumetric determinations were carried out by *Civil/Survey* software. This program offers several methods for volume determinations. The grid method is most appropriate for the type of data available. To determine shoal volumes, the upper and lower surfaces of the shoals, and their flanking boundaries must be defined. The upper surface is the bathymetric surface, derived from the bathymetric model. The lower surface is the surface upon which the shoal developed. The lower bounding surface is determined from seismic and core data that are in turn used to generate a TIN model of the subbottom reflectors. Shoal edges are defined by either pinch-out of shoal sediments, or significant fining in flank sediment texture. Pinch-out was considered to occur where shoal sediments thin to one meter or less, which is the practical limit for dredging. These conditions were determined from seismic and core data. The volumetric program overlays grids on the upper and lower TINs, within the shoal boundaries. The three-dimensional coordinates for the corners, or nodes, of each grid cell on both surfaces are sampled. If any corner of any cell falls outside the boundary of either surface, the cell is discarded. The volume between each upper and lower cell is split vertically to produce two prisms. The volumes of both prism halves are summed to determine the cell volume. Cell volumes for the entire grid are summed to produce the total volume between the grids (Figure 3).

Figure 3


Grid Method
Volumetric Calculations
Grid
Surface #1
(constructed over
bathymetry TIN)
volume
segment
Grid
Surface #2
(constructed over
ravinement
surface TIN)
volume segment
(represents the volume between the
bathymetric surface and ravinement
surface for this cell)
individual prisms
(volumes calculated for each prism and
summed. Repeated for all volume
segments between the two surfaces.)

RESULTS

Shoal Field Structure

Shoal Field III includes eight unnamed shoals, designated F through M. A bathymetric map of Shoal Field III shows features typical of a linear shoal field (Figure 4). Depths range from a minimum of -19 ft. over Shoal M, to a maximum of -109 ft. in a trough east of Shoal K. The mean depth of the shoal field is -48 ft. While each shoal possesses a unique shape, they all display the general morphologic characteristics associated with linear sand ridges:

< elongated bodies with northeast axial trends;
< a bathymetric high, or crest, proximal to the shore to the southwest;
< depth increases to the northeast toward the shore distal end;
< relief above surrounding terrain of tens of feet;
< flank slopes between 0.2E and 7.0E;
< seaward flanks steeper than landward flanks.

The bathymetric map (Figure 4) shows the variations in form of these shoals. Shoals F, G, H and I are narrow and generally parallel the present shoreline. Shoals J and M appear broad and blunt. Farther to the east, Shoals K and L are somewhat arcuate and irregular in shape. Shoal M has the smallest surface area, while Shoal K has the largest. A summary of shoal geometry is presented in Table 1. Based on these parameters, all shoals in Shoal Field III fit the McBride/Moslow model for ebb tidal inlet shoal origins.

TABLE 1: PHYSICAL PARAMETERS

Parameter	Shoal F	Shoal G	Shoal H	Shoal I	Shoal J	Shoal K	Shoal L	Shoal M
Area (mile^2)	5.9	3.5	4.4	5.1	4.1	8.5	4.2	1.5
Axis (Efrom north)	36	31	36	35	56	45	43	38
length of base (ft)	36,900	36,000	36,500	29,600	19,500	34,500	17,900	10,600
width	6,300	3,400	5,700	6,700	7,800	10,100	8,900	5,000
minimum depth	-28	-22	-23	-27	-22	-21	-26	-19
depth of base	-53	-53	-54	-54	-63	-70	-70	-55

Seismic records reveal some of the shallow structure of Shoal Field III. Some shoal bodies exhibit limited internal structure. While this is in part due to the acoustic opacity of

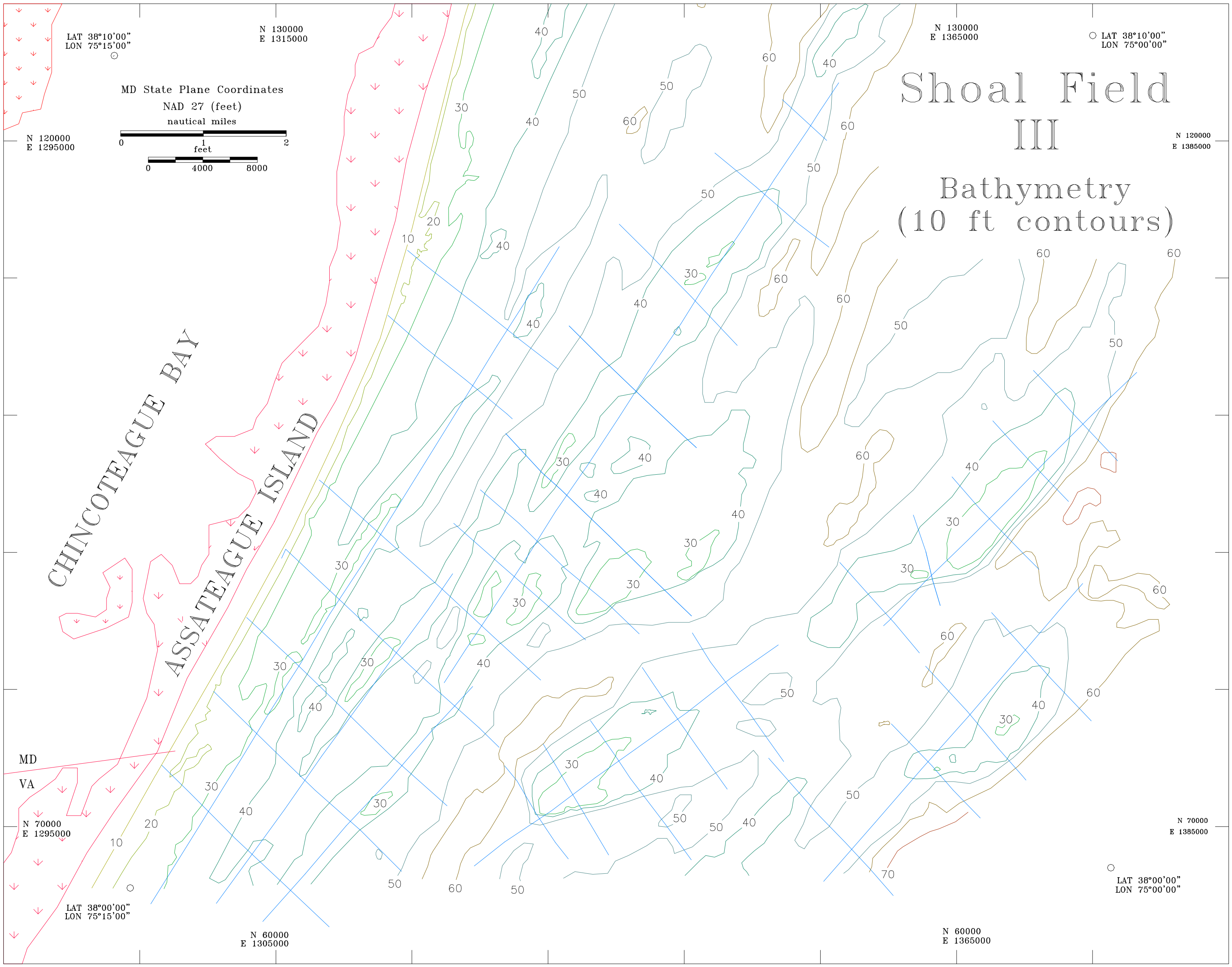

Shoal Field III
Bathymetry (10 ft contours)
MD State Plane Coordinates
NAD 27 (feet)
nautical miles
0
1
2
feet
0
4000
8000
LAT 38°10'00"
LON 75°15'00"
N 130000
E 1315000
N 130000
E 1365000
LAT 38°10'00"
LON 75°00'00"
N 120000
E 1295000
N 120000
E 1385000
N 70000
E 1295000
N 70000
E 1385000
LAT 38°00'00"
LON 75°15'00"
N 60000
E 1305000
N 60000
E 1365000
LAT 38°00'00"
LON 75°00'00"
CHINCOTEAGUE BAY
ASSATEAGUE ISLAND
MD
VA

Figure 4

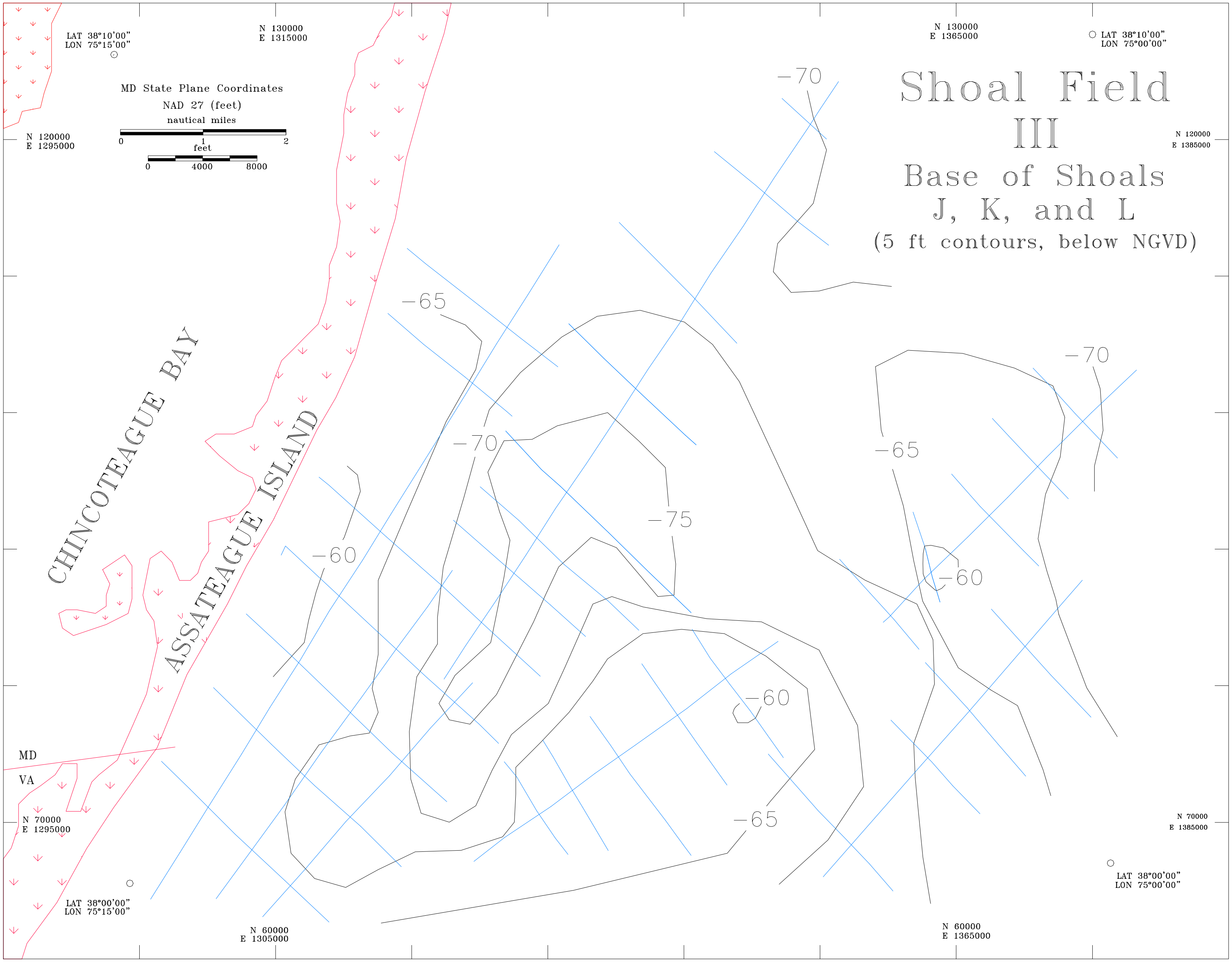
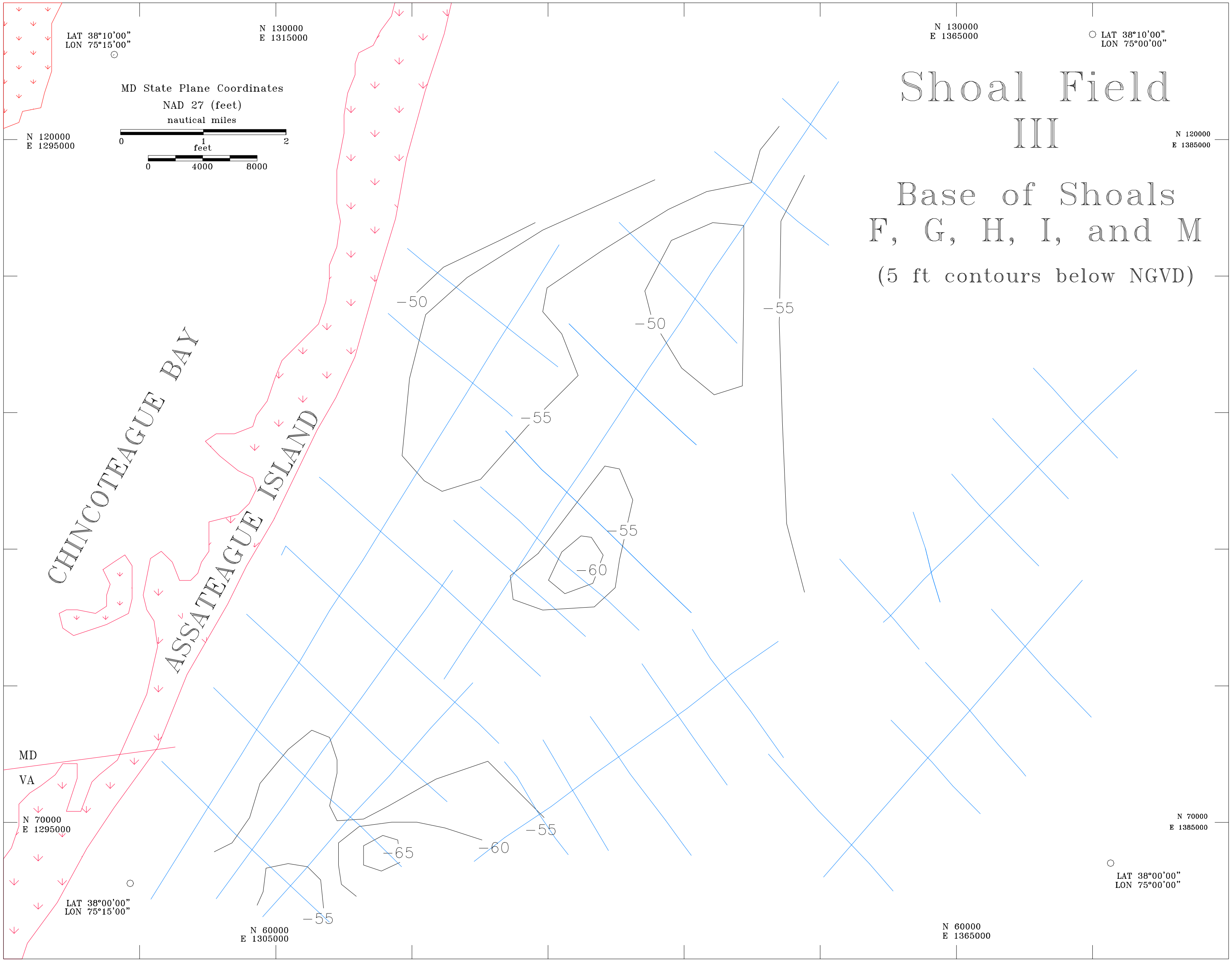

LAT 38°10'00"
LON 75°15'00"
N 130000
E 1315000
N 130000
E 1365000
LAT 38°10'00"
LON 75°00'00"
MD State Plane Coordinates
NAD 27 (feet)
nautical miles
0
1
2
feet
0
4000
8000
N 120000
E 1295000
N 120000
E 1385000
Shoal Field
III
Base of Shoals
J, K, and L
(5 ft contours, below NGVD)
−70
−65
−70
−75
−65
−70
−60
−60
−60
−65
CHINCOTEAGUE BAY
ASSATEAGUE ISLAND
MD
VA
N 70000
E 1295000
N 70000
E 1385000
LAT 38°00'00"
LON 75°15'00"
N 60000
E 1305000
N 60000
E 1365000
LAT 38°00'00"
LON 75°00'00"

Figure 5



Shoal Field III

Base of Shoals F, G, H, I, and M

(5 ft contours below NGVD)

Figure 6

these sand bodies, it is also an indication of the massive, homogeneous structure characteristic of linear sand shoals. These internal reflectors are indicative of changes in sediment density. Inter-shoal areas show some buried channels and bedding features.

Shoal Field III is underlain by a basal reflector. The reflector has variable relief, and can be divided into two sections. The western portion of the shoal field is underlain by a reflector having relatively flat relief, varying from -42 ft to -73 ft, with a mean depth of -68 feet. East of Shoal M, this reflector is truncated by troughs with depths exceeding -70 ft. East of Shoal M, the basal reflector ranges from -56 to -80 ft. This seismic reflector represents the surface upon which the linear shoals have developed. Contour maps of this surface (Figures 5 and 6) show the irregular nature of the basal reflector. The contours are based on a surface model derived from digitized seismic data.

Toscano and others (1989) described this basal reflector as evidence of a time-transgressive ravinement surface. The ravinement surface developed from erosional and depositional processes operating on the shoreface during the last Holocene transgression. As sea level rose, the base of the shoreface was eroded and the shoreface profile retreated landward and upward. The erosional surface created at the shoreface base followed the same retreat path. Shoreface sediments redeposited above the erosional surface were subsequently reworked by shelf processes into the modern sea floor. Thus the ravinement surface is both an erosional surface and a sediment transfer surface (Nummedal and Swift, 1987). Modern shelf sands that make up the sea floor, including the linear shoals, overlay the ravinement surface. The ravinement surface is not always apparent on seismic records due to several factors. Mixing of the bounding lithologies may occur during its formation (Toscano and others, 1989) and may prevent the appearance of an acoustically significant reflector. In some instances, the seismic signature is masked by the closeness of the ravinement surface to the ocean floor.

Shoal edges are usually observed in seismic records as a feathering out of shoal sediments over underlying units. However, shoal edges are not always this distinct, particularly where shoal sands have migrated over or overlapped older units. We have defined shoal edge boundaries for this study by the thickness of sediments, or abrupt changes in lithology. Because it is impractical to dredge sand from deposits less than 1 meter thick, we delimit the shoal to thicknesses greater than 1 meter. Additionally, we define the shoal edge where seismic records suggest sediment types become abruptly fine or muddy. These lithologies are not considered potential beach fill material. This condition often occurs where shoal faces truncate the ravinement surface. Figure 7 displays the outline of shoals in Shoal Field III.

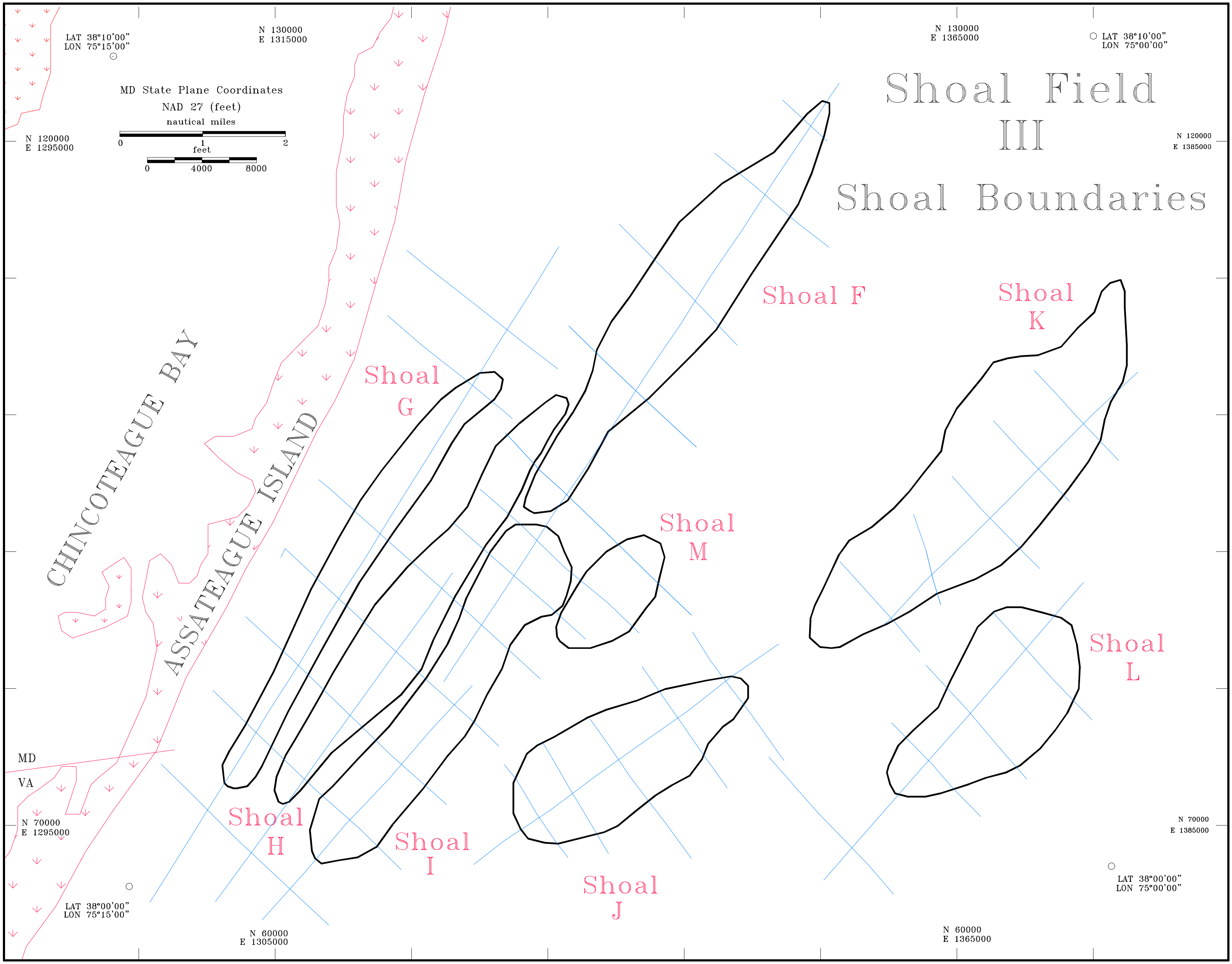

Shoal Field
III
Shoal Boundaries
MD State Plane Coordinates
NAD 27 (feet)
nautical miles
0
1
2
feet
0
4000
8000
LAT 38°10'00"
LON 75°15'00"
N 130000
E 1315000
N 130000
E 1365000
LAT 38°10'00"
LON 75°00'00"
N 120000
E 1295000
N 120000
E 1385000
N 70000
E 1295000
N 70000
E 1385000
LAT 38°00'00"
LON 75°15'00"
N 60000
E 1305000
N 60000
E 1365000
LAT 38°00'00"
LON 75°00'00"
CHINCOTEAGUE BAY
ASSATEAGUE ISLAND
MD
VA
Shoal F
Shoal K
Shoal G
Shoal M
Shoal L
Shoal H
Shoal I
Shoal J

Figure 7

SAND RESOURCE POTENTIAL OF SHOAL FIELD III

Criteria for estimating resource potential

Several factors must be considered in determining the utility of a particular deposit for use as beach fill. The U.S. Army Corps of Engineers and Maryland Department of Natural Resources have previously concluded that offshore deposits are the most desirable from economic and engineering standpoints. Additionally, sand deposits within a 15-mile radius from the point of use are most desirable. Water depths of less than 50 feet are also advantageous for dredging technologies. We concentrated on the geologic factors affecting the value of shoal deposits as potential sand sources.

Previous work on offshore sand resources in Maryland suggests that the most likely sites for suitable beach fill material will be found in linear, shore-detached sand ridges (Wells, 1994; Toscano *et al.*, 1989). All of the shoals in Shoal Field III conform to the McBride/Moslow model for ebb-tidal shoal classification.

Potential beach fill material should exhibit textural parameters similar to the native sands they are intended to replenish. The Shore Protection Manual (U.S. Army Corps, 1984) describes methodologies to determine acceptable textural parameters for beach fill for any particular site. An important consideration is the overfill factor. The overfill factor is derived from the comparison of textural properties, such as composite graphic mean (Folk and Ward, 1957) and sorting of the potential borrow sediments to those of the native beach sand, using overfill criteria developed by James (1975). The overfill factor takes into account that portion of borrow material expected to remain on the beach after equilibrium is achieved. High overfill factors suggest the borrow material will be unstable on the native beach because finer fractions will be removed more rapidly than coarse fractions. Thus, a larger volume of borrow material with a high overfill factor must be placed on the beach to maintain stability. Appropriate grain size parameters for Assateague beach fill will be calculated during initial stages of the beach restoration project. Because these parameters are not yet available, we will use data for native Ocean City beach sands. These sands have a composite graphic mean of 1.84 f and a sorting of 1.22 f (Anders and others, 1987; Anders and Hansen, 1990). Sediments that are finer or more poorly sorted than the native sand will have increasingly higher overfill factors. Therefore, sand most suitable for beach fill should have a mean grain size coarser than 1.84 f and have a sorting value less than 1.22 f . Assuming that Assateague native beach sands are similar to native Ocean City beach sands, similar parameters can be applied to Shoal Field III sediments.

Sediment quality

Figures 8 to 13 shows data from vibracores collected by Field (1976) and Toscano *et al.* (1989). These figures compare mean diameter with depth. The data are summarized in Appendix A. Interpretation of sediment quality in Shoal Field III is based on these cores and the seismic record. Seismic reflections vary according to sediment type, an effect that produces characteristic seismic signatures. Coarse sediments tend to be excellent reflectors, and limit the amount of signal penetration into underlying sediments. Fine sediments are more acoustically transparent than coarse material. Coarse sediments produce dark, surface reflectors with little detail below the surface. Finer sediments produce less distinct surface reflectors and allow better detailing of underlying units (Figure 14). Thus the seismic record when compared to sediment samples can assist in determining sediment types.

Figure 8

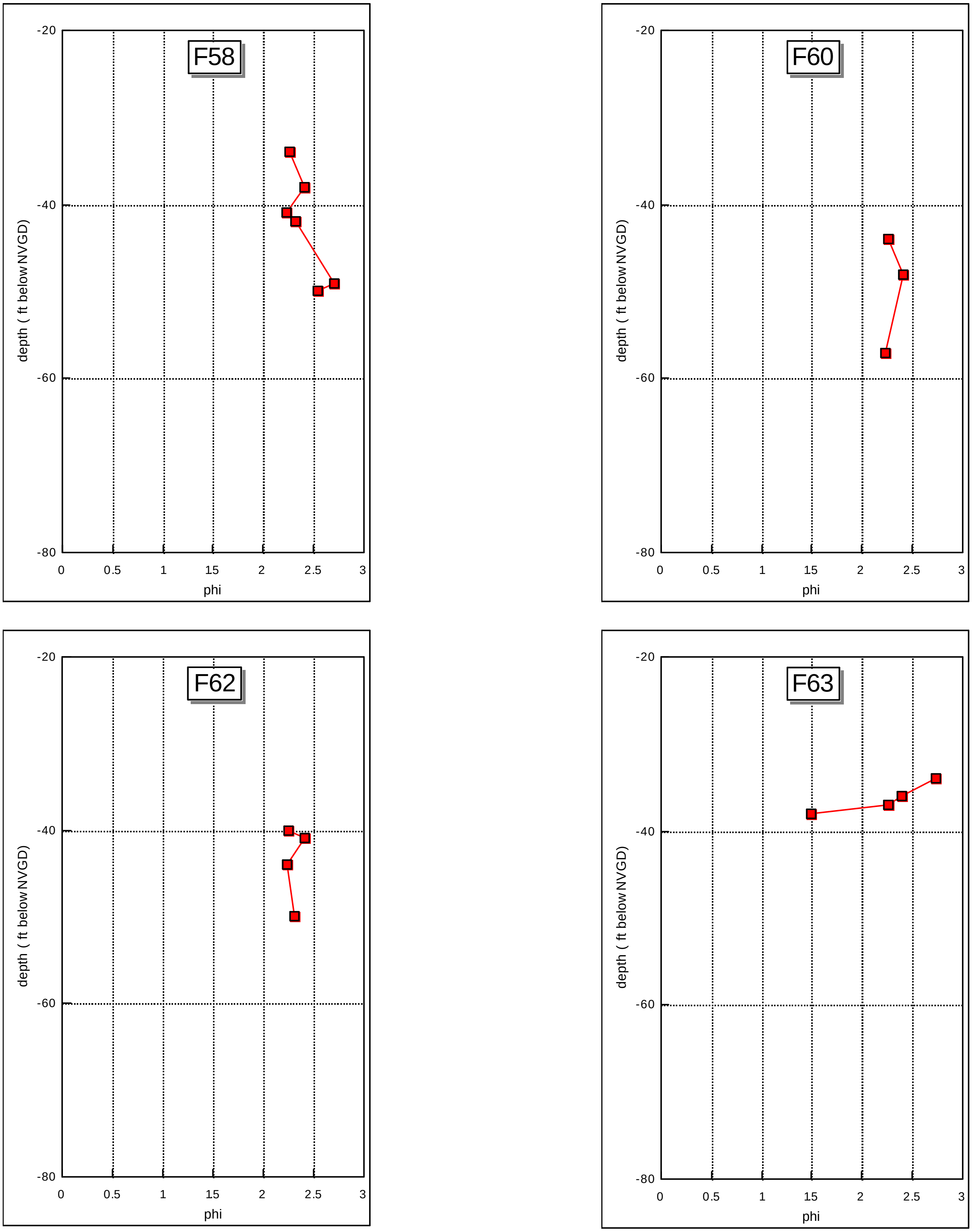


Figure 9

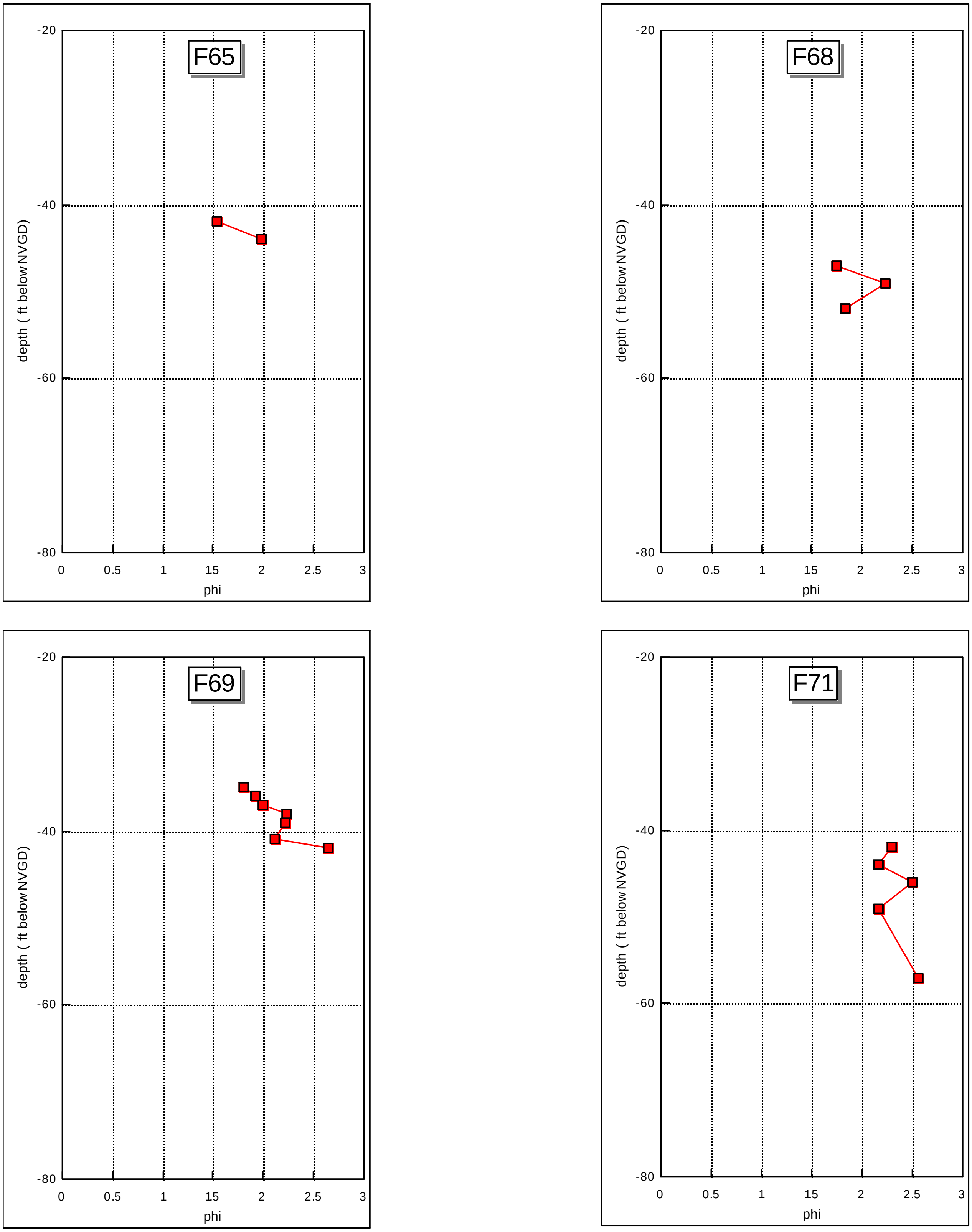


Figure 10

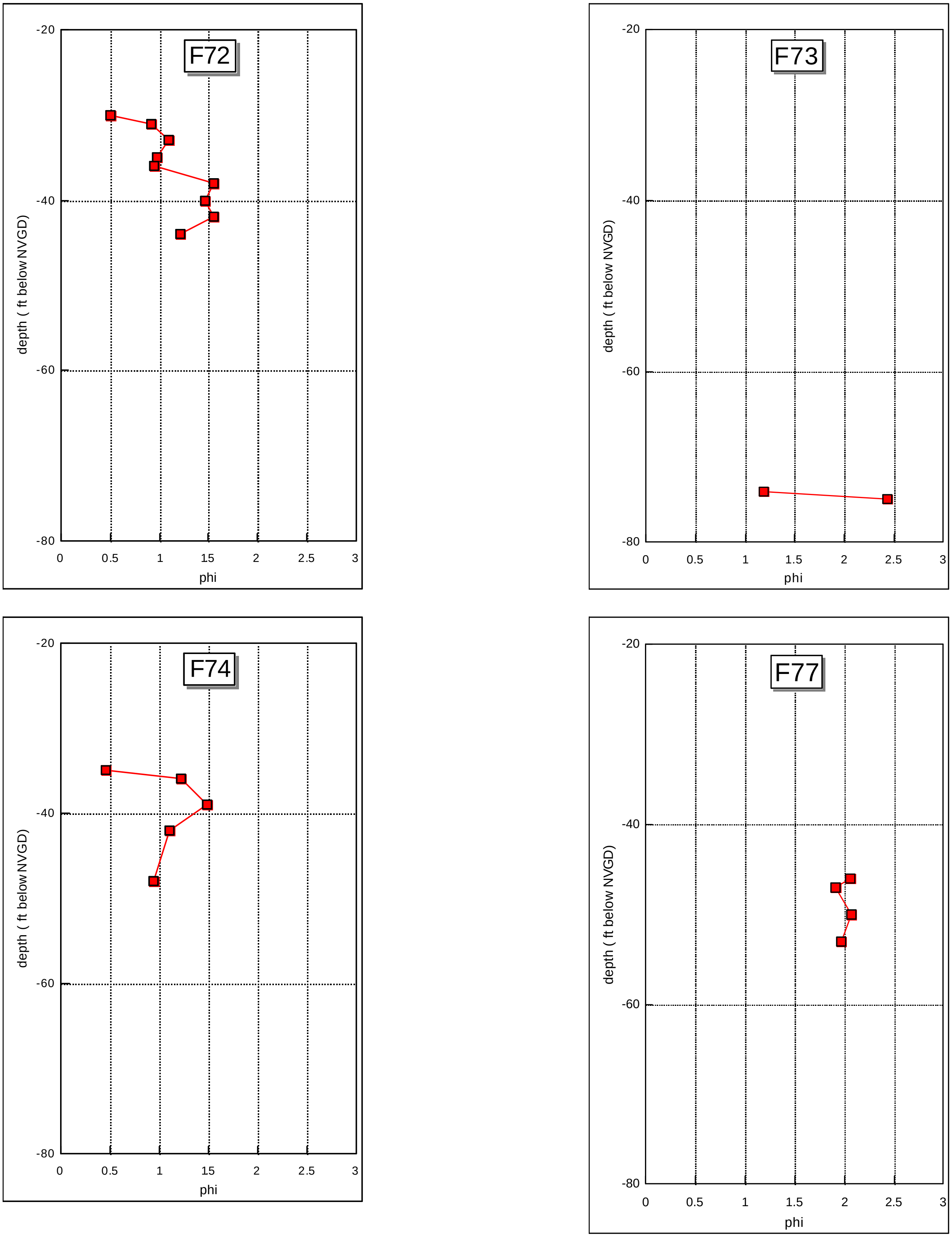

F72
-20
-40
-60
-80
depth (ft below NVGD)
0
0.5
1
15
2
2.5
3
phi
F73
-20
-40
-60
-80
depth (ft below NVGD)
0
0.5
1
1.5
2
2.5
3
phi
F74
-20
-40
-60
-80
depth (ft below NVGD)
0
0.5
1
15
2
2.5
3
phi
F77
-20
-40
-60
-80
depth (ft below NVGD)
0
0.5
1
1.5
2
2.5
3
phi

Figure 11

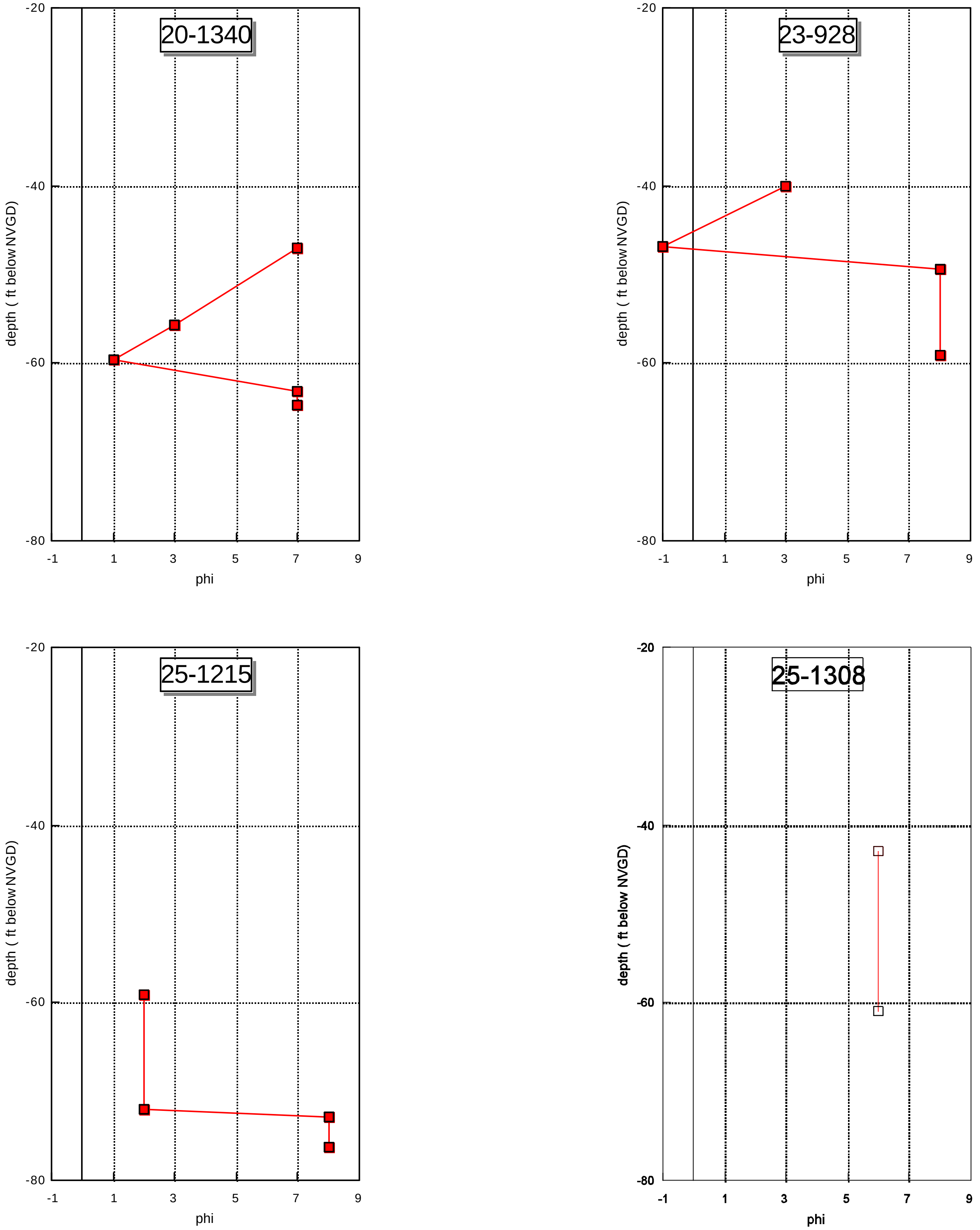
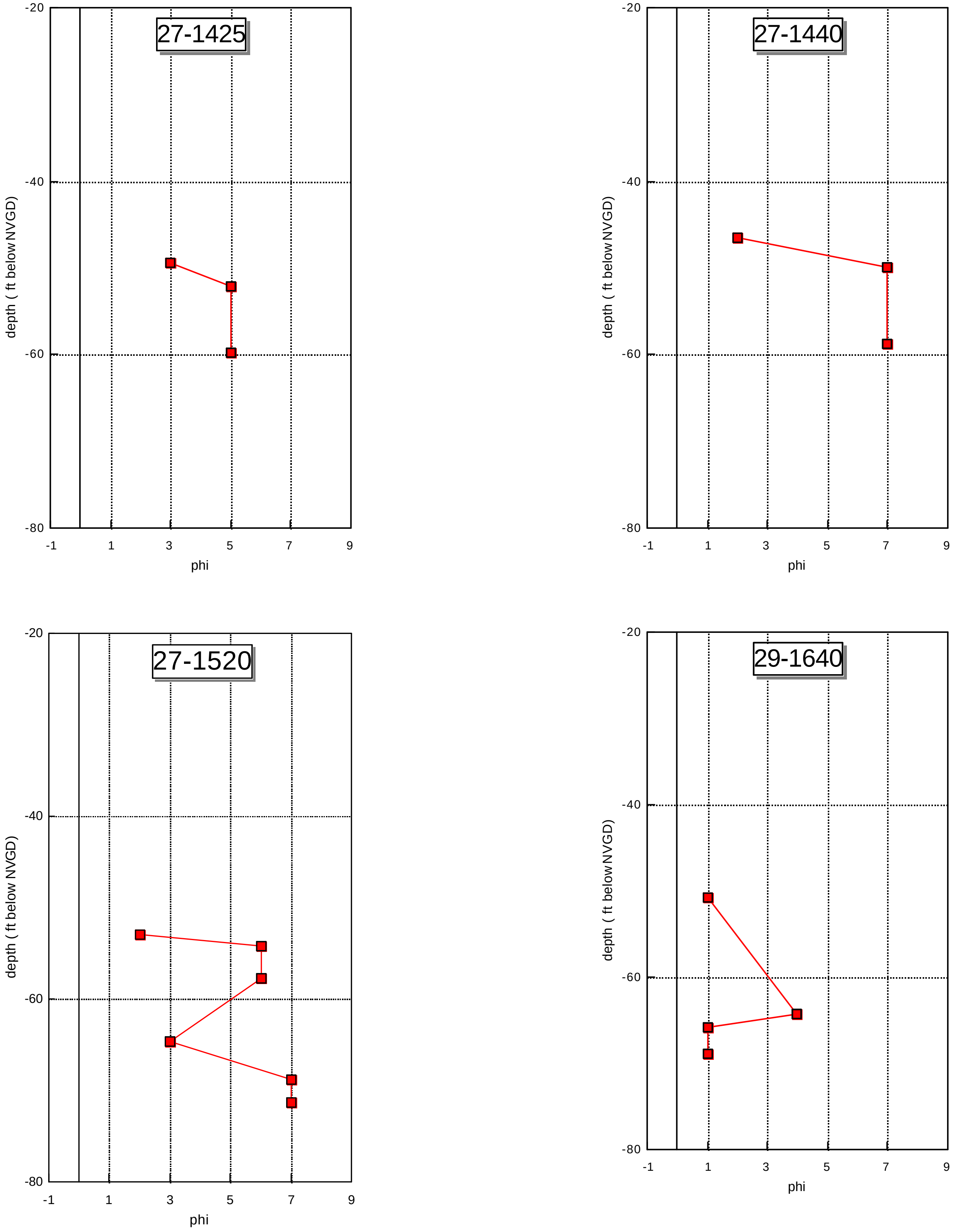

20-1340
23-928
25-1215
25-1308
depth (ft below NVGD)
phi
-20
-40
-60
-80
-1
1
3
5
7
9

Figure 12



27-1425
27-1440
27-1520
29-1640
-20
-40
-60
-80
depth (ft below NVGD)
-1
1
3
5
7
9
phi

Figure 13

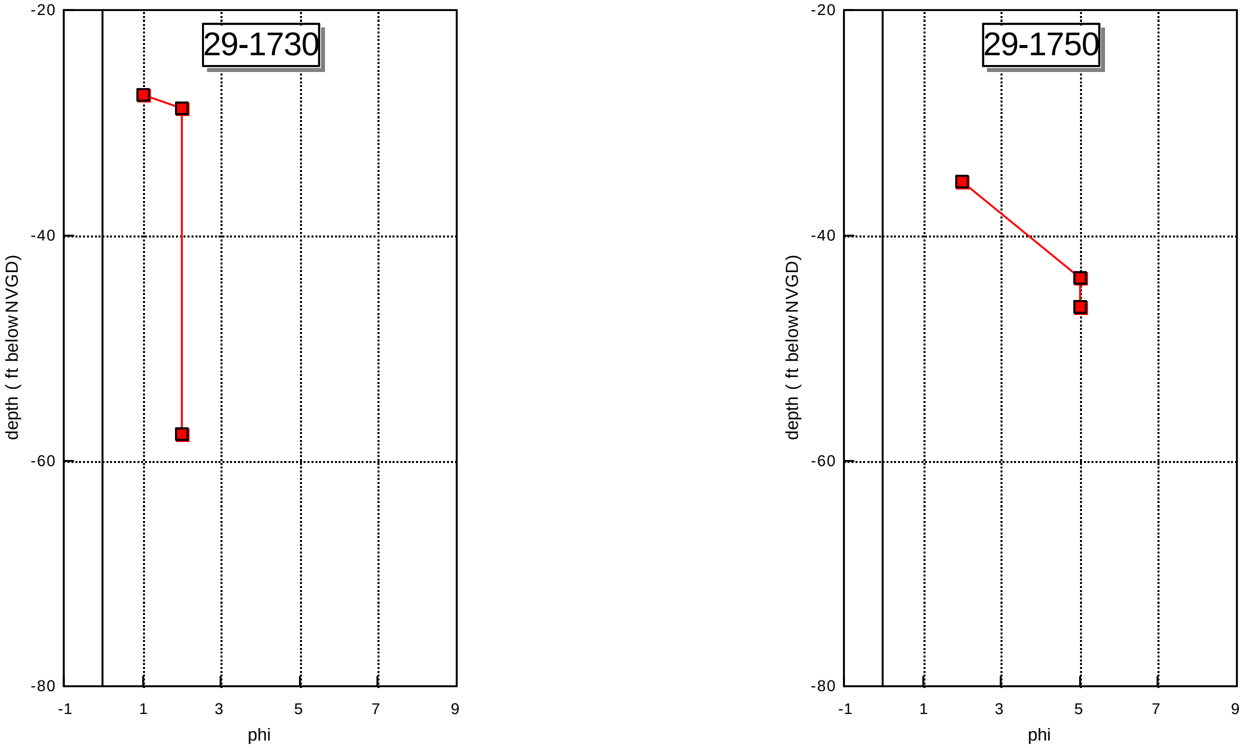
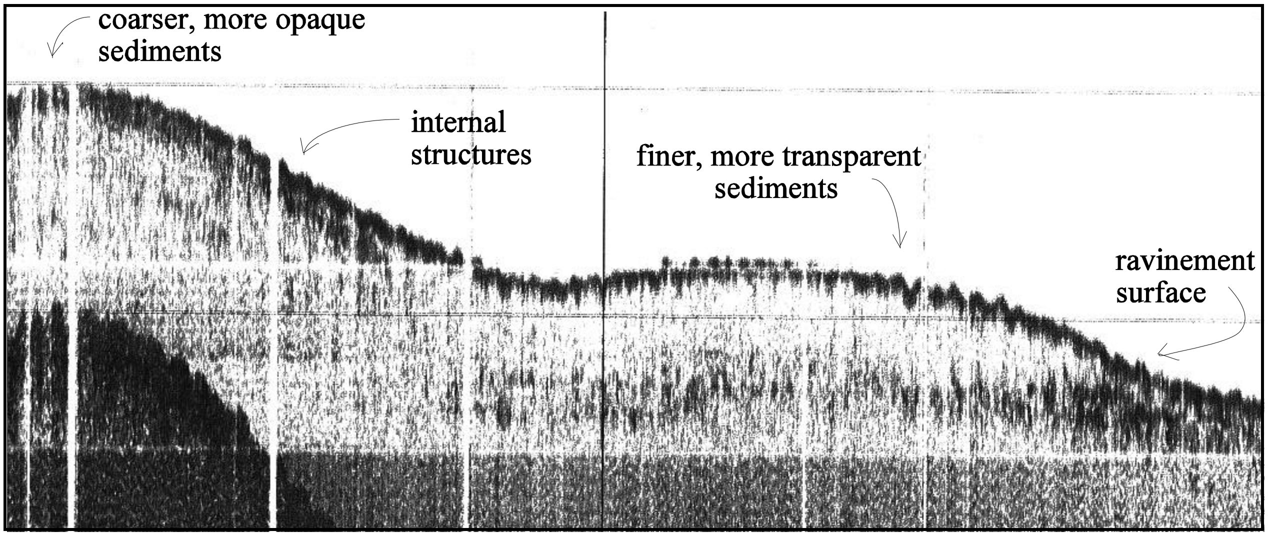

29-1730
depth (ft below NVGD)
-20
-40
-60
-80
-1
1
3
5
7
9
phi
29-1750
depth (ft below NVGD)
-20
-40
-60
-80
-1
1
3
5
7
9
phi

Figure 14



Examples of Seismic Reflectors

In Shoal F, core F74 on the crest shows coarse to medium sand from the shoal surface to -48 ft. Core 23-928, off the shoal to the east, indicates that region is underlain by layers of muddy sands and muds. Seismic reflectors on Shoal F suggest that the southwestern extent contains medium to fine sands. The reflectors in the northeastern area suggest an area of fine to medium sand surrounding a core of medium to coarse sands at the center of the shoal. The bulk of the shoal appears to contain fine to medium sand that may become mixed with muds toward the base.

Shoal G is a narrow body of fine to medium sand overlaying finer sediments. Seismic records show this shoreface-attached shoal to be relatively thin, with some internal structure. Cores F60, F63 and F65, located near the northwest flank, suggest that this internal structure consists of fine sands overlying fine to medium sands. Wells (1994) found that similar shore-attached shoals in the Ocean City vicinity to the north generally consisted of sediments unsuitable for beach nourishment. Given Shoal G's structural similarities to shoreface-attached shoals to the north, this sand body probably does not contain much usable sand.

Shoal H seismic records reveal a similar internal structure to Shoal G. This shoal has a hummocky surface, and probably consists of two or more smaller shoals that have coalesced. Core F77, taken from the southwestern flank, shows fine to medium sands from the shoal surface down to -53 ft. The seismic record in this area suggests medium sands will be found near the shoal's crest, and fine sands will overlay fine to medium sands toward the flanks. Medium to fine sands from the shoal surface down to -52 ft were found in core F68, located on the northwest flank. The sediment distribution in the northern shoal is probably similar to that found in the southern end, based on seismic similarities. Sediments in the central section of Shoal H vary greatly in their seismic reflectivity, indicating changes from medium sands to fine sands, and possibly some regions of muddy sand. This variability and the topographic irregularity of the mid-shoal region degrade Shoal H’s resource potential.

Shoal I displays similar surficial and internal structures to Shoal H. Like Shoal H, the middle section is hummocky and contains fine sediments. Core F71, on the central western flank contains fifteen feet of fine sand, to -57 ft. Almost directly east of core F71, core 27-1425 on the lower east flank shows a three-foot layer of medium to fine sand overlaying six feet of mud. The northeastern section of Shoal I is covered by at least ten feet of medium sand, as seen in core F62. While no cores are available from the southern reaches of Shoal I, seismic records show a similarity to the northern section. Shoal I has a similar resource potential to Shoal H.

Core F 58, on the western middle flank of Shoal J contains sixteen feet of fine sand. On the southeast flank, core 29-1730 contains one foot of coarse to medium sand. The shoal’s central and northern regions have irregular topography, which displays an irregular distribution of near-surface sediment types. This pattern, when compared with seismic records for this shoal, suggests the shoal has a central region of five to eight feet of medium to coarse sands overlaying fine sands. Because of the irregular sediment distribution, this shoal has at best a moderate sand resource potential.

Shoal K seismic data indicate the presence of medium to coarse sand in the central and northeastern sections, and somewhat finer sands in the southwestern reaches. Core F72, in the center of this shoal, contains fourteen feet of medium to coarse sands. The central section probably contains ten feet or more of medium to coarse sand overlaying medium to fine sands, with medium to fine sands along the flanks. This sediment distribution gives Shoal K a moderate to high potential as a sand resource.

No cores are available on Shoal L. The seismic data for this shoal suggest a sediment distribution similar but possibly somewhat finer, to Shoal K. The central section of Shoal L has an area of fine sand, which decreases its overall potential to moderate, at best.

Seismic data on Shoal M indicate a small region of medium sand along the crest. No cores have been taken on Shoal M. Core 25-1380, taken just north of the northwestern flank of Shoal M, contains eighteen feet of mud. This suggests the base of Shoal M sands is relatively shallow, and sediments near the base will be muddy. The central portion of this shoal has a moderate resource potential.

Sediment volumes

A summary of sediment volumes contained within Shoal Field III is presented in Table 2. Total shoal volumes, and volumes of regions with moderate and high potentials are calculated. Volumes are based on an entire shoal body, from its surface to its basal reflector. Shoal K has the greatest potential for sand resources, followed by Shoal F. Shoal G has little potential due to a predicted fine grain sand content and small volume.

Table 2:
SEDIMENT VOLUMES WITHIN SHOAL FIELD III

SHOAL	REGION	VOLUME (million yds^3)
F	total	54.6
	moderate potential, southern	6.1
	moderate potential, northern	9.1
	high potential, northern	12.4
G	total	23.6
	low potential	23.6
H	total	41.8
	moderate potential, southern	9.2
	moderate potential, northern	5.8
I	total	65.7
	moderate potential, southern	15.1
	moderate potential, northern	4.6
J	total	63.3
	moderate potential	63.3
K	total	138.1
	moderate potential	77.6
	high potential	60.5
L	total	72.0
	moderate potential	72.0
M	total	19.8
	moderate potential	19.8
All shoals	**total**	**478.9**
	total, moderate potential	**282.6**
	total, high potential	**72.9**

RESOURCE POTENTIAL

A summary of sediment grain size parameters and volumes is presented as a map in Figure 15. This map shows the distribution of potential beach fill material within Shoal Field III. Areas of high potential contain sands

1) estimated to have mean grain sizes and sortings acceptable as beach fill;
2) in depths less than -50 ft;
3) in deposits thicker than 1 meter.

Areas of moderate potential contain sands

1) suspected to have mixed or marginal grain size parameters;
2) in depth about -50 ft or less
3) in deposits thicker than 1 meter.

Areas of low potential are regions with fine sediment or those that lie below -50 ft.

The map suggests regions that are most likely to contain usable sand resources. A detailed sampling program that includes vibracoring capable of penetrating the shoals to at least -50 ft would be required to confirm these potentials.

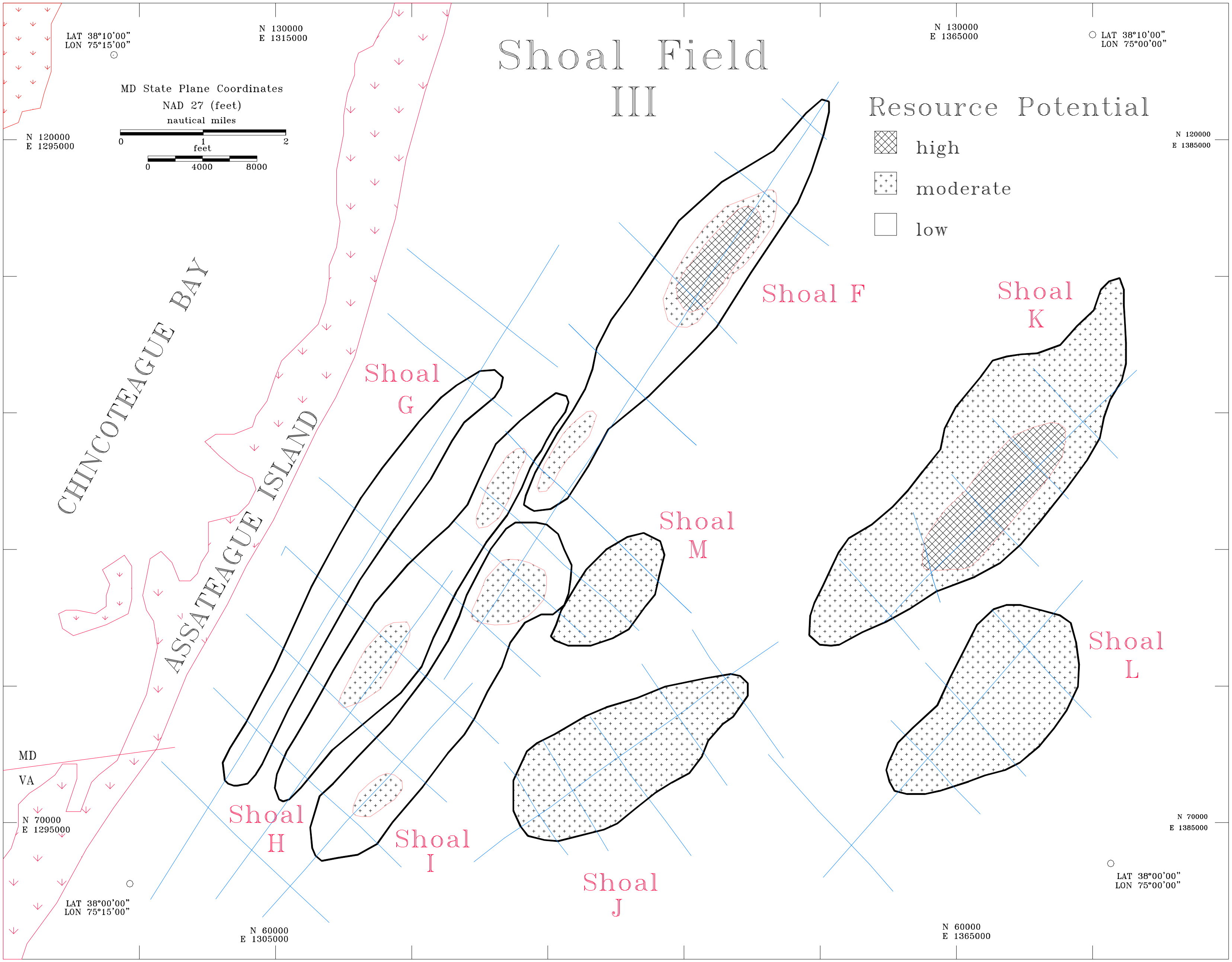

Shoal Field III
Resource Potential
▨ high
⁘ moderate
☐ low
MD State Plane Coordinates
NAD 27 (feet)
nautical miles
0
1
2
feet
0
4000
8000
LAT 38°10'00"
LON 75°15'00"
N 130000
E 1315000
N 130000
E 1365000
LAT 38°10'00"
LON 75°00'00"
N 120000
E 1295000
N 120000
E 1385000
CHINCOTEAGUE BAY
ASSATEAGUE ISLAND
Shoal F
Shoal G
Shoal K
Shoal M
Shoal L
Shoal H
Shoal I
Shoal J
MD
VA
N 70000
E 1295000
N 70000
E 1385000
LAT 38°00'00"
LON 75°15'00"
N 60000
E 1305000
N 60000
E 1365000
LAT 38°00'00"
LON 75°00'00"

Figure 15

CONCLUSION

Shoal Field III encompasses eight shoals, two of which have high potential for sand resources. Shoal K and F have the highest potential for volume and quality of material. Shoals H, I, J, L, and M have a moderate potential for sand resources, but contain significant amounts of finer sands. Shoal G, a shoreface-attached shoal, most likely contains fine sands and a relatively small volume. Shoal Field III is located within economical distances and depths for beach restoration projects planned on northern Assateague Island. A complete sampling scheme to at least -50 ft within these shoals is needed to confirm these potentials.

The ocean floor between the shoals has limited potential for sand resources. Relatively thin layers of fine and mixed sediments overlaying early and pre-Holocene sediments dominate the inter-shoal areas within Shoal Field III. These qualities and water depths of greater than -50 ft make non-shoal deposits less important as potential sand sources.

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Appendix A

Vibracore Sample Grain Size Parameters

(after Field, 1976, and Toscano *et al.*, 1989)

Grain Size Parameters from Field's Vibracores (1989)

Core and sample	Depth (ft)	Sample interval (ft)	Sample depth (ft)	Description	mean diameter (f)	sorting (f)
F58-1	-34	0	-34	FINE	2.26	0.36
F58-4	-34	-4	-38	FINE	2.41	0.38
F58-7	-34	-7	-41	FINE	2.24	0.54
F58-8	-34	-8	-42	FINE	2.32	0.48
F58-15	-34	-15	-49	FINE	2.71	0.44
F58-16	-34	-16	-50	FINE	2.55	0.58
BULK					2.42	
F60-1	-44	0	-44	MEDIUM	1.51	0.99
F60-4	-44	-4	-48	FINE	2.35	0.41
F60-13	-44	-13	-57	COARSE	0.79	0.41
BULK				MEDIUM	1.55	
F62-0	-40	0	-40	MEDIUM	1.68	0.46
F62-1	-40	-1	-41	MEDIUM	1.59	0.36
F62-4	-40	-4	-44	MEDIUM	1.68	0.45
F62-10	-40	-10	-50	MEDIUM	1.69	0.71
BULK				MEDIUM	1.66	
F63-0	-34	0	-34	FINE	2.74	0.81
F63-2	-34	-2	-36	FINE	2.40	1.82
F63-3	-34	-3	-37	FINE	2.26	1.02
F63-4	-34	-4	-38	MEDIUM	1.49	1.05
BULK				FINE	2.22	
F65-0	-42	0	-42	MEDIUM	1.54	0.93
F65-2	-42	-2	-44	MEDIUM	1.98	0.62
BULK				MEDIUM	1.76	
F68-0	-47	0	-47	MEDIUM	1.75	0.71
F68-2	-47	-2	-49	FINE	2.24	0.49
F68-5	-47	-5	-52	MEDIUM	1.84	0.89
BULK				MEDIUM	1.94	
F69-0	-35	0	-35	MEDIUM	1.80	0.89
F69-1	-35	-1	-36	MEDIUM	1.93	0.81
F69-2	-35	-2	-37	FINE	2.00	0.67
F69-3	-35	-3	-38	FINE	2.23	0.67
F69-4	-35	-4	-39	FINE	2.22	0.76
F69-6	-35	-6	-41	FINE	2.12	0.90

Core and sample	Depth (ft)	Sample interval (ft)	Sample depth (ft)	Description	mean diameter (f)	sorting (f)
F69-7	-35	-7	-42	FINE	2.65	0.44
BULK				FINE	2.14	
F71-0	-42	0	-42	FINE	2.29	0.61
F71-2	-42	-2	-44	FINE	2.16	0.49
F71-4	-42	-4	-46	FINE	2.50	0.41
F71-7	-42	-7	-49	FINE	2.17	0.57
F71-15	-42	-15	-57	FINE	2.57	0.65
BULK				FINE	2.34	
F72-0	-30	0	-30	COARSE	0.50	0.95
F72-1	-30	-1	-31	COARSE	0.91	0.96
F72-3	-30	-3	-33	MEDIUM	1.09	0.54
F72-5	-30	-5	-35	COARSE	0.97	0.73
F72-6	-30	-6	-36	COARSE	0.94	0.72
F72-8	-30	-8	-38	MEDIUM	1.55	0.53
F72-10	-30	-10	-40	MEDIUM	1.46	0.46
F72-12	-30	-12	-42	MEDIUM	1.55	0.44
F72-14	-30	-14	-44	MEDIUM	1.22	0.53
BULK				MEDIUM	1.13	
F73-0	-74	0	-74	MEDIUM	1.19	1.25
F73-1	-74	-1	-75	FINE	2.43	0.93
BULK				MEDIUM	1.81	
F74-0	-35	0	-35	COARSE	0.46	0.74
F74-1	-35	-1	-36	MEDIUM	1.22	0.70
F74-4	-35	-4	-39	MEDIUM	1.48	0.73
F74-7	-35	-7	-42	MEDIUM	1.11	0.68
F74-13	-35	-13	-48	COARSE	0.94	0.68
BULK				MEDIUM	1.04	
F77-0	-46	0	-46	FINE	2.06	0.35
F77-1	-46	-1	-47	MEDIUM	1.91	0.60
F77-4	-46	-4	-50	FINE	2.07	0.42
F77-7	-46	-7	-53	MEDIUM	1.97	0.44
BULK				FINE	2.00	

Grain Size Estimates from Toscano et al. Vibracores (1989)

Sample ID	Core depth (ft)	Sample depth (ft)	Description	Estimated mean diameter (f)
20-1340	-47.7	-47.0	MUD	7
		-55.7	MUD AND SAND	3
		-59.6	COARSE TO MEDIUM SAND	1
		-63.2	MUD	7
		-64.7	MUD	7
23-928	-40.0	-40.0	FINE SAND AND MUD	3
		-46.9	COARSE SAND AND GRAVEL	-1
		-49.4	MUD	8
		-59.1	MUD	8
25-1215	-59.1	-59.1	MEDIUM TO FINE SAND	2
		-72.0	MEDIUM TO FINE SAND	2
		-72.9	MUD	8
		-76.3	MUD	8
25-1308	-42.9	-42.9	MUD	6
		-61.0	MUD	6
27-1425	-49.4	-49.4	MEDIUM TO FINE SAND	3
		-52.1	MUD	5
		-59.8	MUD	5
27-1440	-46.6	-46.6	MEDIUM TO FINE SAND	2
		-50.0	MUD	7
		-58.8	MUD	7
27-1520	-52.9	-52.9	MEDIUM TO FINE SAND	2
		-54.2	MUD	6
		-57.7	MUD	6
		-64.7	MUDDY FINE SAND	3
		-68.8	MUD	7
		-71.3	MUD	7
29-1640	-50.7	-50.7	COARSE TO MEDIUM SAND	1
		-64.3	MUD	4
		-65.7	COARSE TO MEDIUM SAND	1
		-68.8	COARSE TO MEDIUM SAND	1
29-1730	-27.5	-27.5	COARSE TO MEDIUM SAND	1
		-28.8	MEDIUM TO FINE SAND	2
		-57.6	MEDIUM TO FINE SAND	2
29-1750	-35.3	-35.3	MEDIUM TO FINE SAND	2
		-43.8	MUD	5

Sample ID	Core depth (ft)	Sample depth (ft)	Description	Estimated mean diameter (f)
		-46.4	MUD	5