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Offshore Sand Resources in Central 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, MD was sampled for potential sand resources. This field, designated Shoal Field II, is located approximately 6 kilometers off Assateague Island. The eastern edge of the shoal field extends to 20 kilometers offshore.

Vibracore samples were used to estimate the quality and quantity of sediments contained in five shoals. The following figures represent the minimum amount of sand contained in the shoals, suitable for beach nourishment projects:

Shoal B - 30.l million cubic meters
Shoal C - 2.5 million cubic meters
Shoal D - 12.3 million cubic meters
Great Gull Bank - 11.5 million cubic meters
Little Gull Bank - 19.3 million cubic meters

These sand resources are similar in character to native beach sands found on Assateague and Ocean City beaches.

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 12.9 km of Fenwick Island within Maryland consist of public beaches fronting commercial and private real estate. South of the inlet, the 51.3 km of Assateague Island in Maryland are undeveloped state and Federal park lands. Maryland’s barrier islands and coastal bays 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 actually 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 a 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. Proximity of sand sources to nourishment projects 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 located 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. An increase in the frequency of strong storms has accelerated erosion of the restored beaches, placing increased demands on sand resources within state waters. It is conceivable that these resources could be depleted within a decade. New sand sources must be found to meet the growing demand for suitable beach nourishment material. 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 of this information.

The Maryland portion of the cooperative project is referred to as the Offshore Sand Resources Study. This report summarizes the fourth year investigations of the five year project. To date, the study has identified eighteen shoals in three shoal fields, containing an estimated 925 million cubic meters (1230 million cubic yards) of sand (Conkwright and Gast, 1994a, Conkwright and Gast, 1994b, Conkwright and Gast, 1994c). The fourth year objective was to detail sand resources within five of the eight shoals in Shoal Field II. The shoals are currently being considered as a sand source for beach restoration projects on Assateague Island, MD. We confined the study to five of the eight shoals, based on their resource potential determined during the 1993 Offshore Sand Resources Study (Conkwright and Gast, 1994)

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FOURTH YEAR GEOLOGICAL INVESTIGATIONS

Objective

Shoal Field II is an important sand resource for both Ocean City and Assateague Island beach restoration projects. In 1993 the shoal field's resource potential was investigated (Conkwright and Gast, 1994b). That study used seismic profile interpretations and archival vibracore data to examine the resources. Because insufficient sedimentologic data was available on the shoals to characterize sand quality and quantity accurately, only estimates of these parameters were calculated. Based on these findings, shoals B, C, D, and Little and Great Gull Banks were targeted for sampling in 1995.

The objective of this study is to accurately define the resource potential of these shoals. This was achieved by vibracore sampling to determine sediment quality in each shoal. Shoal sands were then classified as having high, moderate or low resource potential based on grain size, sorting and deposit depth. The volume of sand for each resource classification was calculated. Generally, volumes were calculated only to the depth of vibracore penetration, rather than to the base of the shoal. Thus, the volumes represent a minimum quantity of sand in each shoal, with known, not estimated, grain size parameters.

Previous Studies

Numerous scientists have investigated the Atlantic inner continental shelf. Comprehensive reviews of these works have been published by Duane and others (1972), Field (1976, 1980), Toscano *et al.* (1989), McBride and Moslow (1991), 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 nine m, side slopes of a few degrees, and extend for tens of kilometers.
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 assigned a common origin to these features. Generally, it was assumed that linear ridges represented relict barriers or subaerial beaches, developed at a lower sea level stand, and preserved by the transgressive oceans (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 from the interaction of storm-induced currents with 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 geomorphologic 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 developed a model for shoal field genesis and evolution, based on the formation and migration of ebb-tidal deltas. This model describes a source of sediment for shoal formation, and explains the orientation, shape, distribution and evolution of linear shoals. While the authors recognized that diverse mechanisms account for shoal formation, the ebb-tidal shoal model provided 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 Toscano and others (1989) and Toscano and Kerhin (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 39 km 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 generally contained fine sands and muds, unsuitable as beach fill. Coarser sands were generally found in shore-detached shoals. The Offshore Sand Resources Study employs the Toscano-Kerhin model of Maryland Quaternary shelf deposits to define shoal field structures.

Study Area

Shoal Field II, located approximately 6.4 km east of Ocean City Inlet, was the focus for the 1995 Offshore Sand Resources Study. The eastern edge of the shoal field extends to

19.3 km offshore. The study region includes Great Gull and Little Gull Banks, off northern Assateague Island, and five unnamed shoals, designated A through E. Shoal Field II encloses 244 square km of ocean floor, from depths of -4.8 m to -30 m below NGVD. This shoal field was the subject of a 1993 resource study. Lack of available sedimentologic data on the shoals permitted only estimates of grain size parameters and volumes of shoal sands.

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 be located within a 24 km radius from the point they are needed, and in waters less than 15 m deep. Portions of Shoal Field II conform to these suggested parameters. Figure 1 details the location of Shoal Field II.

Index of Shoal Fields

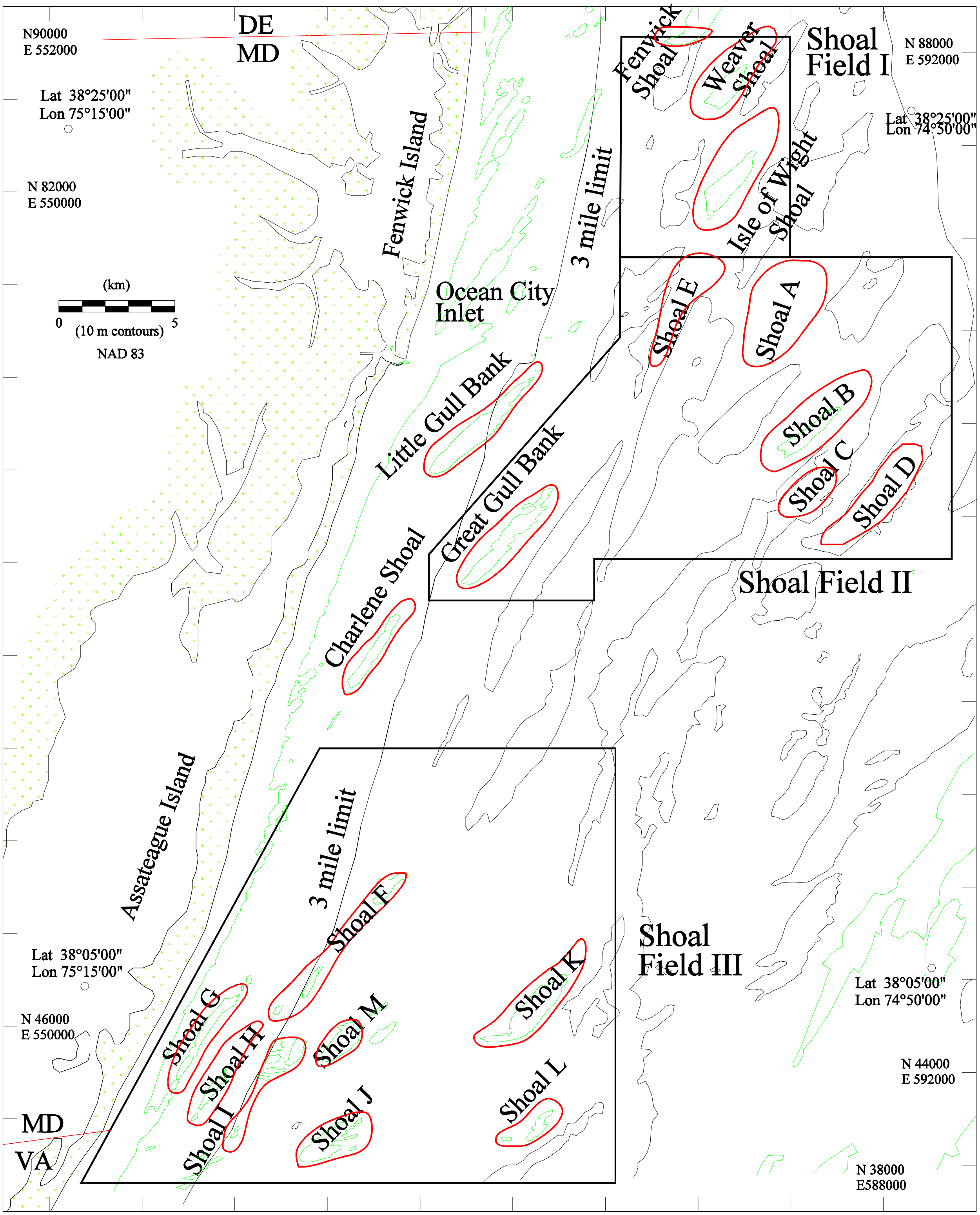


Figure 1

Study Methodology

Our goal in the fourth year of the Cooperative was to accurately define the potential sand resources within Shoal Field II. To achieve this goal, forty-three, 6 m vibracores we taken in and around the shoal field. Seismic data obtained during the 1993 study (Conkwright and Gast, 1994b) provided a basis for stratigraphic and volumetric analysis of the shoals. Textural parameters of shoal sediments are based on vibracore samples and seismic records. Data from vibracores obtained by Field (1976), and Toscano and Kerhin (1989) are also available for this region. Using this information, the shoals were classified according to their resource potential. The data also contributed to the model of regional shoal classification.

Previous studies by McBride and Moslow (1991), Toscano and Kerhin (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 and their flanks. Seismic lines were arrayed to provide cross-sections and axial profiles of the linear shoals, and the perimeter of the shoal field. Sediment samples provided 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 1993. More than 185 km 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 91 m, shallow water depths and a generally hard, sandy sea floor limited penetration to less than 27 meters in shoal areas. However, this limitation was not significant for the study because our interests were in shallow and surficial sediments. Better seismic penetration was obtained in inter-shoal regions, due to the presence of more acoustically transparent, fine sediments. Bathymetry was recorded at 200 kHz. Trackline positioning was determined by an onboard geographical positioning system, which provided fix marks at five minute intervals (Figure 2). Horizontal data is reported in Maryland State Plane Coordinates (NAD 83, meters). Water depths from electronic soundings were corrected to NGVD, and based on NOAA predicted tides for the time of sampling. Conversion between Maryland State Plane Coordinates and geographic coordinates was performed by *CORPSCON* software.

Sediment sampling

Forty-three vibracores were obtained during the fall and winter of 1995. Vibracore sampling stations were selected based on the findings of the 1993 Offshore Sand Resources Study (Conkwright and Gast, 1994b). That study found Shoals B, C, and D to have the highest resource potential, based on archival vibracore data. Great Gull Bank was estimated to have only a moderate potential, but its proximity to Assateague Island beaches was the reason for its inclusion in this study. Little Gull Bank was not explored in the 1993 study, and was also included this year due to its proximity to the shore. Coring stations were generally positioned to fall on or near existing seismic lines (Figure 2).

Vibracore Sites and Seismic Survey Tracklines

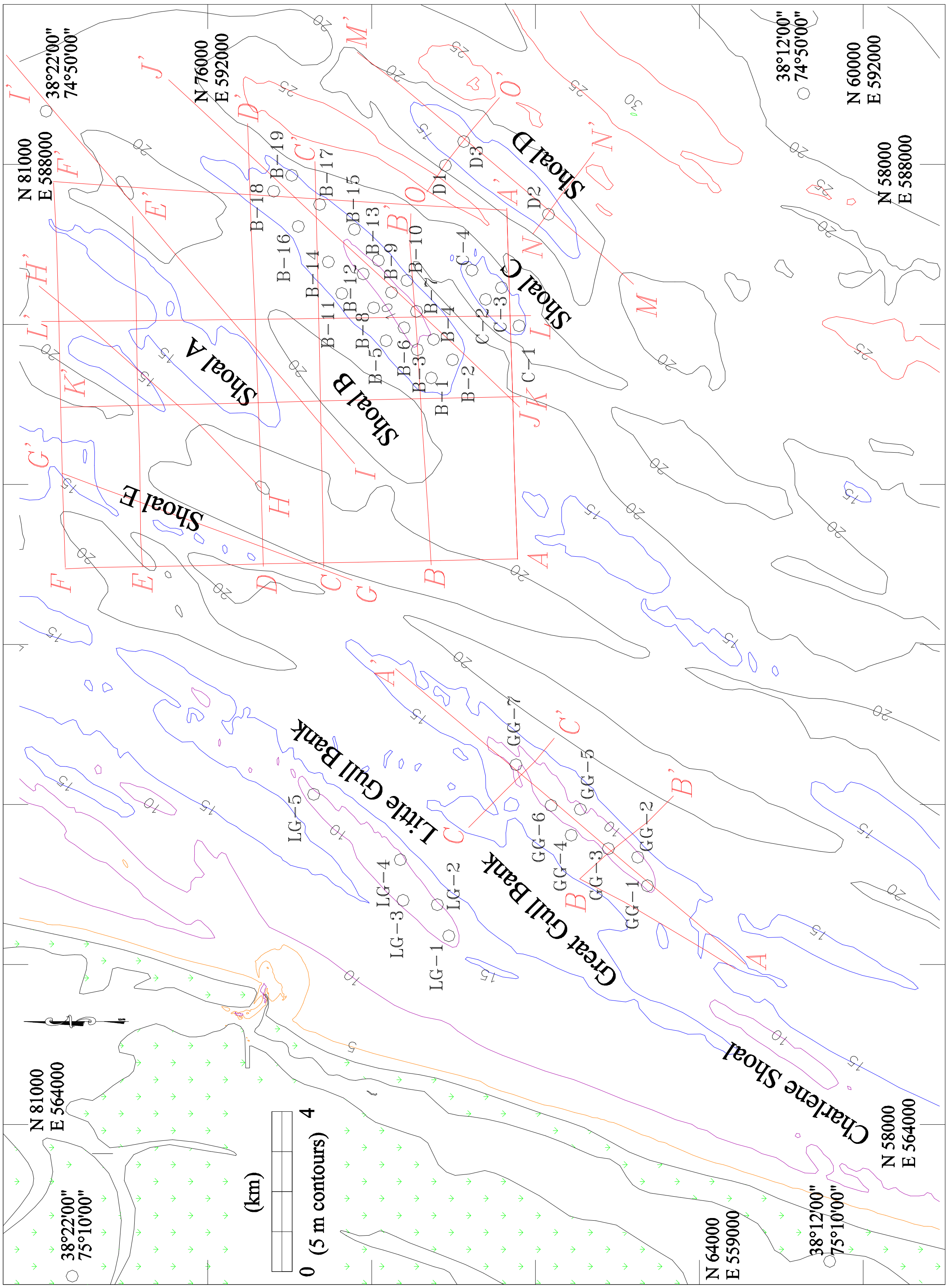


Figure 2

Table 1 summarizes vibracore station details. Several cores were taken on the northeast-trending, long axis of each shoal. Cores on the southwest crest, the center, and the northeast tail provide axial trend information. Cores from the west and east flanks provide cross-sectional data. We hoped to penetrate the lower boundary of the shoals on at least one flank.

Vibracoring was contracted to Ocean Surveys, Inc. of Old Saybrook, CT. Ocean Surveys provided a 34 m vessel for the work. A custom drill rig, the OSI Model 1500, was outfitted to take 6 m by 9.2 cm cellulose butyrate-lined vibracores. The rig was fitted with a penetrometer and a high pressure water pump for jet retries. When the penetrometer indicated penetration refusal of less than 0.3 m in two minutes, the choice to retry in the same location would be made. During repenetration, the incomplete core is withdrawn and saved, and the corer is replaced on-station. The core barrel is jetted down to the depth of refusal, and vibracoring is continued for another 6 m, or until another refusal is encountered. Upon retrieval, the 6 m cores were cut into 1.5 m sections and labeled for transportation to the laboratory.

TABLE 1
Vibracore Locations

Core ID	easting	northing	latitude	longitude	depth	core length
B-1	582663.60	70543.74	38 17' 00.00"	74 54' 43.50"	-13.08	3.96
B-2	583117.76	70025.58	38 16' 42.92"	74 54' 25.31"	-11.95	4.27
B-3	583367.70	70886.96	38 17' 10.67"	74 54' 14.21"	-10.03	4.36
B-4	583624.96	70488.89	38 16' 57.57"	74 54' 04.01"	-10.15	4.57
B-5	583590.82	71647.44	38 17' 35.16"	74 54' 04.31"	-13.47	2.13
B-6	583916.66	71207.92	38 17' 20.66"	74 53' 51.33"	-10.64	3.44
B-7	584326.02	70904.34	38 17' 10.52"	74 53' 34.77"	-9.20	3.51
B-8	584416.24	71949.20	38 17' 44.33"	74 53' 30.07"	-12.22	2.90
B-9	584800.30	71517.30	38 17' 30.03	74 53' 14.68"	-8.69	3.35
B-10	585096.57	71139.66	38 17' 17.57"	74 53' 02.85"	-13.11	4.88
B-11	584772.56	72729.50	38 18' 09.36"	74 53' 14.67"	-13.90	4.24
B-12	585265.43	72207.99	38 17' 52.08"	74 52' 54.89"	-10.00	2.13
B-13	585601.63	71836.14	38 17' 39.77"	74 52' 41.41"	-10.70	3.17
B-14	585563.84	73059.00	38 18' 19.45"	74 52' 41.79"	-12.71	4.54
B-15	586378.28	72422.28	38 17' 58.19"	74 52' 08.89"	-12.28	4.27
B-16	586451.44	73791.76	38 18' 42.53"	74 52' 04.57"	-12.65	4.48
B-17	587000.40	73269.33	38 18' 25.18"	74 51' 42.48"	-12.28	4.42
B-18	587328.37	74391.93	38 19' 01.33"	74 51' 27.90"	-12.92	4.20
B-19	587727.67	73951.80	38 18' 46.75"	74 51' 11.90"	-13.50	4.69
C-1	583966.95	68402.52	38 15' 49.67"	74 53' 51.92"	-12.22	3.72
C-2	584625.03	69217.87	38 16' 15.61"	74 53' 24.08"	-12.56	4.33
C-3	584919.47	68827.73	38 16' 02.74"	74 53' 12.34"	-12.74	3.84
C-4	585356.26	69552.86	38 16' 25.92"	74 52' 53.68"	-14.14	5.45
D1	587976.08	70199.98	38 16' 44.91"	74 51' 05.31"	-18.17	5.54
D2	586754.41	67685.65	38 15' 24.33"	74 51' 57.98"	-11.55	3.52
D3	588573.50	69753.76	38 16' 29.99"	74 50' 41.17"	-12.35	3.76
GG-1	569969.94	65267.85	38 14' 18.08"	75 03' 30.29"	-7.22	3.69
GG-2	570681.96	65503.15	38 14' 48.49"	75 03' 00.18"	-8.35	4.48
GG-3	570894.41	66220.96	38 14' 48.35"	75 02' 51.45"	-8.23	4.18
GG-4	571230.30	67129.87	38 15' 17.58"	75 02' 36.84"	-12.10	3.47
GG-5	571879.23	66904.62	38 15' 09.83"	75 02' 10.35"	-9.14	4.57
GG-6	571974.94	67617.86	38 15' 32.89"	75 02' 05.78"	-7.86	3.44
GG-7	572995.74	68476.49	38 16' 00.01"	75 01' 23.04"	-9.27	4.33
LG-1	568716.58	70117.86	38 16' 56.20"	75 04' 17.60"	-6.22	6.10
LG-2	569496.28	70399.19	38 17' 04.79"	75 03' 45.29"	-8.05	4.24
LG-3	569602.05	71233.74	38 17' 31.78"	75 03' 40.20"	-8.32	1.83
LG-4	570617.96	71302.02	38 17' 33.29"	75 02' 58.35"	-8.32	4.11
LG-5	572254.16	73416.12	38 18' 40.70"	75 01' 49.16"	-8.26	4.11

Core Processing

Core segments were opened by cutting the plastic liners along their length. An electro-osmotic knife (Strum and Matter, 1972) was used to split muddy cores lengthwise. This tool slices the sediment without smearing internal structures, thus providing a clear cross-section for photography. Sandy cores did not require electro-osmotic cutting. The cores were photographed and logged for sedimentary and biogenic structures, texture, color, approximate grain size and other features. Sediment, biologic, and age dating samples were removed for further analysis, and the remaining materials were sealed and archived for future work.

Textural Analysis

Grain size was analyzed by two laboratories. Sediments from Shoals B, C and Great Gull and Little Gull Banks were analyzed by the U.S. Army Corps of Engineers, Baltimore District, Soils Lab, according to their standard methodology (U.S. Army Corps of Engineers, 1984). Samples from Shoal D were analyzed by Maryland Geological Survey. The Army Corps uses wet sieve techniques, while the Survey employs a rapid sediment analyzer. Although the data obtained from these differing techniques are not directly comparable, they both produce valid and reasonably accurate grain size distribution estimates.

Maryland Geological Survey's textural analysis procedure is detailed in Kerhin and others (1988). Sediment samples were first treated with 10% solution of hydrochloric acid to remove carbonate material such as shells and then treated with a 6 or 15% solution of hydrogen peroxide to remove organic material. The samples were then passed through a 63-micron mesh sieve, followed by a 2-mm sieve, separating sands from mud and gravel fractions. Mud fractions were analyzed using a pipette technique to determine silt and clay contents. Weights of the sand, silt and clay fractions were converted to weight percentages. Sediments were categorized according to Shepard's (1954) classification based on percent sand, silt and clay components.

Sand fractions were analyzed using a rapid sediment analyzer (RSA) (Halka and others, 1980). The RSA technique measured cumulative weight in ¼ f (phi) intervals. Data were normalized to a 100% sand distribution, and the method of Folk and Ward (1957) was used to report graphic mean and sorting. When mud contents were less than 5%, grain size analyses were conducted only on the sand fraction. Pipette analyses were used to determine silt and clay content in samples with greater than 5% mud.

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 into a three-dimensional, digital model. We used a Calcomp 9800, large format digitizer to enter the seismic data into *AutoCAD 13*. A program was developed for *AutoCAD* that calculates the three coordinates 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 subsurface horizon. The TIN surfaces derived from these data are then used to calculate area, 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 meters below their surfaces, few subsurface data points under the shoals were obtained. The 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 on reflector surfaces under ridges. Predicting the net effect of this phenomenon on seismic reflectors is difficult. Although the pull-up effect causes inaccuracies in portions of the surface models, it is limited to a tolerance of approximately a meter 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 Calculations

Volumetric determinations were carried out by *Civil/Survey*. 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 defined as the bathymetric surface, derived from the bathymetric model. The lower bounding surface is determined from core and seismic data. Shoal edges are defined by either pinch-out of shoal sediments, or a 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).

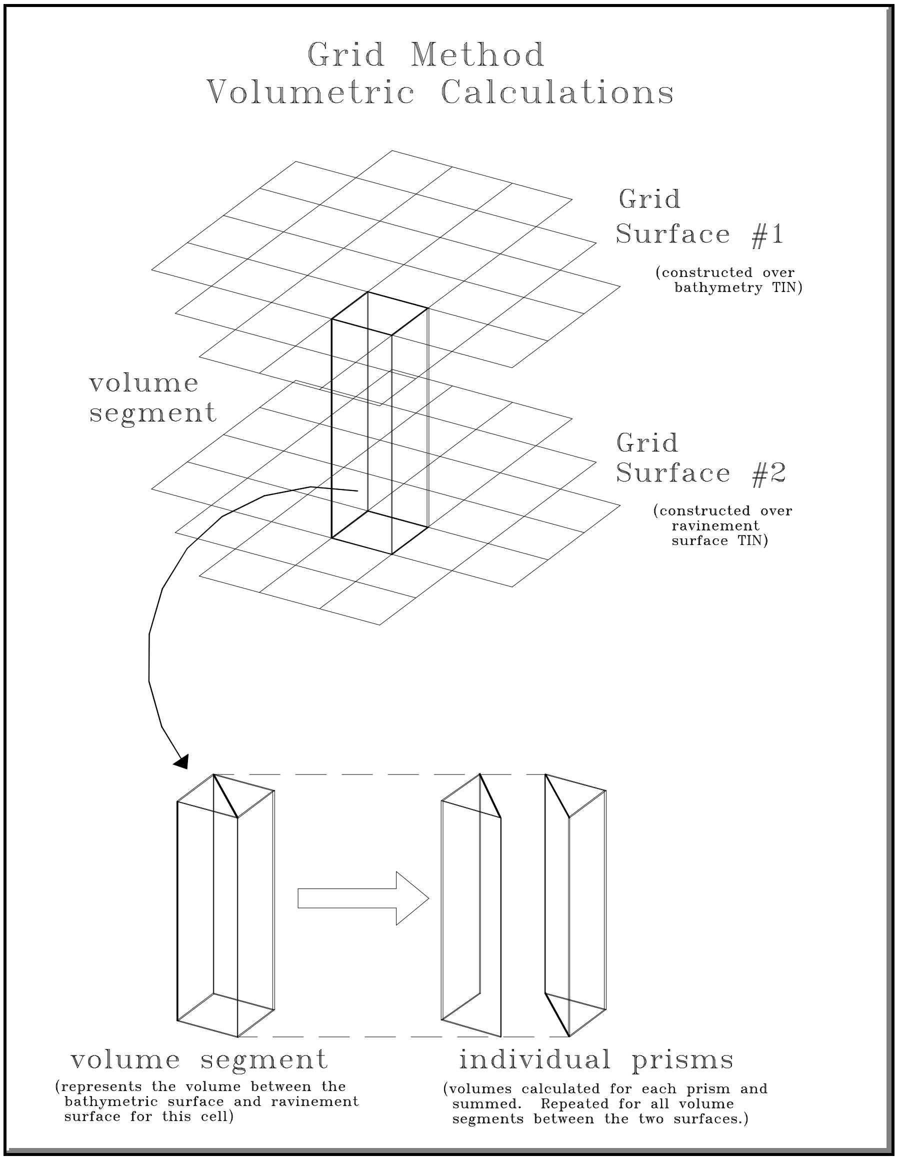


Figure 4

RESULTS

Shoal Field Structure

Shoal Field II includes Great Gull Bank, Little Gull Bank and five unnamed shoals, designated alphabetically A through E. A bathymetric map of Shoal Field II shows features typical of a linear shoal field (Figure 4). Depths range from a maximum of -4.8 m on the crest of Little Gull Bank to a minimum of -30 m in a trough in the northeast corner of the field. The mean depth of the shoal field is -18 m. 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 usually less than 15 meters;
< flank slopes between 0.2E and 7.0E;
< seaward flanks are steeper than landward flanks.

The bathymetric map (Figure 4) shows the variations in form of these shoals. Shoals A and E are narrow in the southwest and spread out to the northeast. Shoals B and C appear broad and blunt.

Shoal Field II Bathymetry

Figure 4

Shoal C has the smallest surface area. Shoal D has an arcuate crest that abruptly bends to the west at the proximal end. Great Gull Bank also displays this arcuate crest. A summary of shoal geometry is presented in Table 2. Based on these parameters, all shoals in Shoal Field II fit the McBride/Moslow model for ebb tidal inlet shoal origins.

PHYSICAL PARAMETERS

Parameter	Shoal B	Shoal C	Shoal D	Little Gull Bank	Great Gull Bank
area (million $meter^2$)	11.5	1.9	6.6	7.6	7.3
axis (E from north)	49	45	43	47	41
base length (km)	7.5	2.4	5.8	6.8	6.0
maximum width(km)	2.0	1.0	1.4	1.4	1.5
minimum depth (m)	-8.2	-10.1	-11.0	-4.8	-5.2
base depth (m)	-18.3	-18.3	-18.3	-13.0	-15.2

TABLE 2

Subsurface details of Shoal Field II have been previously described by Conkwright and Gast (1994). The shoal bodies exhibit little internal structure. While this is in part due to the acoustic opacity of these sand bodies, it is also an indication of the massive, homogeneous structure characteristic of linear sand shoals. These internal reflectors suggest changes in sediment density. Inter-shoal areas show buried channels and bedding features.

Shoal Field II is underlain by a basal reflector. In the west, under Little and Great Gull Banks, the reflector has a mean depth of -15.5 m and slopes upward toward the southwest. In the center of the shoal field the reflector has relatively flat relief, varying from -20 m to -22 m, with a mean depth of -21 m. The reflector is truncated to the west of Shoal E to the east of Shoal C and by troughs with depths exceeding -21 m. It reemerges east of Shoal C and is seen under Shoal D, but is indistinct and not entirely mappable there. A 30 m deep trough to the east of Shoal D truncates the reflector. This seismic reflector represents the surface upon which the linear shoals have developed.

Toscano and others (1989) described this basal reflector as evidence of a time-transgressive ravinement surface. The ravinement surface developed as a result of 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 to form 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 prevent the appearance of an acoustically significant reflector. Sometimes, the seismic signature is masked by the closeness of the ravinement surface to the ocean floor.

In the 1993 sand resources study (Conkwright and Gast, 1994b) the seismically defined ravinement surface was used as the lower structural boundary for volume calculations. However, the purpose of the current study is to estimate only the volume of sand with measured physical parameters. Therefore, the lower boundary for volumetric calculations was determined primarily by the grain size parameters of vibracore samples. The lower boundary surface was set at the depth where the sampled sand became too fine or too poorly sorted for use as beach fill. In those cases where the entire length of core contained usable sand, the boundary surface was set at the depth of maximum vibracore penetration. Because vibracore penetrations on Little and Great Gull Banks were generally within a meter of the ravinement surface, that surface was used as the lower boundary for those shoals, unless vibracore samples indicated otherwise.

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 to dredging sand from deposits less than 1 meter thick is impractical, we delimited 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 occurs where shoal faces truncate the ravinement surface. The truncation of the basal reflectors at the edges of the shoals marks the boundary of shoal sediments.

SAND RESOURCE POTENTIAL OF SHOAL FIELD II

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 24 km radius from the point of use are most desirable. Water depths of less than 15 m are also advantageous for dredging technologies.

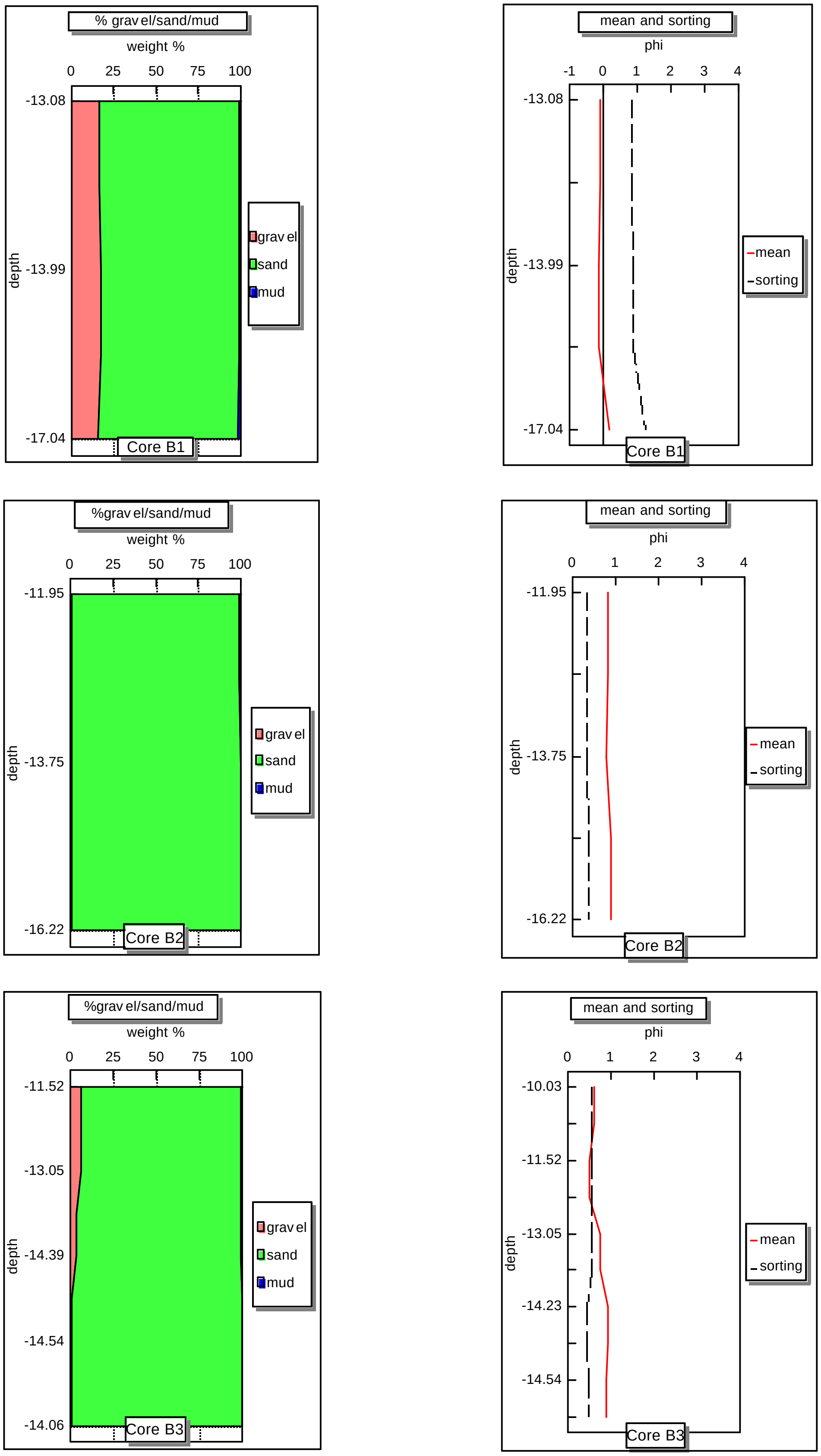
Potential beach fill material should exhibit textural parameters similar to the native sands they are intended to replenish. The Shore Protection Manual (U.S. Army Corps, 1984) describes methodologies to determine acceptable beach fill textural parameters for any particular site. An important consideration 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 an 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 indicate 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.

Native Ocean City beach sands have a composite graphic mean diameter of 1.84 f and a sorting of 1.22 f (Anders and others, 1987; Anders and Hansen, 1990). Sands native to northern Assateague Island have a composite graphic mean diameter of 1.76 f (U.S. Army Corps of Engineers, 1996). Sediments that are finer or more poorly sorted than native sands will have increasingly higher overfill factors. Therefore, sand suitable for beach fill should have a mean grain size coarser than 1.84 f (medium sand) and have a sorting value less than 1.22 f (moderately sorted). To be classified as high potential sand resources, deposits must exceed these grain size parameters. Sands that fall between 1.88 and 2.0 f mean diameter and/or with less a sorting of greater than 1.22 f are classified as having a moderate potential. Deposits below -15 m are also considered to have a moderate potential. Sediments with mean diameters less than 2 f are considered low potential.

None of the vibracores taken at the shoal crests penetrated the entire shoal bodies. Significant sand deposits may exist below the maximum vibracore penetration depths, but no attempt was made to include these hypothetical sands in volume calculations. Only sediments that were analyzed were included in this study. A sampling project that used a 12 m vibracore would penetrate these shoals and provide an accurate estimate of sand resources in Shoal Field II.

Sediment quality

Figures 5 to 19 compare vibracore samples' mean diameter to depth. The data are summarized in Appendix A. Interpretation of sediment quality in Shoal Field II 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. Thus the seismic record when compared to sediment samples can assist in determining sediment types.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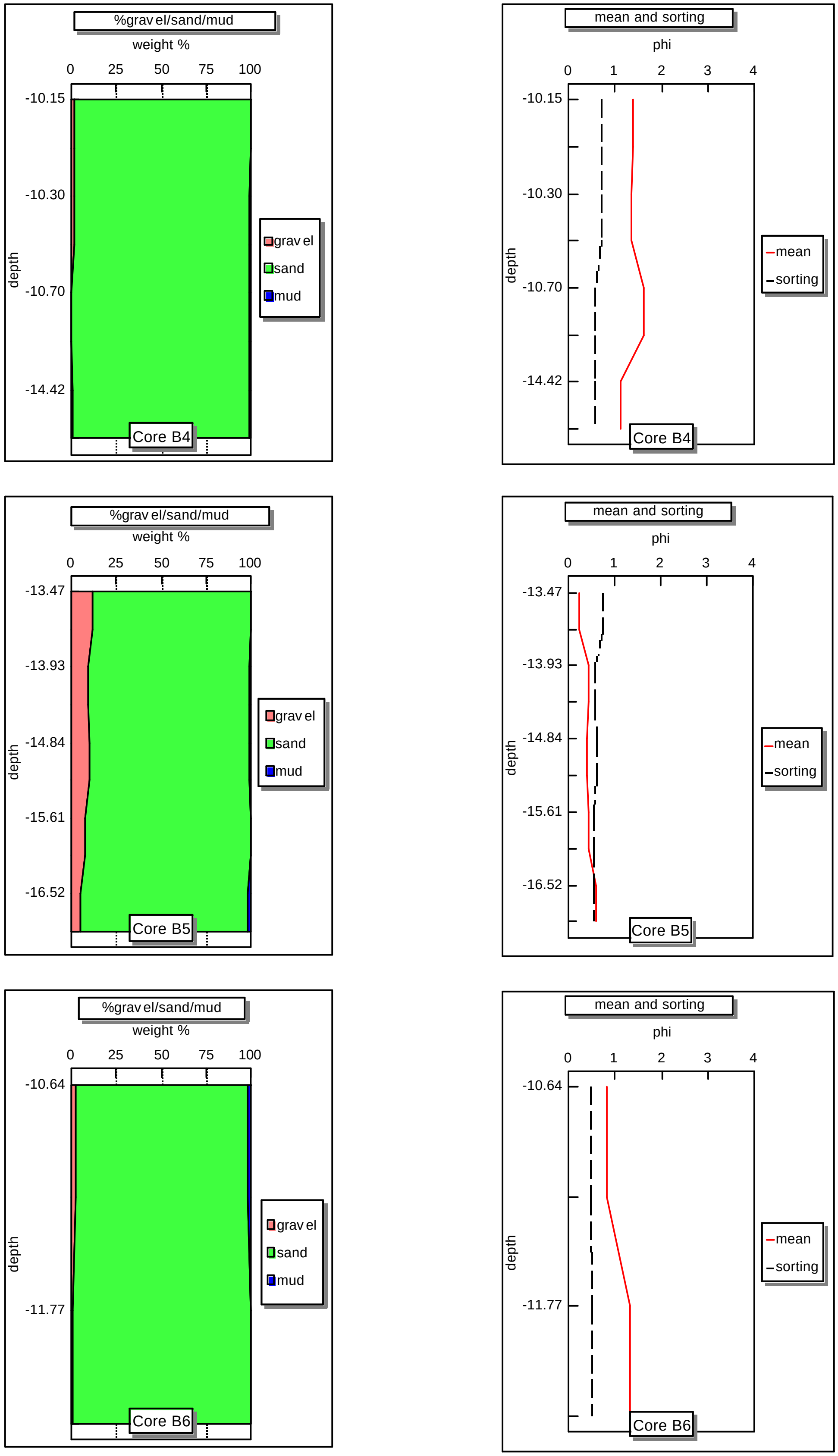
weight %
0
25
50
75
100
-13.08
-13.99
-17.04
depth
grav el
sand
mud
Core B1
mean and sorting
phi
-1
0
1
2
3
4
-13.08
-13.99
-17.04
depth
mean
sorting
Core B1
%grav el/sand/mud
weight %
0
25
50
75
100
-11.95
-13.75
-16.22
depth
grav el
sand
mud
Core B2
mean and sorting
phi
0
1
2
3
4
-11.95
-13.75
-16.22
depth
mean
sorting
Core B2
%grav el/sand/mud
weight %
0
25
50
75
100
-11.52
-13.05
-14.39
-14.54
-14.06
depth
grav el
sand
mud
Core B3
mean and sorting
phi
0
1
2
3
4
-10.03
-11.52
-13.05
-14.23
-14.54
depth
mean
sorting
Core B3

Figure 5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weight %
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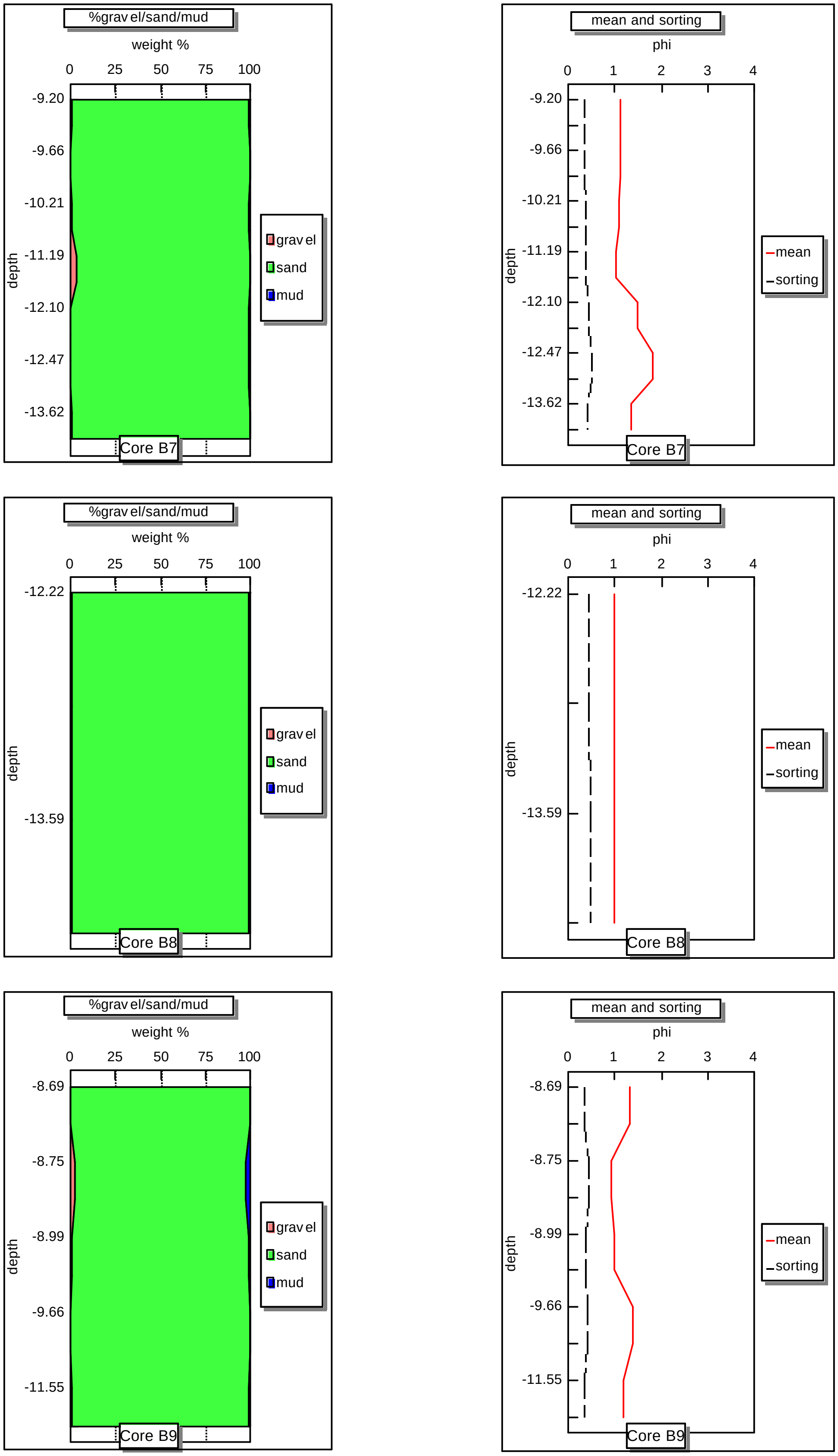
-10.30
-10.70
-14.42
depth
grav el
sand
mud
Core B4
mean and sorting
phi
0 1 2 3 4
-10.15
-10.30
-10.70
-14.42
depth
mean
sorting
Core B4
%grav el/sand/mud
weight %
0 25 50 75 100
-13.47
-13.93
-14.84
-15.61
-16.52
depth
grav el
sand
mud
Core B5
mean and sorting
phi
0 1 2 3 4
-13.47
-13.93
-14.84
-15.61
-16.52
depth
mean
sorting
Core B5
%grav el/sand/mud
weight %
0 25 50 75 100
-10.64
-11.77
depth
grav el
sand
mud
Core B6
mean and sorting
phi
0 1 2 3 4
-10.64
-11.77
depth
mean
sorting
Core B6

Figure 6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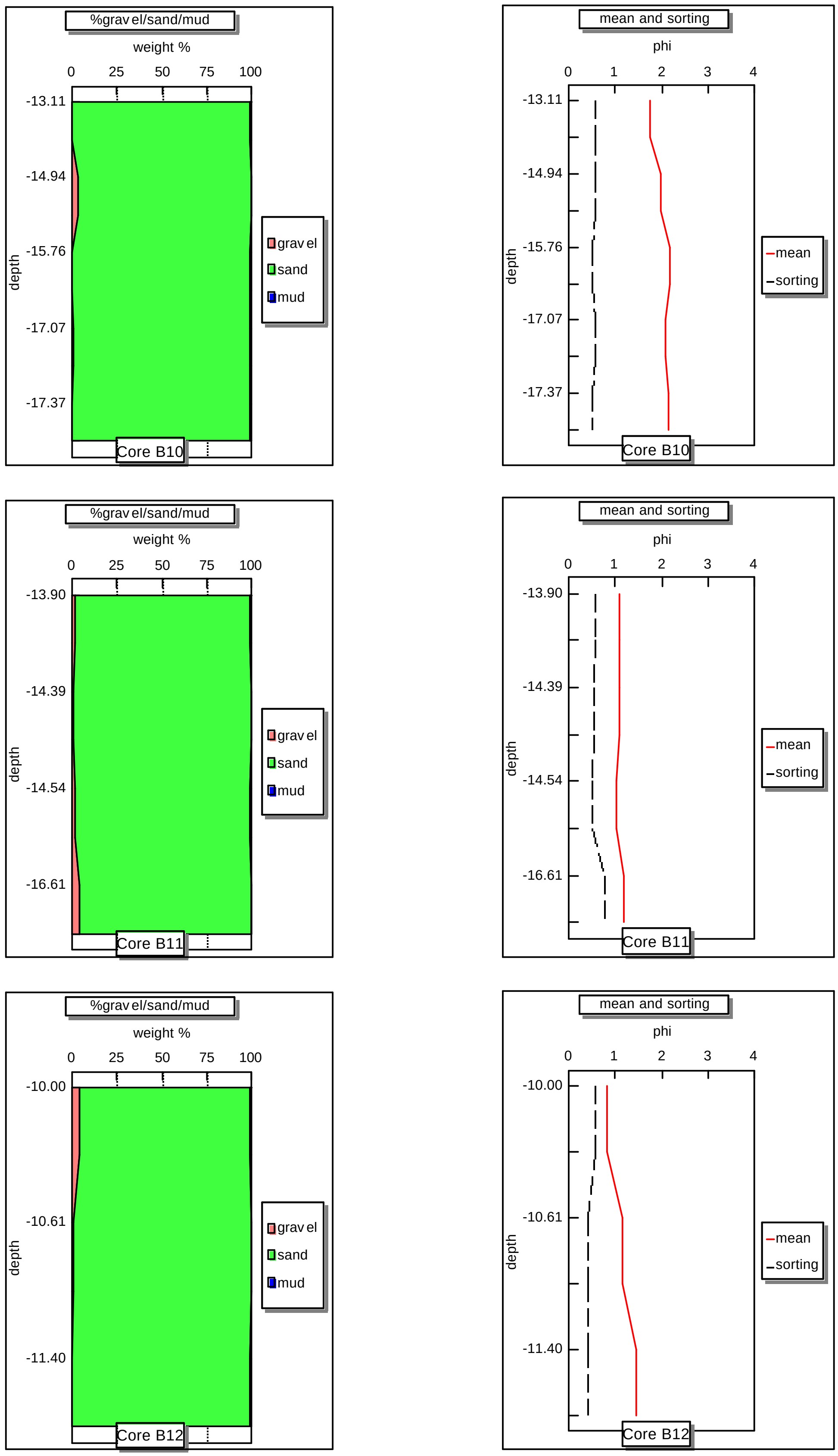
weight %
0
25
50
75
100
-9.20
-9.66
-10.21
-11.19
-12.10
-12.47
-13.62
depth
gravel
sand
mud
Core B7
mean and sorting
phi
0
1
2
3
4
-9.20
-9.66
-10.21
-11.19
-12.10
-12.47
-13.62
depth
mean
sorting
Core B7
%gravel/sand/mud
weight %
0
25
50
75
100
-12.22
-13.59
depth
gravel
sand
mud
Core B8
mean and sorting
phi
0
1
2
3
4
-12.22
-13.59
depth
mean
sorting
Core B8
%gravel/sand/mud
weight %
0
25
50
75
100
-8.69
-8.75
-8.99
-9.66
-11.55
depth
gravel
sand
mud
Core B9
mean and sorting
phi
0
1
2
3
4
-8.69
-8.75
-8.99
-9.66
-11.55
depth
mean
sorting
Core B9

Figure 7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weight %
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25
50
75
100
-13.11
-14.94
-15.76
-17.07
-17.37
depth
grav el
sand
mud
Core B10
mean and sorting
phi
0
1
2
3
4
-13.11
-14.94
-15.76
-17.07
-17.37
depth
mean
sorting
Core B10
%grav el/sand/mud
weight %
-13.90
-14.39
-14.54
-16.61
Core B11
mean and sorting
phi
-13.90
-14.39
-14.54
-16.61
Core B11
%grav el/sand/mud
weight %
-10.00
-10.61
-11.40
Core B12
mean and sorting
phi
-10.00
-10.61
-11.40
Core B12

Figure 8

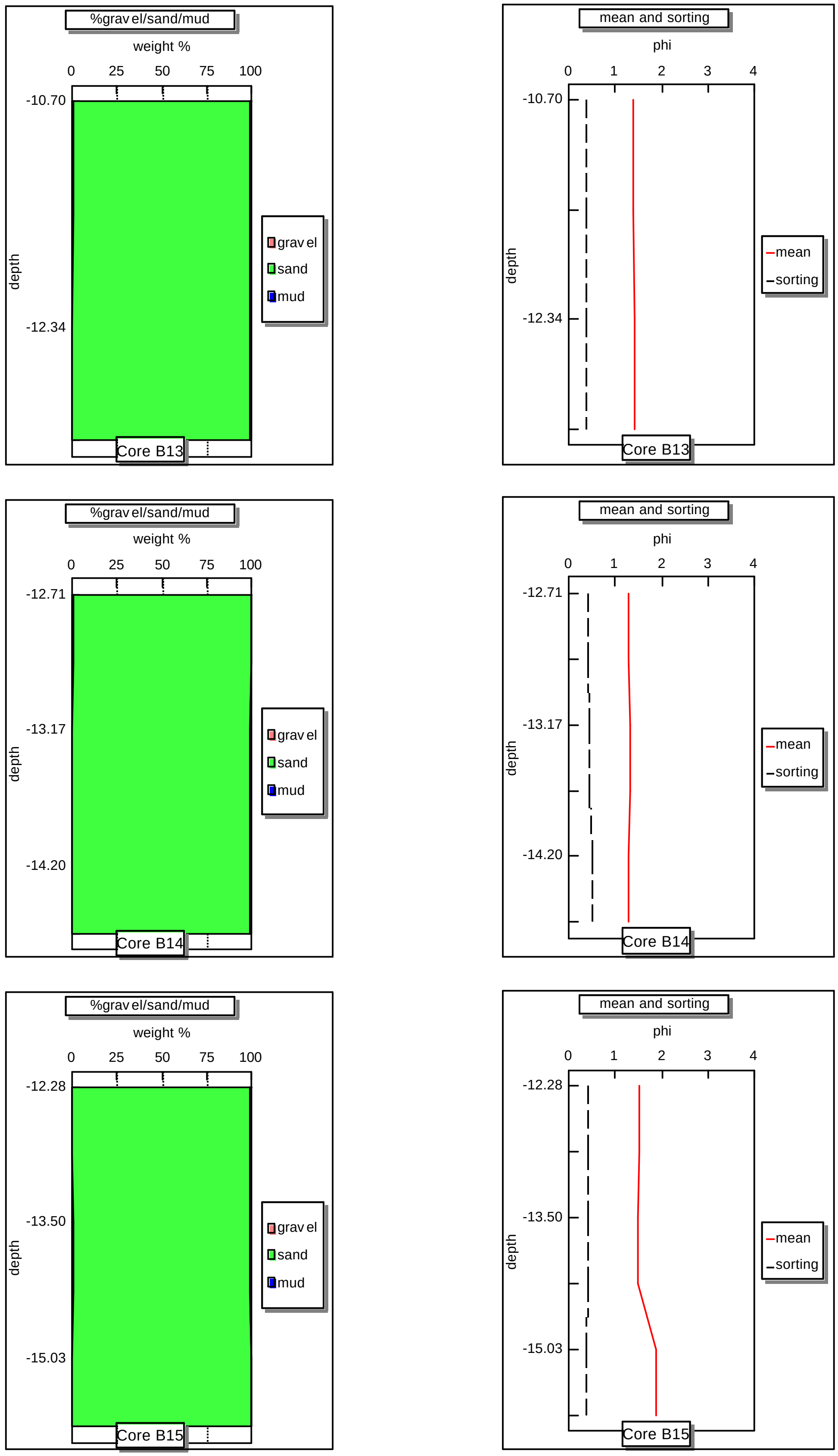
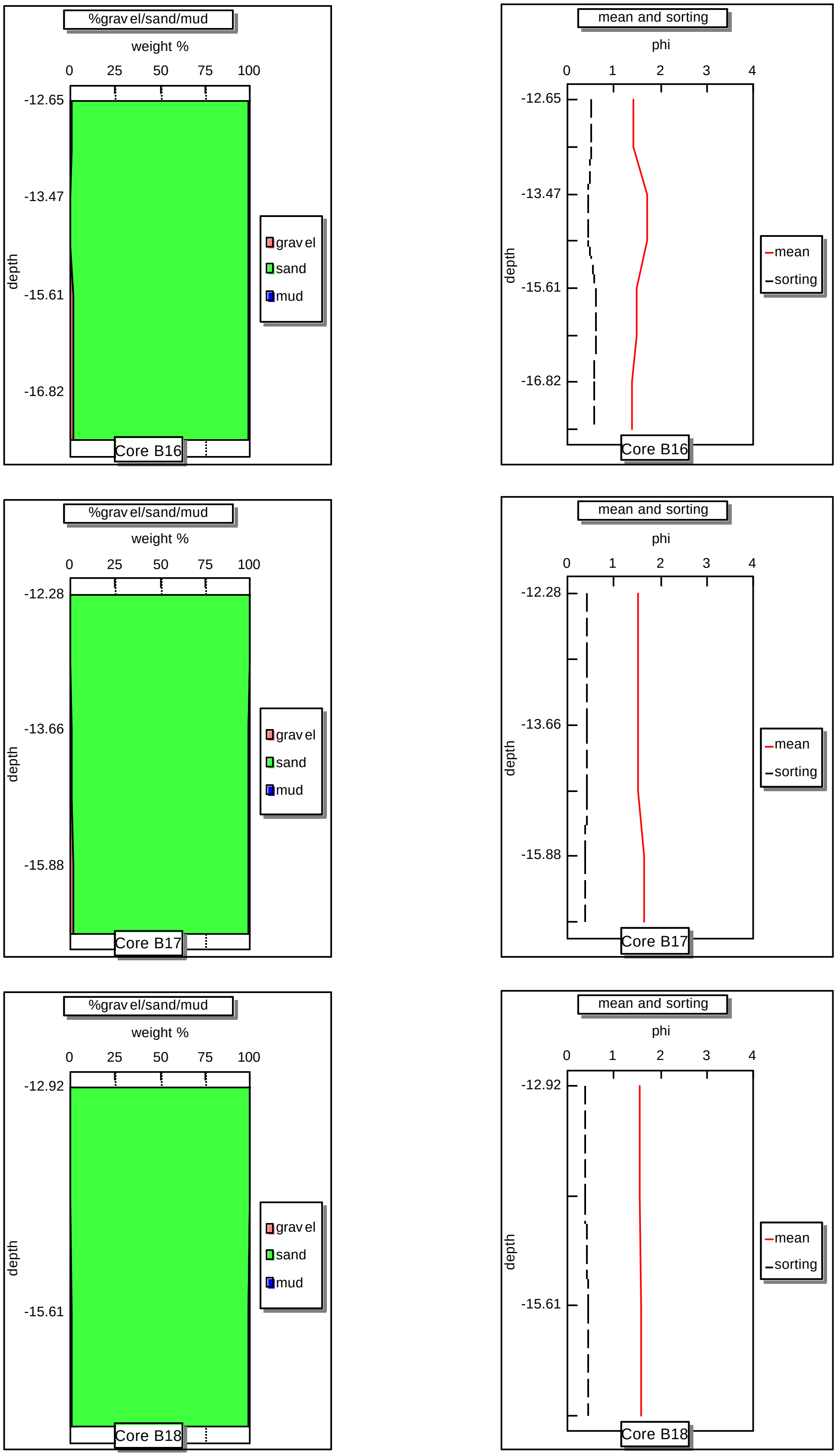
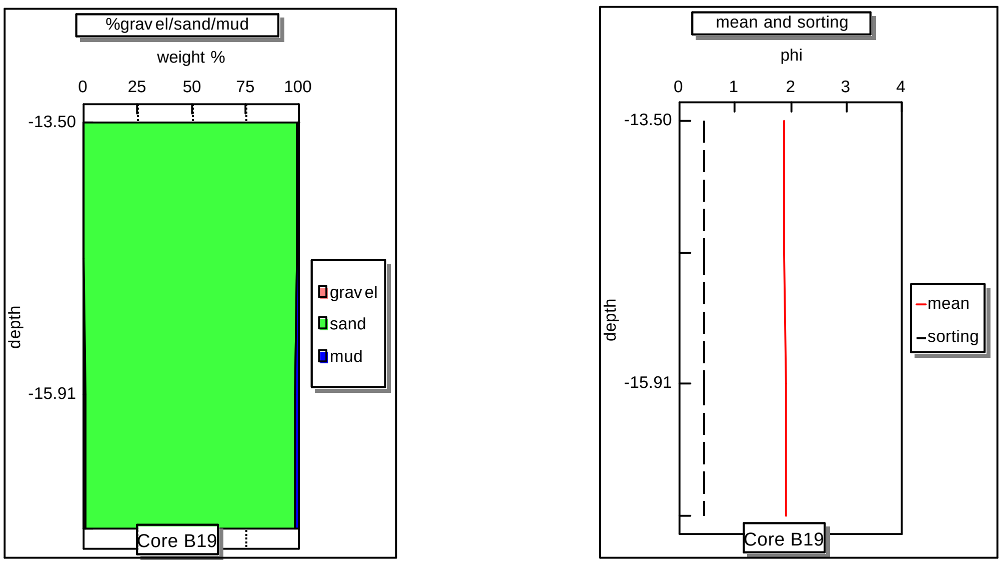

%grav el/sand/mud
weight %
0 25 50 75 100
-10.70
-12.34
depth
grav el
sand
mud
Core B13
mean and sorting
phi
0 1 2 3 4
-10.70
-12.34
depth
mean
sorting
Core B13
%grav el/sand/mud
weight %
0 25 50 75 100
-12.71
-13.17
-14.20
depth
grav el
sand
mud
Core B14
mean and sorting
phi
0 1 2 3 4
-12.71
-13.17
-14.20
depth
mean
sorting
Core B14
%grav el/sand/mud
weight %
0 25 50 75 100
-12.28
-13.50
-15.03
depth
grav el
sand
mud
Core B15
mean and sorting
phi
0 1 2 3 4
-12.28
-13.50
-15.03
depth
mean
sorting
Core B15

Figure 9


%gravel/sand/mud
weight %
0 25 50 75 100
-12.65
-13.47
-15.61
-16.82
depth
gravel
sand
mud
Core B16
mean and sorting
phi
0 1 2 3 4
-12.65
-13.47
-15.61
-16.82
depth
mean
sorting
Core B16
%gravel/sand/mud
weight %
0 25 50 75 100
-12.28
-13.66
-15.88
depth
gravel
sand
mud
Core B17
mean and sorting
phi
0 1 2 3 4
-12.28
-13.66
-15.88
depth
mean
sorting
Core B17
%gravel/sand/mud
weight %
0 25 50 75 100
-12.92
-15.61
depth
gravel
sand
mud
Core B18
mean and sorting
phi
0 1 2 3 4
-12.92
-15.61
depth
mean
sorting
Core B18

Fio}re 10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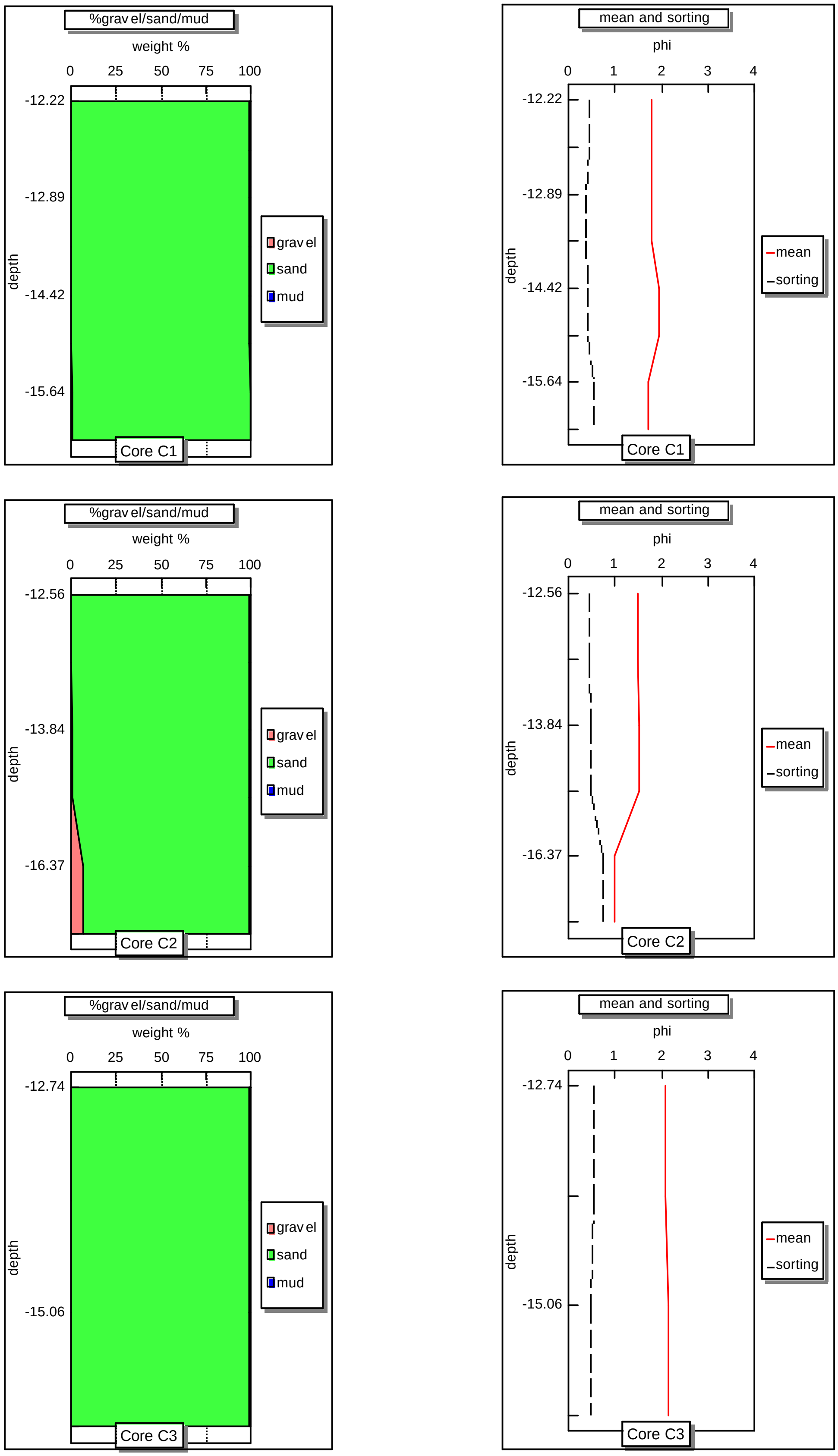
weight %
0
25
50
75
100
-13.50
-15.91
depth
grav el
sand
mud
Core B19
mean and sorting
phi
0
1
2
3
4
-13.50
-15.91
depth
mean
sorting
Core B19

Figure 11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weight %
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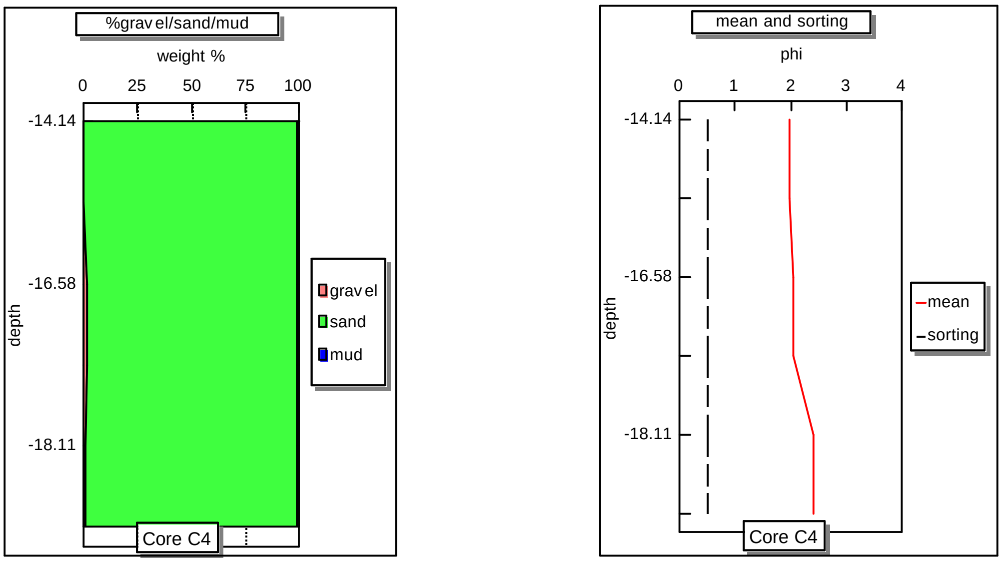
-12.89
-14.42
-15.64
depth
grav el
sand
mud
Core C1
mean and sorting
phi
0 1 2 3 4
-12.22
-12.89
-14.42
-15.64
depth
mean
sorting
Core C1
%grav el/sand/mud
weight %
0 25 50 75 100
-12.56
-13.84
-16.37
depth
grav el
sand
mud
Core C2
mean and sorting
phi
0 1 2 3 4
-12.56
-13.84
-16.37
depth
mean
sorting
Core C2
%grav el/sand/mud
weight %
0 25 50 75 100
-12.74
-15.06
depth
grav el
sand
mud
Core C3
mean and sorting
phi
0 1 2 3 4
-12.74
-15.06
depth
mean
sorting
Core C3

Figure 12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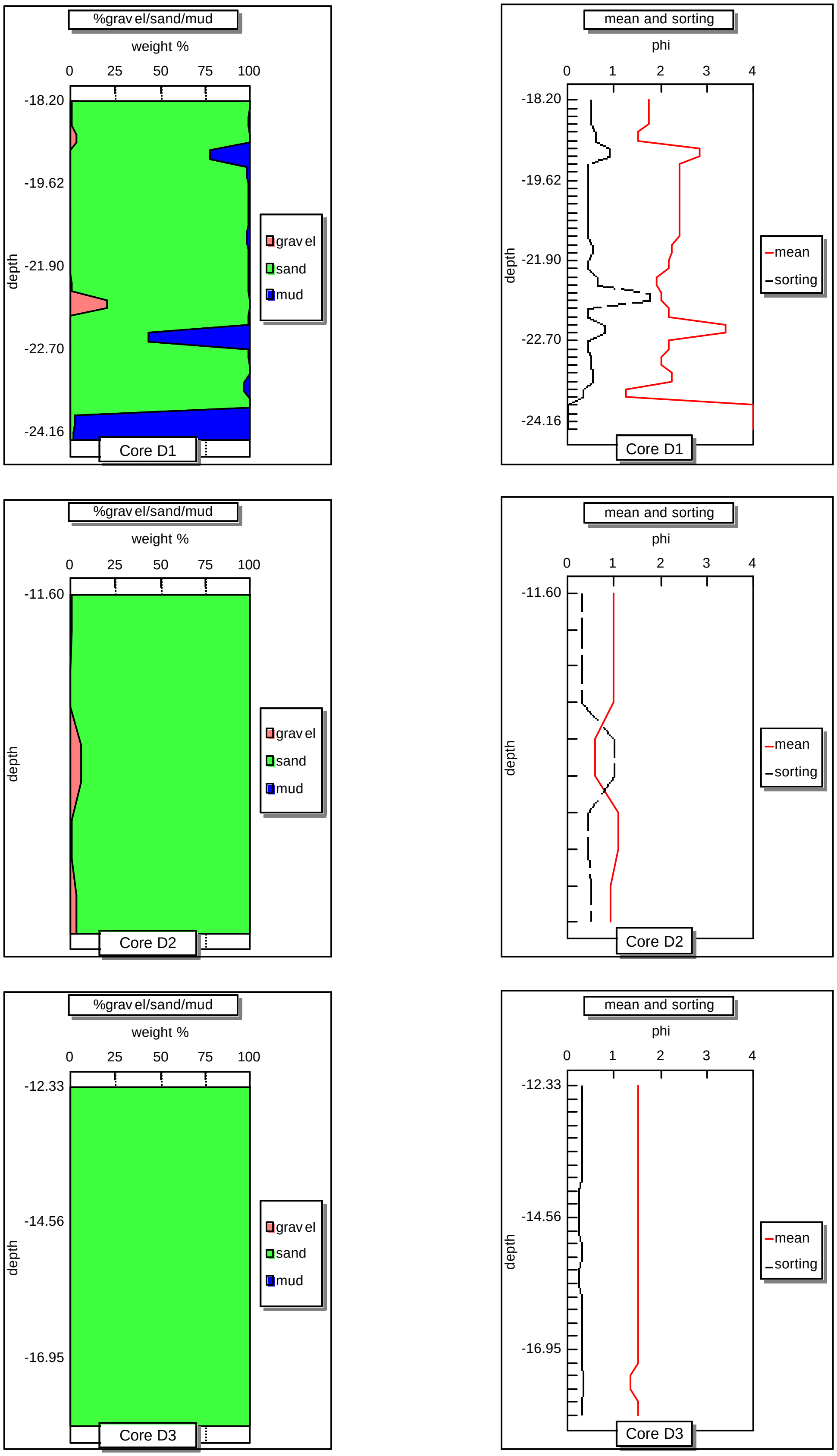
weight %
0
25
50
75
100
-14.14
-16.58
-18.11
depth
gravel
sand
mud
Core C4
mean and sorting
phi
0
1
2
3
4
-14.14
-16.58
-18.11
depth
mean
sorting
Core C4

Figure 13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weight %
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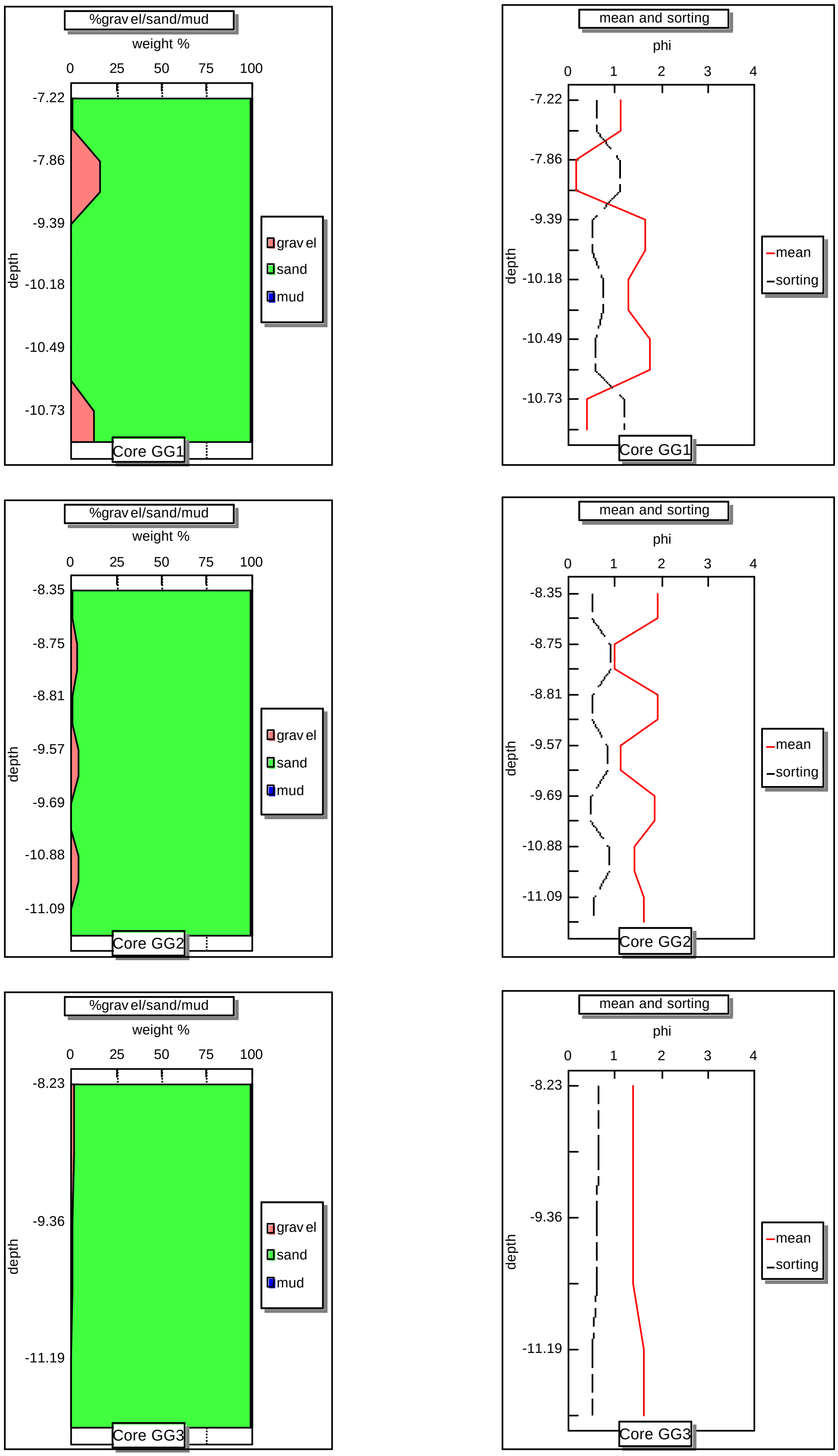
-19.62
-21.90
-22.70
-24.16
depth
grav el
sand
mud
Core D1
mean and sorting
phi
0 1 2 3 4
-18.20
-19.62
-21.90
-22.70
-24.16
depth
mean
sorting
Core D1
%grav el/sand/mud
weight %
0 25 50 75 100
-11.60
depth
grav el
sand
mud
Core D2
mean and sorting
phi
0 1 2 3 4
-11.60
depth
mean
sorting
Core D2
%grav el/sand/mud
weight %
0 25 50 75 100
-12.33
-14.56
-16.95
depth
grav el
sand
mud
Core D3
mean and sorting
phi
0 1 2 3 4
-12.33
-14.56
-16.95
depth
mean
sorting
Core D3

Figure 14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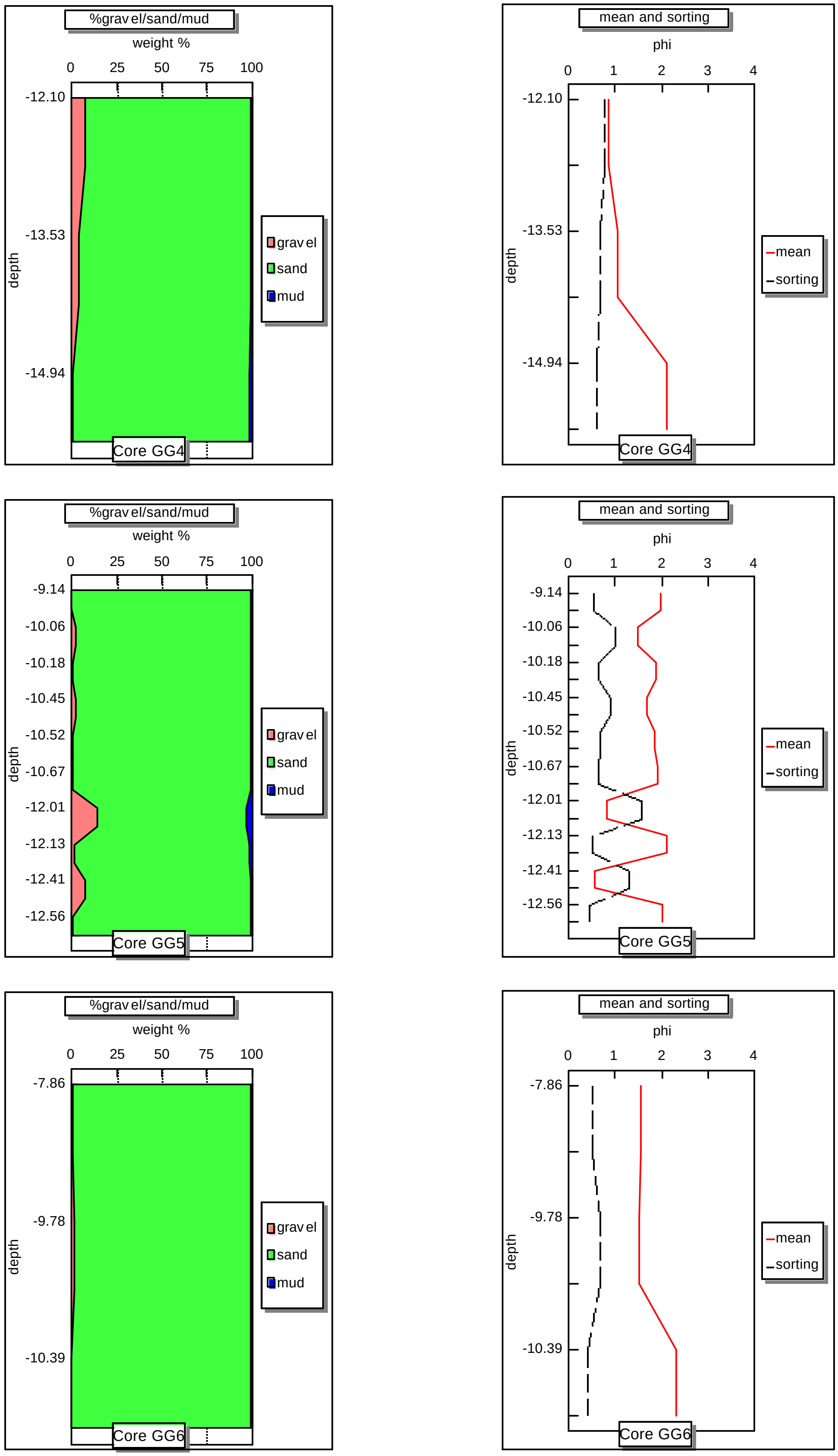
weight %
0
25
50
75
100
-7.22
-7.86
-9.39
-10.18
-10.49
-10.73
depth
grav el
sand
mud
Core GG1
mean and sorting
phi
0
1
2
3
4
-7.22
-7.86
-9.39
-10.18
-10.49
-10.73
depth
mean
sorting
Core GG1
%grav el/sand/mud
weight %
-8.35
-8.75
-8.81
-9.57
-9.69
-10.88
-11.09
Core GG2
mean and sorting
phi
-8.35
-8.75
-8.81
-9.57
-9.69
-10.88
-11.09
Core GG2
%grav el/sand/mud
weight %
-8.23
-9.36
-11.19
Core GG3
mean and sorting
phi
-8.23
-9.36
-11.19
Core GG3

Figure 15


%grav el/sand/mud
weight %
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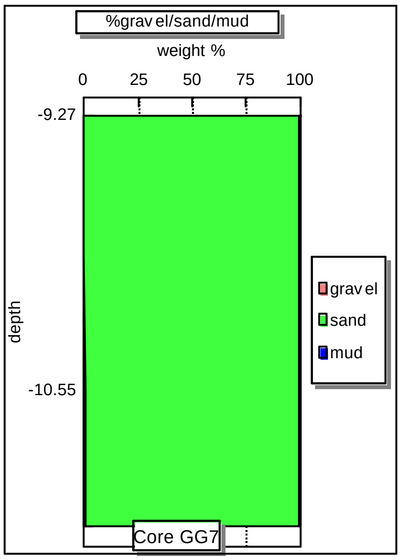
-12.10
-13.53
-14.94
depth
grav el
sand
mud
Core GG4
mean and sorting
phi
0 1 2 3 4
-12.10
-13.53
-14.94
depth
mean
sorting
Core GG4
%grav el/sand/mud
weight %
0 25 50 75 100
-9.14
-10.06
-10.18
-10.45
-10.52
-10.67
-12.01
-12.13
-12.41
-12.56
depth
grav el
sand
mud
Core GG5
mean and sorting
phi
0 1 2 3 4
-9.14
-10.06
-10.18
-10.45
-10.52
-10.67
-12.01
-12.13
-12.41
-12.56
depth
mean
sorting
Core GG5
%grav el/sand/mud
weight %
0 25 50 75 100
-7.86
-9.78
-10.39
depth
grav el
sand
mud
Core GG6
mean and sorting
phi
0 1 2 3 4
-7.86
-9.78
-10.39
depth
mean
sorting
Core GG6

Figure 16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weight %
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25
50
75
100
-9.27
-10.55
depth
grav el
sand
mud
Core GG7

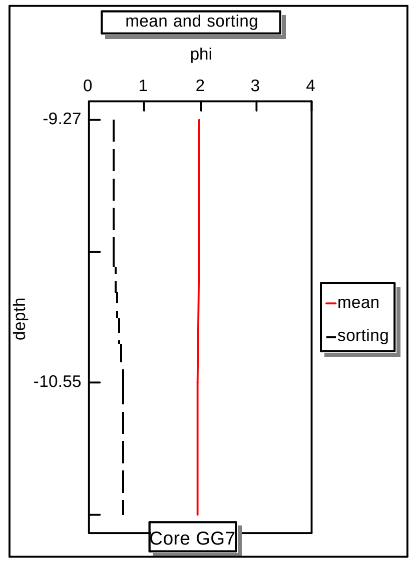
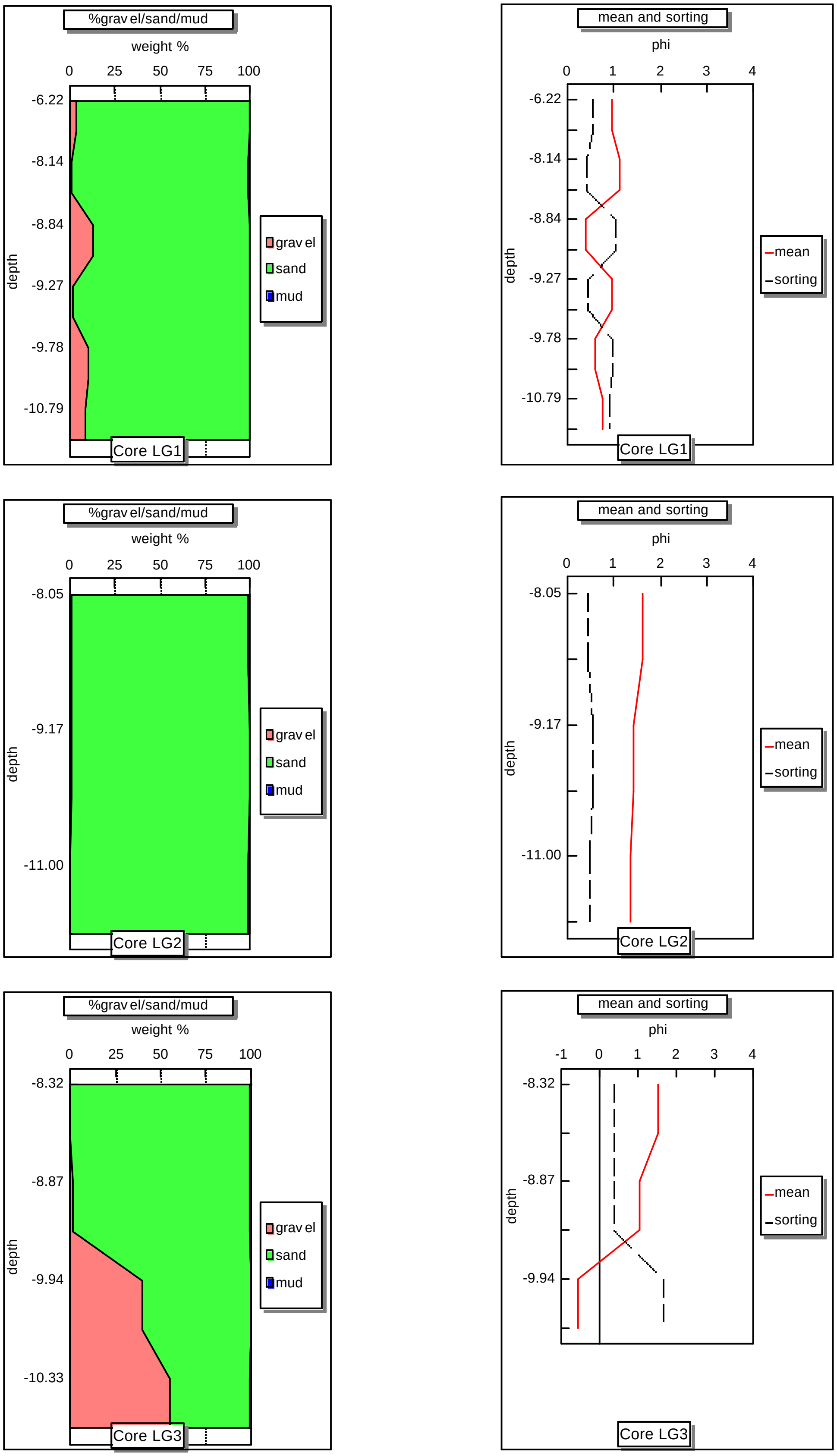

mean and sorting
phi
0
1
2
3
4
-9.27
-10.55
depth
mean
sorting
Core GG7

Figure 17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0
25
50
75
100
-6.22
-8.14
-8.84
-9.27
-9.78
-10.79
depth
grav el
sand
mud
Core LG1
mean and sorting
phi
0
1
2
3
4
-6.22
-8.14
-8.84
-9.27
-9.78
-10.79
depth
mean
sorting
Core LG1
%grav el/sand/mud
weight %
0
25
50
75
100
-8.05
-9.17
-11.00
depth
grav el
sand
mud
Core LG2
mean and sorting
phi
0
1
2
3
4
-8.05
-9.17
-11.00
depth
mean
sorting
Core LG2
%grav el/sand/mud
weight %
0
25
50
75
100
-8.32
-8.87
-9.94
-10.33
depth
grav el
sand
mud
Core LG3
mean and sorting
phi
-1
0
1
2
3
4
-8.32
-8.87
-9.94
depth
mean
sorting
Core LG3

Figure 18

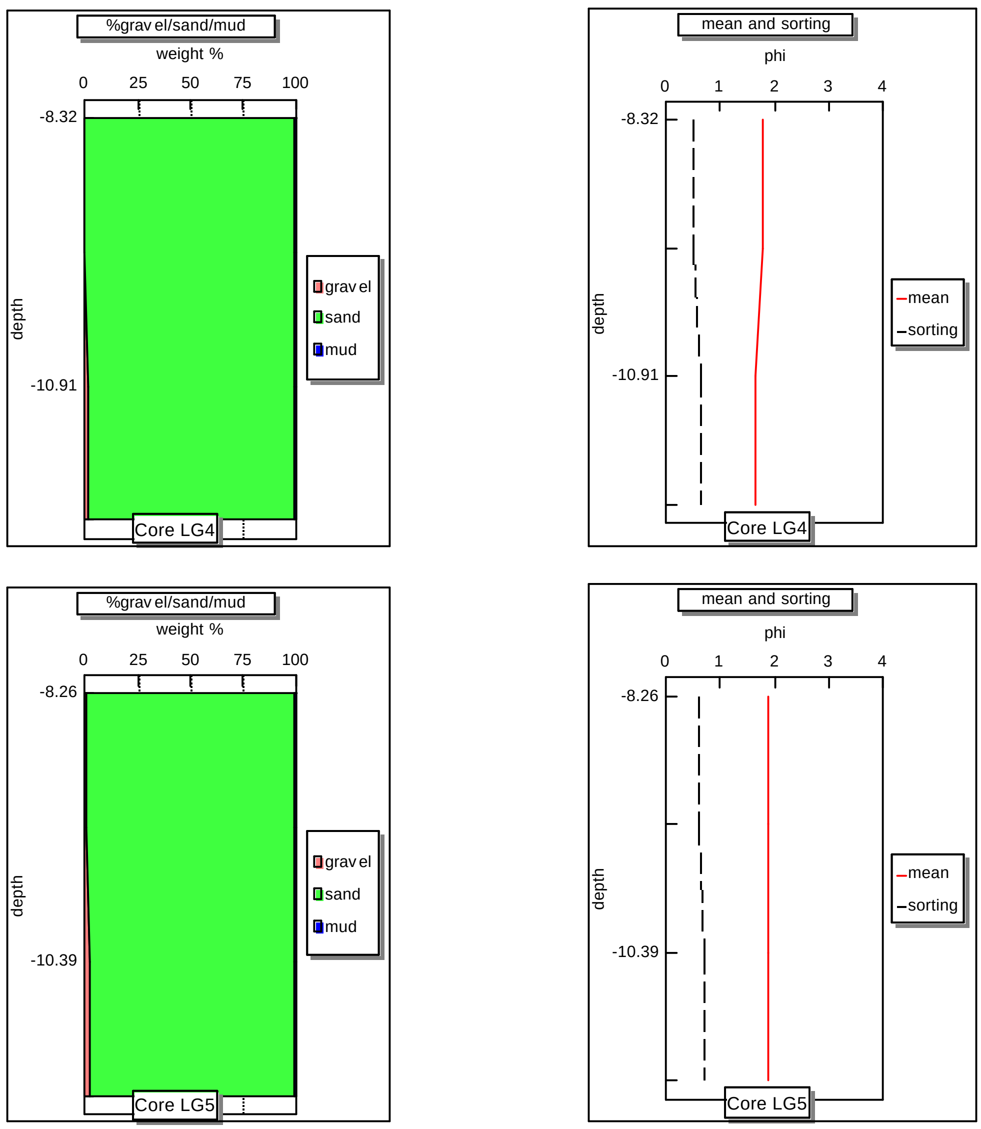
%grav el/sand/mud
weight %
0
25
50
75
100
-8.32
-10.91
depth
gravel
sand
mud
Core LG4
mean and sorting
phi
0
1
2
3
4
-8.32
-10.91
depth
mean
sorting
Core LG4
%grav el/sand/mud
weight %
0
25
50
75
100
-8.26
-10.39
depth
gravel
sand
mud
Core LG5
mean and sorting
phi
0
1
2
3
4
-8.26
-10.39
depth
mean
sorting
Core LG5

Figure 19

Vibracore Descriptions

Shoal B

Shoal B was sampled with 19 vibracores. Except cores B-10 and B-19, all cores contained sands that meet or exceed high potential grain size parameters. Material along the crest of Shoal B, especially in the south-west, is the coarsest. Finer, but suitable sands are found in the northern crest and upper flanks. Core B-11, the second deepest, penetrated to a depth of -18 meters, and contained medium sand at that depth. Because all of these cores contained suitable sand to the depths of penetration, volume calculations we based on penetration depths, except for B-10 and B-19. The lower surface at these points was set at -15 m and -16 m, respectively, because sands below these depths became too fine for beach fill.

Shoal C

Shoal C was sampled with four vibracores. Cores C-1 and C-2 indicated this shoal contains usable sand along the crest, especially in the central region. Core C-1 contained medium sand to a depth of - 16 m except a 1.2 m segment of sand from -14.4 m to -15.6 m, which was slightly finer (1.95 f) than native Ocean City sand. Core C-2 contained medium sand to a depth of nearly -17 m. Both cores C-3 and C-4 suggest sand on the northeastern section and flanks is too fine for beach fill. The best quality sands on Shoal C are confined to the central crest, to a depth of at least -14 m.

Shoal D

Three vibracores were taken on Shoal D. Core D-1, located on the northwest edge of the shoal, contained 0.5 m of medium sand overlaying fine sand and mud. Core D-2 was taken on the southwestern crest, where seismic records show a hard bottom, suggesting sediments are coarse and well-packed. The core penetrated only 1.5 m before refusal, confirming the seismic interpretation. Sand in D-2 was coarse, and well sorted to a depth of -13 m. Core D-3, on the northeastern crest penetrated to -17.6 m. The entire core contained very well sorted, medium sand. Based on core data and seismic data, the lower volumetric surface was set at -18 m except in the vicinity of D-2, where it was set at -13 m. The best beach nourishment sands are found along Shoal D’s crest to at least -13 m.

Great Gull Bank

Seven vibracores were obtained from Great Gull Bank. Core GG-1 contained moderately sorted, medium sands to a depth of -11 m. Similar sand was found in core GG-3, from the shoal's center, to -12.5 m. Somewhat finer sand was present in GG-2 and GG-5 , to -13 m and - 14 m respectively. Core GG-4 indicated coarse to medium, moderately well sorted sand exists to -16 m along the northwest flanks. Below this depth, sand finer than 2 f is present. Medium sand changes abruptly to fine sand at -10.4 m in core GG-6, located on the northeast crest. Cores GG-2, 4, 5, and 6 define the extent of Great Gull Bank's coarser sands. Core GG-7, on the northeastern edge, contained sand finer than 1.9 f to -13.6 m. This is smaller than the optimum 1.84 f diameter suggested for beach fill. High potential sands are limited to the southwestern half of Great Gull Bank's crest, to at least -14 m.

Little Gull Bank

Little Gull Bank was sampled with five vibracores. Core LG-1 penetrated to -12.3 m and contained coarse, well sorted sand. Medium, well sorted sands were found to approximately -12.5 m in cores LG-2, 4 and 5. LG-3, in the center of the shoal, showed 1.6 m of medium, very well sorted sand atop a layer of coarse sand, cobbles and shell, which prevented further penetration. Little Gull Bank's best sands are confined to the southwest crest to at least -12 m.

Sediment volumes

A summary of sediment volumes contained within the shoals studied is presented in Table 2. Total shoal volumes, and volumes of regions with moderate and high potentials are calculated. Generally, volumes are based on an entire shoal body, from its surface to the base of vibracore penetration. Shoal B has the largest volume of usable sand. Shoals D and C have smaller volumes of sediment, limited by an abundance of fine sediment and depths below -15 m. Great Gull and Little Gull Banks have similar volumes of high potential sand.

Table 3
Sediment Volumes (million cubic meters)

SHOAL	REGION		VOLUME (million m^3)
B	total		38.4
	high potential		30.1
C	total		6.3
	moderate potential		2.5
D	total		17.8
	high potential		12.3
Great Gull Bank	total		42.5
	moderate potential		14.7
	high potential		11.5
Little Gull Bank*	total		35.8
	state and federal waters	high potential	19.3
		moderate potential	7.0
	federal waters only	total	12.3
		high potential	4.6
		moderate potential	2.4
Total, high potential			**73.2**
Total, moderate potential			**24.2**

*Little Gull Bank straddles the three mile limit, and is therefore partially within Maryland waters.

RESOURCE POTENTIAL

A summary of sediment grain size parameters and volumes is presented as a map in Figure 20. The map outlines those regions that contain usable sand resources within Shoal Field II. Areas of high potential contain sands

1) have mean grain size greater than 1.84 f and sorting less than 1.22 f
2) are in depths less than -15 m ;

Areas of moderate potential contain sands

1) have mean grain size between 1.84 and 2.0 f and sorting greater than 1.22 f
    or
2) are in depths -15 m or more

Areas of low potential are regions with sediments finer than 2 f .

Sand Resources Potentials

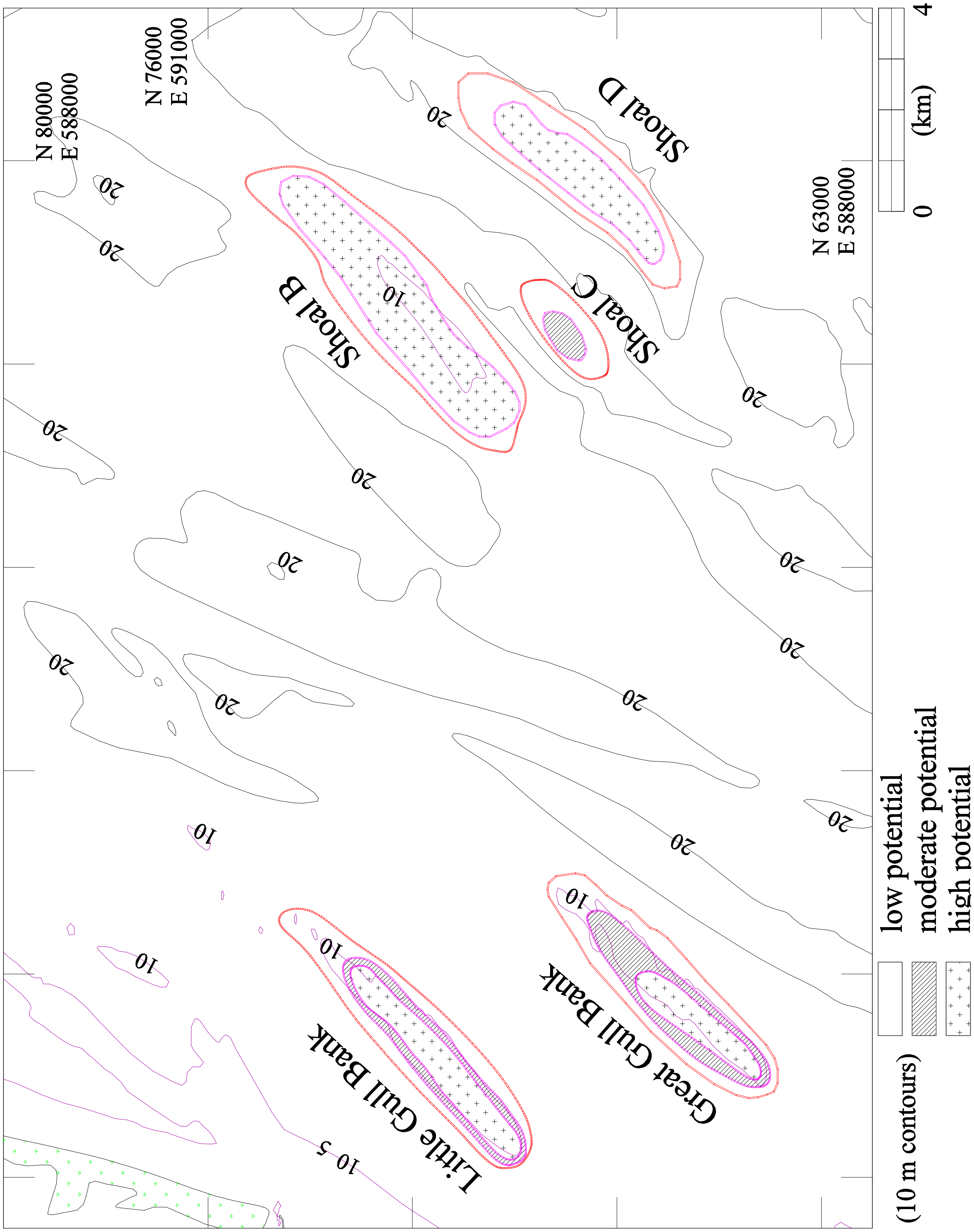

Figure 20

CONCLUSION

Five shoals within Shoal Field II contain at least 73.2 million m^3 of sand with a mean grain diameter of 1.84 f or larger, and a sorting of 1.22 f or less. Because these sands have physical parameters that meet or exceed required for beach nourishment projects in the Maryland region, Shoal Field II is a major sand resource. The sand deposits are within -15 m of the surface, which makes them accessible to dredging equipment used in the area. Significant deposits may exist below this depth. Sampling of these deposits was limited to 6 m below the ocean bottom, the length of vibracoring for this project. Significant deposits may exist below these depths, but because they were not sampled, they were not considered in this study. Twelve meter cores are required to penetrate the shoal bodies.

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and
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Appendix A

Vibracore Sample Grain Size Parameters

Core depths and sampling intervals are reported in meters below NGVD.

Vibracores analyzed at the U.S. Army Corps of Engineers Soils Lab

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
B-1	-13.08	-13.99	-0.11	0.83	82.9	16.6	0.5	brown coarse sand with shell
B-1	-13.99	-15.51	-0.16	0.88	81.9	17.4	0.7	brown coarse sand with shell, higher shell concentration 50.1'-50.3'
B-1	-15.51	-17.04	0.18	1.21	82.9	15.7	1.4	brown coarse sand with shell
B-2	-11.95	-13.17	0.83	0.31	98.8	0.5	0.7	brown med/coarse sand with shell
B-2	-13.17	-13.75	0.78	0.31	98.8	0.7	0.5	brown med/coarse sand with shell
B-2	-13.75	-16.22	0.88	0.36	98.5	1.0	0.5	brown med/coarse sand with shell, greyish sand @ bottom 0.6'
B-3	-10.03	-11.52	0.59	0.55	92.9	6.3	0.8	brown coarse sand with shell
B-3	-11.52	-13.05	0.48	0.54	93.1	6.2	0.7	brown coarse sand with shell, heavy shell zone 39.8'-40.8'
B-3	-13.05	-14.39	0.73	0.54	96.0	3.4	0.6	brown coarse sand with shell
B-3R	-14.23	-14.54	0.93	0.43	98.7	0.9	0.4	brown and grey med sand, trace shell
B-3R	-14.54	-16.06	0.88	0.47	98.6	1.2	0.2	brown med sand, trace shell, heavy shell layer 52.4'-52.7'
B-4	-10.15	-10.30	1.38	0.69	98.1	1.4	0.5	brown med sand, trace shell
B-4	-10.30	-10.70	1.35	0.68	98.1	1.3	0.6	grey/brown med sand, trace shell
B-4	-10.70	-14.72	1.63	0.56	99.1	0.2	0.7	grey med/fine sand, trace shell
B-4R	-14.42	-16.25	1.13	0.54	99.0	0.4	0.6	brown med sand, trace shell, moist
B-5	-13.47	-13.93	0.24	0.72	87.3	12.3	0.4	brown coarse sand, shell frag, shell layer 45.6'-45.8'
B-5	-13.93	-14.84	0.42	0.55	90.3	9.1	0.6	brown med/coarse sand, shell frag
B-5	-14.84	-15.61	0.39	0.59	89.0	10.3	0.7	brown/grey med/coarse sand, shell, heavy shell layer 49.9'-51.2'
B-5R	-15.61	-16.52	0.42	0.54	91.6	7.9	0.5	brown med/coarse sand, shell fragments
B-5R	-16.52	-16.95	0.59	0.52	93.4	5.0	1.6	grey med sand, shell

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
B-6	-10.64	-11.77	0.83	0.46	95.9	2.1	2.0	brown med/coarse sand, shell fragments
B-6	-11.77	-13.29	1.33	0.49	99.0	0.8	0.2	brown med/fine sand, shell fragments
B-7	-9.20	-9.66	1.12	0.34	98.6	0.8	0.6	grey med sand, shell, wet
B-7	-9.66	-10.21	1.11	0.34	99.5	0.3	0.2	brown med sand
B-7	-10.21	-11.19	1.10	0.36	98.8	0.6	0.6	brown/grey med sand, trace shell
B-7	-11.19	-12.10	1.02	0.36	96.2	3.6	0.2	brown med sand, shell, shell layer @ 37.9'
B-7	-12.10	-12.47	1.47	0.42	99.2	0.1	0.7	grey/brown med/fine sand
B-7	-12.47	-12.71	1.82	0.48	99.0	0.1	0.9	grey fine sand
B-7R	-13.62	-14.84	1.35	0.39	98.6	1.2	0.2	brown med sand, trace shell, heavy shell lens 47.0'-47.7'
B-8	-12.22	-13.59	0.97	0.43	98.7	0.9	0.4	brown coarse sand, trace shell
B-8	-13.59	-15.12	0.99	0.45	98.9	0.6	0.5	brown coarse sand, trace shell
B-9	-8.69	-8.75	1.31	0.33	99.3	0.1	0.6	brown med sand
B-9	-8.75	-8.99	0.92	0.42	96.6	2.7	0.7	grey/brown med sand, trace shell
B-9	-8.99	-9.66	0.99	0.36	99.0	0.6	0.4	brown med/coarse sand, trace shell
B-9	-9.66	-11.55	1.37	0.40	99.0	0.3	0.7	grey/brown med/coarse sand, trace shell
B-9	-11.55	-12.04	1.20	0.34	98.0	1.2	0.8	brown/grey coarse sand
B-10	-13.11	-14.94	1.76	0.55	99.0	0.3	0.7	grey/brown med sand, trace shell
B-10	-14.94	-15.76	1.98	0.57	96.6	3.1	0.3	light grey med/fine sand, trace shell
B-10	-15.76	-17.07	2.17	0.49	99.1	0.2	0.7	brown fine sand, trace shell
B-10	-17.07	-17.37	2.07	0.56	97.9	1.2	0.9	brown fine sand, shell
B-10	-17.37	-17.98	2.15	0.50	98.9	0.3	0.8	grey/brown fine sand, trace shell
B-11	-13.90	-14.39	1.10	0.55	97.9	1.4	0.7	grey coarse sand, trace shell
B-11	-14.39	-14.54	1.08	0.53	99.0	0.5	0.5	brown coarse sand, trace shell
B-11	-14.54	-16.61	1.02	0.50	97.6	1.8	0.6	grey/brown coarse sand, trace shell
B-11	-16.61	-18.14	1.17	0.74	95.1	4.5	0.4	brown/grey coarse sand, shells

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
B-12	-10.00	-10.61	0.83	0.57	94.7	4.6	0.7	brown very coarse sand, shell
B-12	-10.61	-11.40	1.16	0.39	99.4	0.4	0.2	brown coarse sand, trace shell
B-12	-11.40	-12.13	1.44	0.39	99.3	0.1	0.6	grey/brown med/coarse sand, trace shell
B-13	-10.70	-12.34	1.39	0.37	98.5	0.9	0.6	grey/brown med sand, trace shell
B-13	-12.34	-13.87	1.40	0.37	99.1	0.2	0.7	grey/brown med sand, trace shell
B-14	-12.71	-13.17	1.28	0.40	98.8	0.8	0.4	brown med sand, trace shell
B-14	-13.17	-14.20	1.31	0.41	99.2	0.1	0.7	grey med sand, trace shell
B-14	-14.20	-17.25	1.29	0.48	99.2	0.1	0.7	grey/brown med sand, trace shell
B-15	-12.28	-13.50	1.50	0.38	99.2	0.2	0.6	grey/brown med sand, trace shell
B-15	-13.50	-15.03	1.49	0.38	98.5	0.9	0.6	brown/grey med sand, trace shell
B-15	-15.03	-16.55	1.88	0.36	99.6	0.2	0.2	brown/grey med/fine sand
B-16	-12.65	-13.47	1.42	0.49	98.4	1.0	0.6	grey/brown med sand, trace shell
B-16	-13.47	-15.61	1.71	0.41	99.3	0.1	0.6	grey/brown med/fine sand, trace shell
B-16	-15.61	-16.82	1.49	0.59	97.7	1.5	0.8	grey/brown med/fine sand, shell layer 52.9'-53.1'
B-16	-16.82	-17.13	1.38	0.57	97.4	2.0	0.6	grey/brown med sand
B-17	-12.28	-13.66	1.52	0.39	99.4	0.2	0.4	brown/grey med/coarse sand, trace shell
B-17	-13.66	-15.88	1.50	0.40	98.6	0.8	0.6	brown/grey med/coarse sand, trace shell, shell layer @52.1'
B-17	-15.88	-16.70	1.64	0.36	97.3	1.9	0.8	brown/grey med/coarse sand, trace shell
B-18	-12.92	-15.61	1.55	0.35	99.5	0.2	0.3	brown med sand, trace shell
B-18	-15.61	-17.13	1.57	0.41	98.0	1.2	0.8	brown med sand, trace shell
B-19	-13.50	-15.91	1.87	0.41	99.0	0.3	0.7	brown/grey med sand, trace shell
B-19	-15.91	-18.20	1.90	0.44	97.9	0.6	1.5	grey/brown med sand, trace shell

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
C-1	-12.22	-12.89	1.77	0.43	99.2	0.2	0.6	brown/grey med sand
C-1	-12.89	-14.42	1.78	0.36	99.0	0.2	0.8	brown/grey med sand
C-1	-14.42	-15.64	1.95	0.40	99.3	0.0	0.7	brown/grey med sand
C-1	-15.64	-15.94	1.70	0.51	98.8	0.7	0.5	brown med/coarse sand
C-2	-12.56	-13.84	1.49	0.43	99.2	0.2	0.6	grey/brown med sand
C-2	-13.84	-16.37	1.52	0.47	98.6	0.8	0.6	grey/brown med sand
C-2	-16.37	-16.89	1.00	0.73	92.3	7.0	0.7	brown coarse sand, shell
C-3	-12.74	-15.06	2.09	0.51	98.9	0.3	0.8	grey med/fine sand
C-3	-15.06	-16.58	2.16	0.46	99.2	0.2	0.6	brown med/fine sand
C-4	-14.14	-16.58	1.99	0.49	99.1	0.2	0.7	brown/grey med/fine sand
C-4	-16.58	-18.11	2.04	0.49	97.2	1.9	0.9	grey med/fine sand, shell layer 55.3'-56.6'
C-4	-18.11	-19.63	2.41	0.48	98.1	1.0	0.9	grey med/fine sand, some shell
LG-1	-6.22	-8.14	0.95	0.51	96.3	3.2	0.5	brown coarse sand
LG-1	-8.14	-8.84	1.12	0.39	98.7	0.7	0.6	gray med/coarse sand
LG-1	-8.84	-9.27	0.39	1.01	86.6	12.9	0.5	brown coarse sand
LG-1	-9.27	-9.78	0.94	0.43	98.0	1.8	0.2	brown med/coarse sand
LG-1	-9.78	-10.79	0.58	0.95	89.7	9.8	0.5	gray/brown coarse sand w/ shell
LG-1	-10.79	-12.31	0.77	0.88	91.4	8.2	0.4	brown/gray coarse sand w/ trace shell
LG-2	-8.05	-9.17	1.60	0.43	99.0	0.4	0.6	gray/brown med sand
LG-2	-9.17	-11.00	1.42	0.52	98.5	1.1	0.4	brown med/coarse sand
LG-2	-11.00	-12.28	1.34	0.45	99.0	0.3	0.7	brown coarse sand
LG-3	-8.32	-8.87	1.50	0.35	99.4	0.0	0.6	brown med sand
LG-3	-8.87	-9.94	1.04	0.35	97.8	1.8	0.4	brown coarse sand

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
LG-3	-9.94	-10.15	-0.55	1.62	60.0	39.9	0.1	brown very coarse sand w/ cob. & shells
LG-3R	-10.33	-10.49			43.8	55.5	0.7	coarse sand & cob. w/ shell
LG-4	-8.32	-10.91	1.78	0.49	99.2	0.2	0.6	brown/gray med/fine sand
LG-4	-10.91	-12.44	1.64	0.63	97.7	1.9	0.4	brown med/fine sand
LG-5	-8.26	-10.39	1.87	0.59	99.1	0.4	0.5	brown/gray med/fine sand
LG-5	-10.39	12.37	1.87	0.69	97.5	2.1	0.4	brown/gray med/fine sand
GG-1	-7.22	-7.86	1.13	0.60	98.4	1.2	0.4	brown/gray coarse sand w/ trace shell
GG-1	-7.86	-9.39	0.15	1.08	83.4	16.1	0.5	brown/gray very coarse sand
GG-1	-9.39	-10.18	1.66	0.48	99.1	0.1	0.8	gray med sand
GG-1	-10.18	-10.49	1.27	0.72	99.0	0.3	0.7	brown med/coarse sand
GG-1	-10.49	-10.73	1.74	0.56	99.0	0.1	0.9	brown/gray med sand
GG-1	-10.73	-10.91	0.39	1.17	87.2	12.3	0.5	brown very coarse sand
GG-2	-8.35	-8.75	1.90	0.48	98.7	0.6	0.7	gray/brown med sand
GG-2	-8.75	-8.81	1.00	0.89	96.0	3.5	0.5	brown med/coarse sand
GG-2	-8.81	-9.57	1.92	0.48	98.4	0.8	0.8	gray med sand
GG-2	-9.57	-9.69	1.11	0.83	94.8	4.5	0.7	gray med/coarse sand w/ shell
GG-2	-9.69	-10.88	1.86	0.47	99.3	0.2	0.5	gray/brown med/fine sand
GG-2	-10.88	-11.09	1.40	0.87	95.1	4.3	0.6	brown med sand w/ shell
GG-2	-11.09	-12.83	1.62	0.52	99.2	0.3	0.5	brown med sand
GG-3	-8.23	-9.36	1.39	0.63	97.7	1.7	0.6	brown/gray med sand w/ trace shell
GG-3	-9.36	-11.19	1.38	0.58	98.8	0.8	0.4	brown/gray med sand
GG-3	-11.19	-12.41	1.61	0.48	99.1	0.2	0.7	gray med/fine sand
GG-4	-12.10	-13.53	0.87	0.74	92.3	7.2	0.5	brown/gray coarse sand w/ tr. cobbles
GG-4	-13.53	-14.94	1.05	0.65	95.5	3.8	0.7	brown/gray coarse sand

Core ID	upper	lower	mean f	sorting f	% sand	% gravel	% mud	description
GG-4	-14.94	-15.58	2.11	0.59	98.4	0.5	1.1	gray fine sand
GG-5	-9.14	-10.06	1.98	0.53	99.0	0.3	0.7	gray/brown med sand
GG-5	-10.06	-10.18	1.48	0.98	97.4	2.1	0.5	brown coarse sand
GG-5	-10.18	-10.45	1.88	0.62	98.5	0.8	0.7	gray/brown med sand
GG-5	-10.45	-10.52	1.69	0.89	97.1	2.4	0.5	brown med/coarse sand
GG-5	-10.52	-10.67	1.86	0.67	98.1	1.2	0.7	brown med sand
GG-5	-10.67	-12.01	1.93	0.61	98.9	0.7	0.4	brown fine sand
GG-5	-12.01	-12.13	0.83	1.54	82.4	14.1	3.5	dark gray fat clay w/ sand
GG-5	-12.13	-12.41	2.11	0.50	97.0	1.3	1.7	brown/gray med/fine sand
GG-5	-12.41	-12.56	0.56	1.27	91.8	7.7	0.5	brown coarse sand w/ shell
GG-5	-12.56	-13.72	2.01	0.42	98.4	0.7	0.9	brown/gray med/fine sand
GG-6	-7.86	-9.78	1.55	0.49	98.5	1.0	0.5	gray/brown med sand
GG-6	-9.78	-10.39	1.51	0.67	98.0	1.7	0.3	brown med sand
GG-6	-10.39	-11.31	2.32	0.40	99.2	0.1	0.7	brown fine sand
GG-7	-9.27	-10.55	1.98	0.44	99.4	0.1	0.5	brown/gray med/fine sand
GG-7	-10.55	-13.59	1.94	0.59	98.5	0.6	0.9	brown/gray med sand

Vibracores analyzed by Maryland Geological Survey

(n/a indicates not analyzed)

Sample No.	upper	lower	%sand	%mud	%gravel	%silt	%clay	mean f	sorting f	Shepard's Class	Folk's Class
D1-A1	-18.20	-18.30	98.8	0.5	0.7	n/a	n/a	1.75	0.48	SAND	SAND
D1-A2	-18.45	-18.51	98.9	0.6	0.6	n/a	n/a	1.75	0.48	SAND	SAND
D1-A3	-18.61	-18.64	95.7	0.5	3.7	n/a	n/a	1.50	0.59	SAND	SAND
D1-A4	-18.68	-18.74	78.0	22.0	0.0	8.9	13.2	2.83	0.88	SAND	MUDDY SAND
D1-A5	-19.10	-19.15	98.5	1.5	0.0	n/a	n/a	2.42	0.41	SAND	SAND
D1-A6	-19.62	-19.67	98.6	1.4	0.0	0.9	0.4	2.42	0.41	SAND	SAND
D1-B1	-19.88	-19.93	98.8	1.2	0.0	n/a	n/a	2.42	0.41	SAND	SAND
D1-B2	-20.30	-20.35	98.6	1.4	0.0	n/a	n/a	2.42	0.41	SAND	SAND
D1-B3	-20.80	-20.85	98.6	1.4	0.0	1.0	1.4	2.42	0.41	SAND	SAND
D1-C1	-21.43	-21.48	98.7	1.3	0.0	n/a	n/a	2.25	0.52	SAND	SAND
D1-C2	-21.90	-21.95	99.1	0.9	0.0	n/a	n/a	2.17	0.41	SAND	SAND
D1-C3	-22.20	-22.25	98.1	1.2	0.6	n/a	n/a	1.92	0.62	SAND	SAND
D1-C4	-22.40	-22.45	79.1	0.5	20.4	n/a	n/a	2.03	1.75	SAND	SAND
D1-C5	-22.49	-22.54	99.1	0.9	0.0	n/a	n/a	2.17	0.41	SAND	SAND
D1-C6	-22.57	-22.59	43.3	56.7	0.0	20.4	36.3	3.42	0.78	SAND/SILT/CLAY	SANDY MUD
D1-C7	-22.70	-22.75	99.2	0.7	0.1	n/a	n/a	2.17	0.41	SAND	SAND
D1-D1	-22.86	-22.89	99.6	0.4	0.0	n/a	n/a	2.00	0.48	SAND	SAND
D1-D2	-23.20	-23.23	96.7	3.3	0.0	1.6	1.7	2.25	0.52	SAND	SAND
D1-D3	-23.67	-23.70	99.5	0.5	0.0	n/a	n/a	1.25	0.31	SAND	SAND
D1-D4R	-23.78	-23.81	2.8	97.2	0.0	60.1	37.1	4.00	0.00	CLAYEY SILT	MUD
D1-D5R	-24.16	-24.21	1.6	98.4	0.0	53.8	44.6	4.00	0.00	CLAYEY SILT	MUD
D2-1	-11.60	-11.63	99.4	0.0	0.5	n/a	n/a	1.00	0.28	SAND	SAND
D2-2	-11.95	-11.98	99.8	0.0	0.1	n/a	n/a	1.00	0.28	SAND	SAND
D2-3	-12.20	-12.23	94.0	0.0	6.0	n/a	n/a	0.58	0.98	SAND	SAND
D2-4	-12.60	-12.63	98.7	0.1	1.2	n/a	n/a	1.08	0.41	SAND	SAND

Sample No.	upper	lower	%sand	%mud	%gravel	%silt	%clay	mean f	sorting f	Shepard's Class	Folk's Class
D2-5	-12.94	-12.98	96.4	0.1	3.5	n/a	n/a	0.92	0.49	SAND	SAND
D3-A1	-12.33	-12.36	99.9	0.1	0.1	n/a	n/a	1.50	0.28	SAND	SAND
D3-A2	-12.70	-12.73	99.7	0.1	0.2	n/a	n/a	1.50	0.28	SAND	SAND
D3-A3	-13.04	-13.07	99.9	0.1	0.0	n/a	n/a	1.50	0.28	SAND	SAND
D3-B1	-13.30	-13.34	99.9	0.1	0.1	n/a	n/a	1.50	0.28	SAND	SAND
D3-B2	-13.90	-13.94	99.9	0.1	0.0	n/a	n/a	1.50	0.24	SAND	SAND
D3-B3	-14.56	-14.58	99.8	0.0	0.1	n/a	n/a	1.50	0.24	SAND	SAND
D3-C1	-14.80	-14.82	99.9	0.1	0.1	n/a	n/a	1.50	0.28	SAND	SAND
D3-C2	-15.42	-15.46	99.7	0.1	0.2	n/a	n/a	1.50	0.24	SAND	SAND
D3-C3	-16.10	-16.12	99.9	0.1	0.0	n/a	n/a	1.50	0.28	SAND	SAND
D3-D1	-16.24	-16.28	99.9	0.0	0.0	n/a	n/a	1.50	0.28	SAND	SAND
D3-D2	-16.94	-16.98	99.7	0.1	0.2	n/a	n/a	1.50	0.28	SAND	SAND
D3-D3	-17.34	-17.38	99.6	0.0	0.3	n/a	n/a	1.33	0.31	SAND	SAND
D3-D4	-17.60	-17.62	99.7	0.1	0.2	n/a	n/a	1.50	0.28	SAND	SAND