FEDERAL SAND-RESOURCE ASSESSMENT OF THE DELAWARE SHELF

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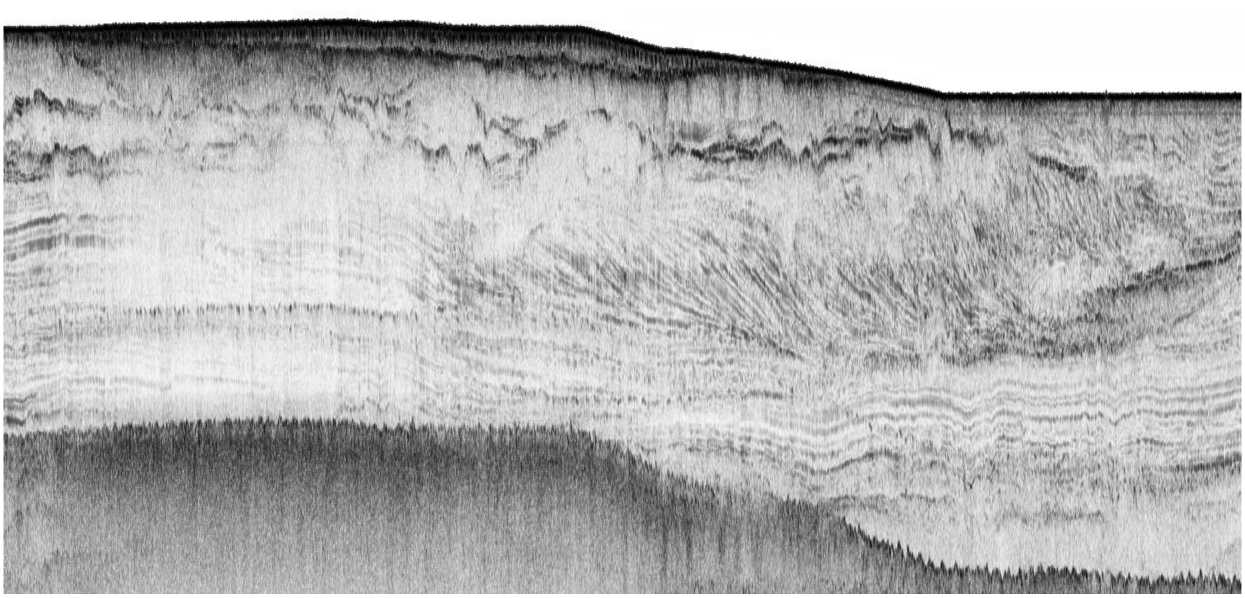

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ABSTRACT

Mapping offshore sand resources is important for the continued success of Delaware's Atlantic shore-protection program. The search for potential nourishment sites is shifting from State to Federal waters (beyond 3 miles of shore), given gradual depletion of permitted sand resource locations in the former. This report is the outgrowth of efforts to delineate suitable sand resources performed as part of the Atlantic Sand Assessment Project (ASAP), a collaborative agreement between the Delaware Geological Survey (DGS) and the Bureau of Ocean Energy Management's (BOEM) Marine Minerals Program. Newly-acquired BOEM sediment vibracores and geophysical data have been integrated with archived stratigraphic picks and texture data from DGS databases and used to characterize sand-resource potentials in Federal waters off the Delaware coast. The total dataset in this area comprises information from 69 sediment cores and 203 km of high-resolution 'chirper' seismic reflection data, which formed the basis for geologic mapping. Stratigraphic framework models of the Delaware shelf, based on lithologic constraints and regional mapping of major subsurface unconformities, offered inputs for sand-volume assessments while grain-size data provided textural constraints for resource rating. While prior work classified resource potentials using a stack-unit classification method, this study used the CMECS classification system and evaluated sand potentials on a geologic map-unit basis. The seafloor geology across the study area is primarily sandy, but texturally heterogeneous. Beach quality sands for Delaware's oceanic shoreline, medium-grained with minimal amounts of gravel and shell, have been identified and quantified across three distinct offshore shoaling areas: 1) The distal portion of the Hen & Chickens Shoal, 2) a lithosome situated around seven miles seaward of Bethany Beach, and 3) the Fenwick Shoal. Sand-volume estimates, assessed from seafloor position and the first high-amplitude subsurface seismic reflector are 108.5 million yd^3, 26.4 million yd^3, and 297.2 million yd^3, respectively. These lithosomes, comprised of beach-quality sand, lie unconformably over muddy Pleistocene valley fills, the Beaverdam Formation, and/or transgressive lag deposits, all unsuitable options for beach nourishment based on sediment texture. Continued refinement of Delaware's offshore stratigraphic framework model and studies linking it to modern shelf sedimentary dynamics are needed to improve efforts to locate current and predict future sand-resource potentials.

INTRODUCTION

Motivation

Delaware's N-S trending Atlantic coastline, ~40 km in length, stretches from the Delaware River bay mouth (i.e., Cape Henlopen) to the Maryland border (i.e., Fenwick Island; Figure 1). Beach towns, which are interspersed with State-owned parks along this coastal stretch, are highly reliant on summer tourism dollars, and beach maintenance by way of replenishment has become the preferred management approach in Delaware (since the 1960s). It is estimated that around 5 million visitors (60% out-of-State) make use of Delaware's beaches on an annual basis, introducing around $700 million to the local economy. Monetary gains from coastal tourism far outweigh the costs of replenishing beaches, making the pursuit of potential offshore borrow areas a feasible and hence important aspect of coastal management.

Nourishment efforts have traditionally targeted areas within State waters (i.e., within 3 nautical miles of shore), from where a total sand volume of 11.1 million yd^3 has been taken since 2005. Shoreface and inner shelf sands have served as borrow areas for the public beaches of Rehoboth Beach/Dewey Beach and Bethany Beach/South Beach (U.S. Army Corps of Engineers, 1996, 1998). A recent Rehoboth/Dewey beach-fill project put around 621,000 yd^3 of nearshore material on the beach (in 2016) at a unit cost of $9.54/cy, bringing total project cost to over $11M (personal communication with Jesse Hayden, DNREC). The depletion of proximal sand sources coupled with the continuous need for sand highlights the need for additional resources from Federal waters (Figure 1).

A preliminary map of the Delaware nearshore/inner shelf geology (to around 6 miles offshore) was delivered as part of the first DGS-BOEM Cooperative Agreement (in 2016). This shows several geologic units of the coastal plain (Pleistocene-aged and perhaps older) to extend far onto the shelf, cropping out along the seafloor where surficial sheet sands are absent. A thin and discontinuous Holocene sand cover has implications for sand-resource assessment, as pre-Holocene units are often muddy or gravelly. However, current stratigraphic models of the shelf are not detailed enough to relate paleo-topography, seafloor geomorphology, and sediment-facies distributions. Prior subsurface studies by Belknap and Kraft (1985) and Williams (1999) traced buried paleovalleys across the DE shelf and inferred a tight coupling between antecedent topography and sediment-facies patterns during Holocene transgression (e.g., patterns of mud and sand distribution). However, the nature of late Pleistocene paleotopography is debatable given fundamental disagreements between proposed subsurface models. The integration of new data from Federal waters off the Delaware coast stands to offer insight to address prior model inconsistencies, as this region contains many data gaps. Refined maps of seafloor geology and models of subsurface architecture stand to improve our process-based understanding of sediment-facies distributions and, subsequently, facilitate sand-resource characterization across previously understudied areas of the Delaware shelf. Two major goals of this BOEM-funded project are as follows: 1) The refinement of pre-existing stratigraphic framework models as a tool for establishing sand thicknesses across the shelf and relating paleotopography to surficial sediment-facies distributions; and 2) Performing a sediment-texture and resource analysis to aid in determining suitable sand bodies.

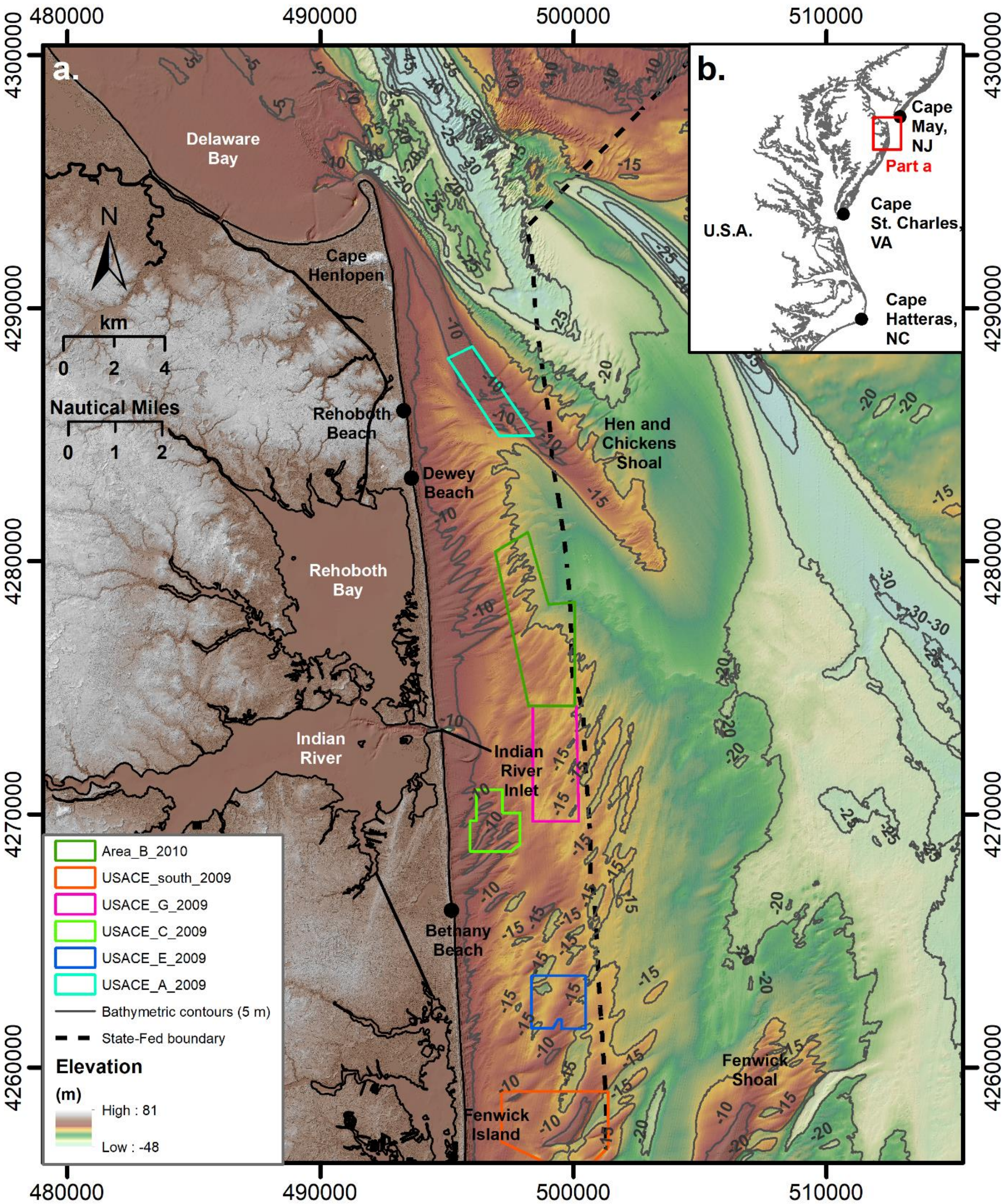

Figure 1 *– GIS-based topo-bathymetric map of Delaware's lower coastal plain and fronting shelf areas based on a seamless 2015 USGS digital elevation dataset (a), displaying bathymetric contours, delineating USACE nourishment areas (color-coded), and labeling key morphologic features of the seafloor. A heavy, dashed line (black) delineates the boundary between State and Federal waters (3 miles from shore). A location map is included, which plots the location of the study area (red box) in context of the mid-Atlantic coastline (b).*

Objectives

The primary objective of this study was the identification of Federal sand resources off the Delaware coast based on established textural criteria for DE beach nourishment. Ramsey (1999) reported on historical beach-sand textures from pre-nourishment sites, determining the "native" (i.e., optimal) beach-sand texture to be medium to coarse (grain sizes from 0.5 to 1.5 phi), well-sorted sand (sorting of -0.5 phi or less). A secondary goal was the specific identification of a sand resource proximal to Rehoboth Beach, which is currently nourished from a site in State waters near Fenwick Island (USACE –south and/or USACE area E; Figure 1). The 15-mile distance from borrow site to beach adds greatly to the cost of nourishment. Textural analyses thus focused on northern areas in Federal waters (near the tip of the Hen and Chickens Shoal). Deliverable products of this work include a map of surface geology (for the entire inner shelf of Delaware) based on a stratigraphic framework assessment, volumetric models of major potential borrow sites within Federal waters (based on seismic mapping), and results of a sediment-texture and resource analysis of surficial map units.

Background

Delaware Shelf Stratigraphy

Our understanding of Delaware shelf stratigraphy is based on past mapping efforts of the Delaware bay-mouth region and areas to the south, which emphasized the delineation of late Pleistocene paleodrainage. Knebel and others (1988) and Knebel and Circé (1988) traced several valley thalwegs beneath Delaware Bay, reconstructing late Pleistocene paleotopography and identifying channel remnants of at least one prior Pleistocene sea-level lowstand beneath the Cape May peninsula. Childers (2014) resolved two SE-trending paleochannels beneath Cape May; it is suggested (based on stratigraphic principles) that both predate the last glacio-eustatic cycle. The most recent episode of fluvial incision appears to have shifted southward given the extension of the Cape May peninsula during the last interglacial (Lacovara, 1997). The position of the most recent Delaware incised valley was mapped across the shelf by Twichell et al. (1977) while efforts by Belknap and Kraft (1985), Belknap and others (1994), Kraft (1971), Kraft and Belknap (1986), Fletcher and others (1990), and Sheridan and others (1974) focused on mapping tributary valleys across the adjacent shoal areas to the south (i.e. Hen and Chickens Shoal; Figure 2). The headwater regions of these systems were mapped beneath the modern Rehoboth Bay and the Indian River estuaries by Chrzastowski (1986). A more recent seismic reflection study by Williams (1999) paints a similar conceptual image of the Delaware shelf subsurface. However, this study and prior work are in disagreement regarding the nature of late Pleistocene paleodrainage (Belknap and Kraft, 1985; Belknap et al., 1994; Kraft, 1971; Kraft and Belknap, 1986). While Williams (1999) maps valleys from modern estuaries to a NE-trending valley originating near the Little Assawoman Bay, prior studies connect them directly to the ancestral Delaware system (Figure 2). Reconciliation of past stratigraphic studies is thus sought as paleotopography can relate to surficial trends in sediment fabric and/or Holocene sediment thickness (Edwards et al., 2003; Locker et al., 2003; Finkl et al., 2006). Understanding the three-dimensional distribution of geologic units across shelves facilitates an improved understanding of process geomorphology, which is useful for developing future resource-assessment strategies. Paleochannels are also shown to represent a significant source of sand to barrier islands along sand-starved margins (Timmons et al., 2010).

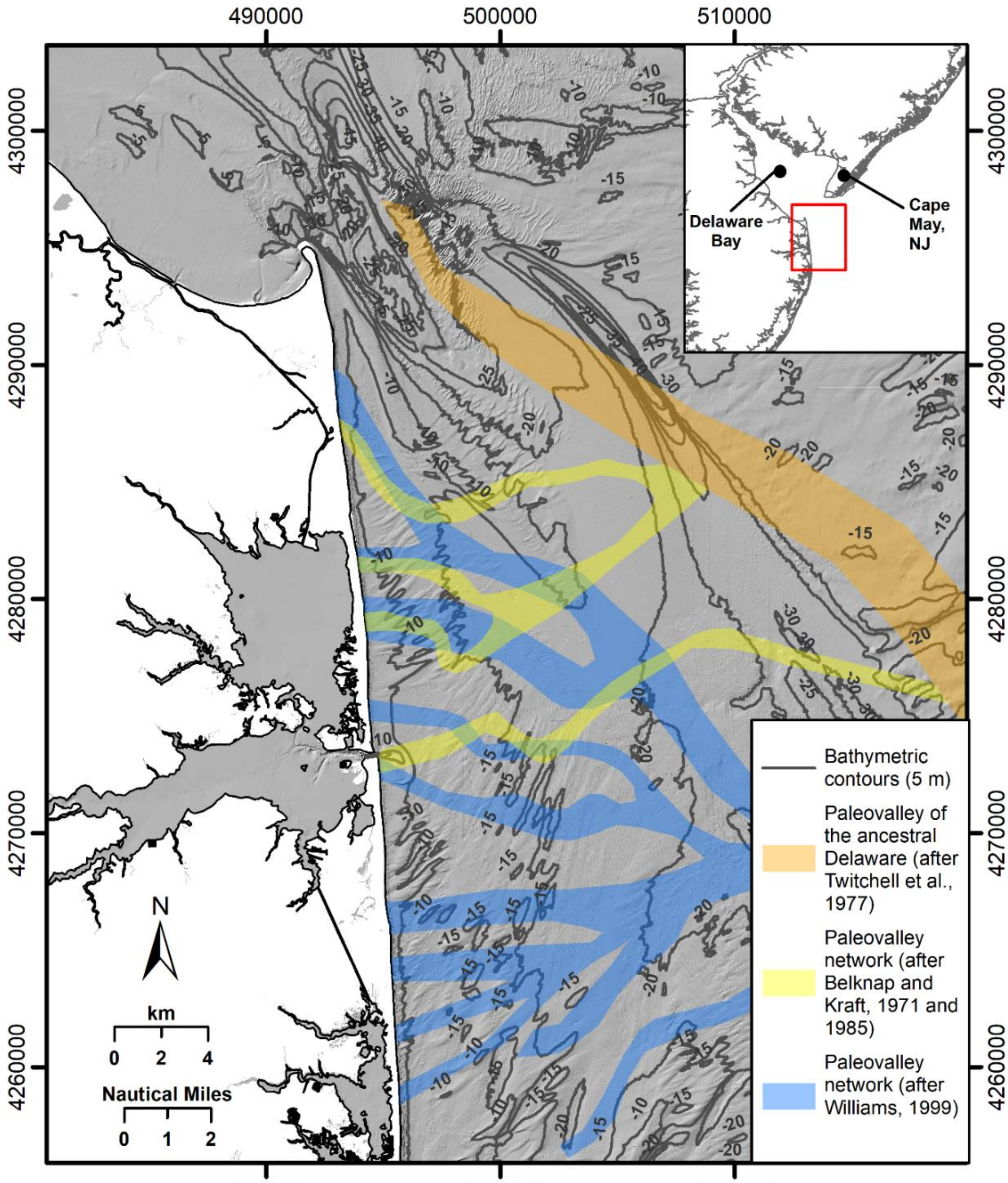

Figure 2 *– Hillshade model of the Delaware shelf (at 10X magnification), showing interpreted paleovalley networks (color-coded by study). Other offshore DE subsurface mapping projects have focused on Delaware Bay and areas to the north (around Cape May, NJ) and are not shown here. Constraint of valley locations is important from a sand-resource perspective. Surficial sediment types and thicknesses often relate to the antecedent topographic conditions. Furthermore, valley fills have been shown to be predominantly muddy, making them unsuitable as sand resources. The paleovalleys mapped by Belknap and Kraft (1971 and 1985) and Twitchell and others (1977) are late Pleistocene in age (with Holocene fills); work by Williams (1999) implies reoccupation of some valleys (with compound fills).*

Delaware Coastal Plain Geology

An integrative model bridging onshore and offshore geologic datasets has not been developed for Delaware, although prior work has shown coastal-plain stratigraphic units to extend onto the shelf (Ramsey and Tomlinson, 2012). The stratigraphy of Delaware's lower coastal plain is summarized in detail by McLaughlin and others (2008) and Ramsey (2010), who build on past data-collection and mapping efforts from borehole, core, and outcrop information (Groot et al., 1990; Ramsey, 1999). The lower coastal plain of Delaware is comprised of swamp to nearshore coastal sedimentary units deposited during middle to late Pleistocene interglacial sea-level highstands. These deposits are divided into three main lithostratigraphic groups (Ramsey, 2010). The Delaware Bay Group, comprised of the Lynch Heights (Qlh) and Scotts Corner (Qsc) Formations (in order of age/superposition), represents bay-margin deposits of varying textures. The Assawoman Bay Group, which includes the Omar (Qo), Ironshire (Qi), and Sinepuxent (Qsi) Formations (in order of age/superposition) is comprised of estuarine, barrier (spit), and backbarrier lagoon deposits south of the Indian River bay (IR). Older portions of the middle Pleistocene-aged Qlh and Qo are assigned to MIS 11 (~400,000 yrs B.P.); the younger portions are correlated with MIS 9 (330,000 yrs B.P.), a particularly warm interglacial with sea-level estimates ranging from 3 to 5 m above present levels (Hearty and Kaufman, 2000). The Qsc and Qi are characterized as late Pleistocene units, dating to MIS 5e to 5a (Ramsey, 2010). Pleistocene units lie unconformably over interglacial fluvial to estuarine/deltaic deposits of the late Pliocene to early Pleistocene Beaverdam Formation (Tbd; Ramsey, 1992) and are locally draped by Holocene shoreline/alluvial, dune/spit, and swamp/marsh deposits. The offshore extents of several prominent coastal plain stratigraphic units are mapped from grab samples and core information along nearshore regions adjacent to Little Assawoman Bay, where the Qsi, Qo, and Tbd crop out at the seafloor (Ramsey and Tomlinson, 2012), and Rehoboth Bay, where Holocene valley fill is mapped along the sediment-water interface (Ramsey, 2011). Figure 3 summarizes the surficial extent of these units across the lower coastal plain and the inner shelf, which provides a template for extending the geologic mapping into Federal waters.

This investigation adheres to established (DGS) nomenclature, looking to promote a seamless onshore-offshore stratigraphic model. This would apply to offshore-resource assessment in two ways: 1) Aiding recognition and quantification of offshore sand volumes; and 2) Helping relate surficial sediment-facies distributions to antecedent topographical conditions and/or source lithologies. While new data collection has augmented subsurface datasets in Federal waters, previous information (predominantly from within State waters and along the barrier shoreline) represents an important component of the overall analysis.

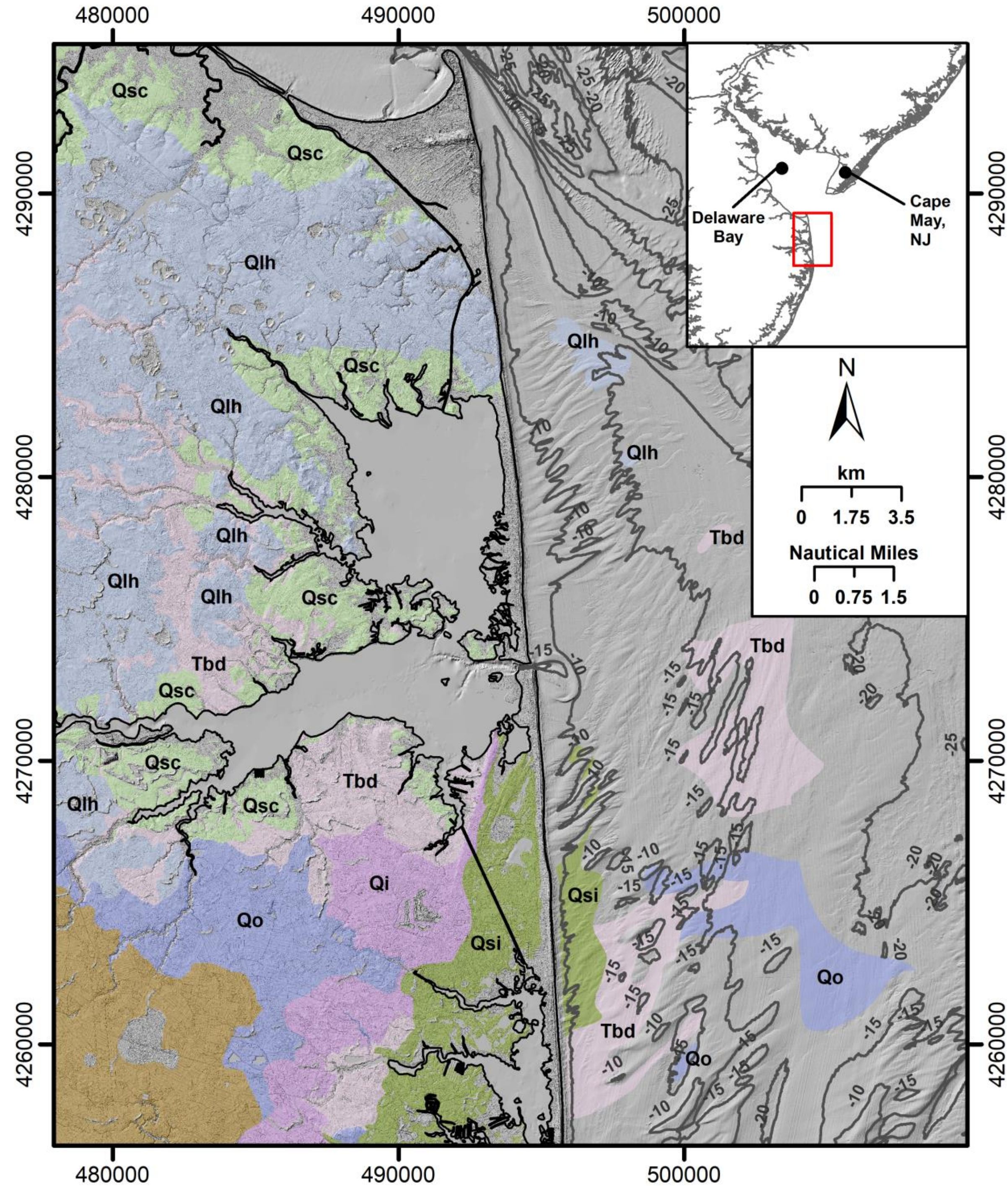

Figure 3 – *Hillshade model of coastal Delaware (based on a 2015 USGS seamless topobathymetric model) showing the distribution of pre-Holocene surface units (Tbd = Beaverdam Formation, Qo = Omar Formation, Qlh = Lynch Heights Formation, Qi = Ironshire Formation, Qsi = Sinepuxent Formation,* and *Qsc = Scotts Corner Formation). The distribution of these units across the coastal plain is based on Ramsey (2010) while their offshore occurrence is mapped based on Ramsey and Tomlinson (2012) and Ramsey and others (2016).*

METHODS AND DATA MANAGEMENT

DGS-BOEM Survey Area

The BOEM survey area is situated entirely within Federal waters and extends from the southern tip of the Hen and Chickens Shoal, a shore-oblique subaqueous sandbar (trending offshore from the Delaware Bay mouth), to the Delaware-Maryland state line (Figure 4). The seafloor topography here is characterized by a gradual transition from the inner shelf platform, marked by a shore-oblique sand-ridge morphology (at < 15 m water depth), to water depths of around 25 m, where seafloor topography is less pronounced. The Fenwick Shoal, a 1 km^2 area where water depths < 15 m, is situated around 12 km offshore and, along with the Hen and Chickens Shoal, represents the only shoaling area within Delaware's Federal waters (Figure 4). Geophysical data and core information from this region were integrated with data from beyond the BOEM survey area for a stratigraphic framework model of the region and mapping of surface geology; volumetric analyses were confined to the BOEM area. Sediment texture data generated for the ASAP project were integrated with historical data in a texture database and evaluated in context of the framework geology (and surficial map units). The following sections detail the analytical procedures.

Stratigraphic Framework Mapping

Geophysical Data

A total of 203 km of high-resolution 'chirper' seismic data were collected by CB&I across Federal waters off the DE coast in mid-June of 2015, using an EdgeTech 3200 sub-bottom profiler with a 512i towfish and sweep frequency pulse of 0.7-12 kHz (Figure 4; Table 1). Two grids were established for data collection purposes: 1) an area extending from the tip of the Hen and Chickens Shoal to just north of the Fenwick Shoals; and 2) The Fenwick Shoals. Tracklines across the former are oriented N-S and E-W while those for the latter are oriented SW-NE and NW-SE, respectively. The seismic survey yielded 32 individual sonar files, which were imported into Chesapeake Software's SonarWiz 6 for processing and interpretation. While navigational offsets (i.e. forward/aft and port/starboard fish towpoint offsets) were accounted for during the original survey and included in the raw sub-bottom files within a positioning accuracy of 10-15 cm, raw sonar data had not been projected to any geoid/vertical datum. Seismic files (.jsf format) were subsequently batch-imported and bottom-tracked individually. Bottom tracking is the delineation of the seafloor position, generally the highest amplitude and first seismic reflection surface. A datum-align function using the bottom track files and a 2015 USGS bathymetric DEM were applied for vertical correction. Tidal and wave effects were thus factored out. Depth conversions were based on two-way signal travel times and a 1,500 m/s sound velocity, the standard used for seawater and soft sediments (Chen et al., 1995; Colman et al., 1990; Knebel and Circé, 1988; Knebel et al., 1988; Shideler et al., 1984; Twitchell et al., 1977). Accurate depth conversion was additionally corroborated by core information. Automatic gain control (AGC) and Time-varying Gain (TVG) functions enhanced the visibility of sub-surface reflections, proportionately amplifying weakened ones at depth.

Sub-surface mapping was based on key stratigraphic principles (e.g. superposition and cross-cutting relationships), the delineation of discordant stratal relationships (e.g. erosional truncation and depositional onlap), and the distinction of seismic facies was based on internal reflection configuration and amplitude. Stratigraphic picks were made within SonarWiz 6 and exported for gridding purposes. Surface and volume models were created using ESRI's ArcGIS 10.5 software package.

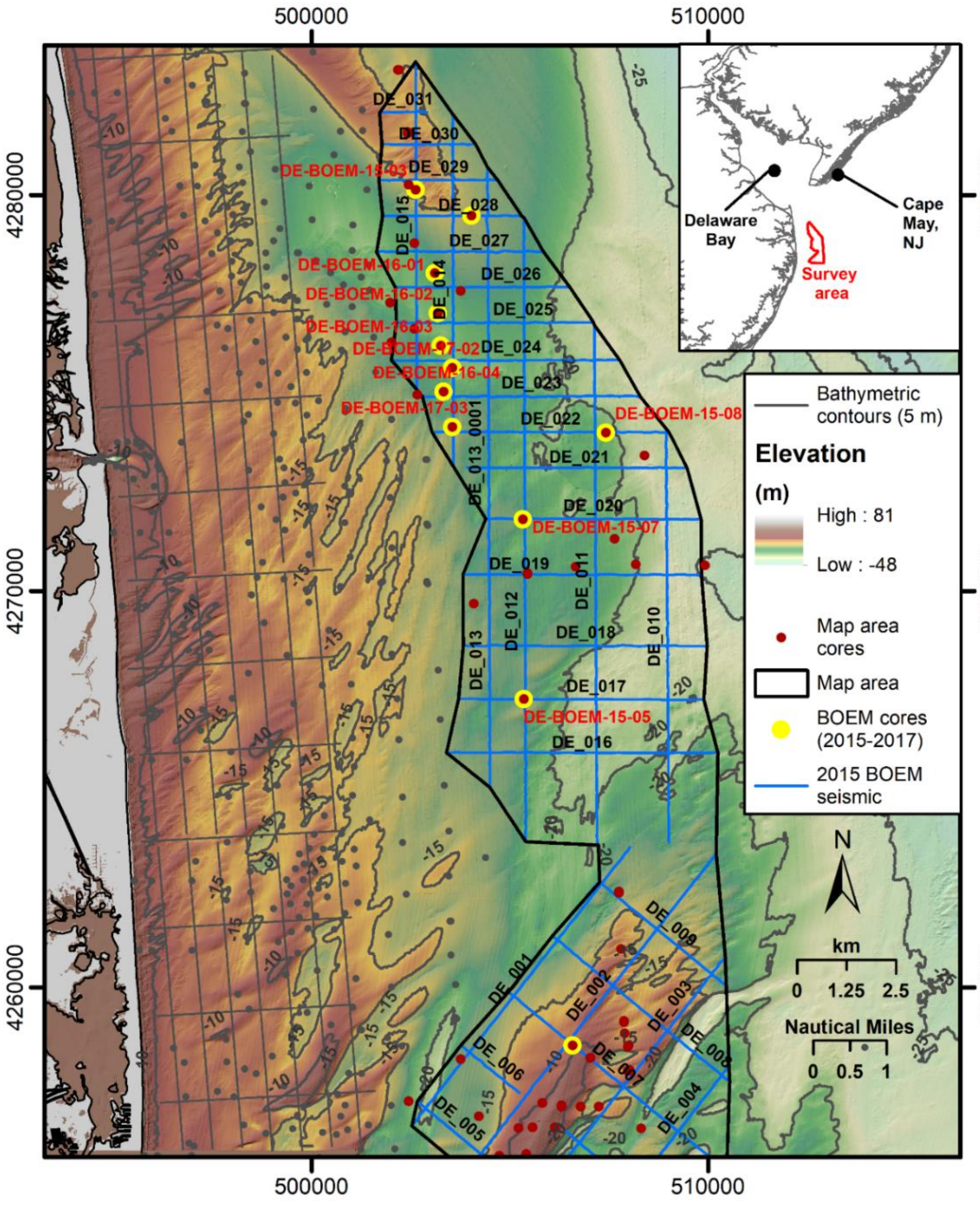

Figure 4 *– Data distribution map. The BOEM survey area, which contains the newly acquired core and geophysical data is outlined in black. There is a noticeable decrease in data density here compared to areas closer to shore, where core records exist from 1970 onward. Spatial data for seismic lines (shown in blue) are listed in Table 1. Newly-collected BOEM cores are highlighted in yellow and labeled by local ID. Table 2 contains core-specific information.*

Table 1 *– Information on the 2015 BOEM 'chirper' seismic dataset by track line, including proximity to sediment cores.*

Line	Area	Start Easting	Start Northing	End Easting	End Northing	Length (m)	Core(s) on line	Core(s) near line
DE_004	FSC	508321	4255160	510548	4257998	3623	None	None
DE_003	FSC	506106	4255244	510429	4260788	7110	None	Rl21-08, Rk35-04
DE_002	FSC	503903	4255352	510225	4263386	10285	None	Rk25-03
DE_001	FSC	502526	4256477	508034	4263542	9053	None	Rk23-05
DE_005	FSC	502676	4257132	504365	4255685	2227	None	None
DE_006	FSC	503795	4258536	505243	4257341	1905	None	None
DE_006_1	FSC	506384	4256376	507799	4255180	1854	None	None
DE_007	FSC	504969	4259885	510486	4255355	7140	Rk25-03	Rk25-01/02
DE_008	FSC	506066	4261289	510552	4257615	5797	None	None
DE_009	FSC	507261	4262660	510475	4260017	4145	None	Ql51-02
DE_013	CR	504444	4271455	504477	4265076	6422	None	None
DE_013_1	HCS/CR	504457	4280713	504474	4271142	9592	None	None
DE_012	HCS/CR	504474	4280720	505403	4263676	15814	Qk24-01	Qk14-01/02, Pk54-01
DE_011	HCS/CR	507155	4276716	507223	4263583	13147	None	None
DE_010	CR	508957	4274044	509009	4263653	10427	None	None
DE_016	CR	503438	4265952	510255	4265899	6856	None	None
DE_017	CR	503738	4267259	509919	4267276	6196	Qk24-01	None
DE_018	CR	503809	4268636	509990	4268601	6174	None	None
DE_019	CR	503791	4270420	509849	4270385	6032	Qk14-01	Qk14-02
DE_020	CR	504374	4271868	509866	4271833	5445	Pk54-01	None
DE_021	CR	503915	4273122	509513	4273087	5565	None	None
DE_022	CR	503067	4274005	509036	4273987	6003	Pl41-02	None
DE_023	HCS	502802	4274912	508306	4274902	5530	None	None
DE_024	HCS	502012	4275830	507781	4275830	5781	None	None
DE_025	HCS	502139	4276759	507121	4276774	4995	None	None
DE_026	HCS	502114	4277661	506522	4277671	4408	None	Pk23-01
DE_027	HCS	501642	4278554	505853	4278564	4240	None	None
DE_028	HCS	501784	4279467	505300	4279462	3519	Pk13-02	None
DE_029	HCS	501693	4280370	504696	4280385	3002	None	None
DE_030	HCS	501774	4281269	504138	4281279	2368	None	None
DE_031	HCS	501723	4282070	502915	4282106	1195	None	None
DE_014	HCS/CR	503541	4282053	503573	4273160	8923	Pk33-02, Pk43-01	None
DE_015	HCS	502628	4283354	502614	4275164	8282	Ok52-05/06	Pk12-01, Pk22-01

Core Data

Lithologic information on 68 core locations in the map area are currently archived by the DGS, including that of recently acquired BOEM cores. This lithologic dataset was used to correlate the offshore stratigraphic framework in Federal waters to areas closer to shore (for which more than 300 additional core records exist) and the coastal plain. Chronostratigraphic control was provided by catalogued radiocarbon dates and age determinations based on amino-acid racemization (AAR) dating of shell material. Twelve new vibracores, collected in 2015-2017 for the BOEM project at key seismic grid nodes, were described, photographed, and sampled for texture analysis (Table 2). Many of these form a N-S oriented core transect below the distal Hen and Chickens Shoal (Figure 4). Core descriptions are provided in Appendix 1 and accompanying texture-data syntheses are found in Appendix 2.

***Table 2** – Core locations for 2015-2017 BOEM cores collected in Federal waters of DE.*

Local ID	DGS ID	Drill Date	Northing	Easting	Seafloor Elevation (ft.)	Core length (ft.)
DE-BOEM-15-01	Rk25-03	9/18/2015	4258538	506587	-39.4	16.9
DE-BOEM-15-03	Ok52-05	9/19/2015	4280130	502629	-51	12.7
DE-BOEM-15-05	Qk24-01	9/18/2015	4267280	505360	-60.5	20
DE-BOEM-15-07	Pk54-01	9/18/2015	4271819	505335	-62.4	13.7
DE-BOEM-15-08	Pl41-02	9/19/2015	4274002	507425	-64.9	12.6
DE-BOEM-16-01	Pk13-01	8/21/2016	4278034	503111	-57.4	17.3
DE-BOEM-16-02	Pk23-02	8/21/2016	4277025	503188	-60	16.6
DE-BOEM-16-03	Pk23-03	8/21/2016	4276196	503269	-59.4	18.5
DE-BOEM-16-04	Pk33-01	8/21/2016	4275040	503338	-58.2	16.2
DE-BOEM-17-01	Pk13-02	12/4/2017	4279480.5	504033.5	-54.07	19.8
DE-BOEM-17-02	Pk33-02	12/4/2017	4275639.7	503556	-63.69	16.7
DE-BOEM-17-03	Pk43-01	12/4/2017	4274146.1	503557	-58.83	19.5

BOEM cores collected in 2016 and 2017 were opened and processed at the DGS facility at the University of Delaware, while CB&I performed these tasks on the 2015 cores (in FL); the DGS has since received archive core halves. After 2016-2017 cores were split length-wise (at the DGS), archive halves were wrapped and labeled for storage at Lamont Doherty’s core facility at Columbia University. Sample halves were photographed, described, and sub-sampled for texture analysis if sand content was estimated at >50%. The 2016 cores were processed for texture at the DGS while analysis on 2015 and 2017 cores was outsourced to CB&I and AECOM, respectively. The following particle-size information was obtained for each texture sample: 1) Percent mud (silt and clay-sized particles), 2) Percent sand (particles between 63 µm and 2 mm in size), and 3) Percent gravel (particles exceeding 2 mm in size). Relative proportions of very fine, fine, medium, coarse, and very coarse sand as defined by the Wentworth size classification were also established as follows:

Size class (Wentworth)	Size range	Phi scale	Mesh size (ASTM No.)
Gravel	>2 mm	<-1	10
Very coarse sand	1 to 2 mm	0 to -1	18
Coarse sand	0.5 to 1 mm	1 to 0	35
Medium sand	0.25 to 0.5 mm	2 to 1	60
Fine sand	125 to 250 µm	3 to 2	120
Very fine sand	62.5 to 125 µm	4 to 3	230
Silt and clay	<62.5 µm	>4	Pan

The clay fraction was removed from the coarse clastic component by wet sieving and was combined with particles falling into this size category after dry sieving. Sand and gravel percentages as well as individual weight percentages of sand subclasses were derived by the standard dry sieve method. Dry weights for each of the aforementioned size classes were recorded in an Excel spreadsheet and used in statistical calculations (median, mean, sorting, skewness, and kurtosis). Summary results are provided in Appendix 2.

Surface and Volume Models

Stratigraphic picks from seismic and core were extracted from the DGS Access Database and exported for surface gridding and volume model creation. The barrier coastline provided the western bounds of surface geologic mapping, while volumetric analyses focused on the BEOM survey area. Picks were imported into ArcMap 10.5.1 and gridded using the Nearest Neighbor gridding algorithm. The raster calculator function was used to subtract younger from older surfaces, yielding isopach maps of sediment thickness. Volumes of surface units such as sheet sands were determined from differences in depth between the seafloor, assessed from the 2015 USGS bathymetric dataset, and the first high-amplitude subsurface seismic reflection.

GEOLOGIC MAPPING RESULTS

Results are provided in two parts: Part 1 presents the map of surface geology and sediment-volume models based on the mapped stratigraphic framework; Part 2 details insights from sediment-texture studies and resource analysis.

Seismic Mapping

Subsurface Interpretations

It is common for seafloor-sediment composition and water depth to noticeably affect seismic echo character (Damuth and Hayes, 1977; Damuth, 1978; Damuth et al., 1983; García-García et al., 2004). Offshore DE data resolution and depth penetration in Federal water are poorest across outer platform shoal fields (e.g. the Fenwick Shoal). This is because the sandy seafloor here is highly reflective and shallow, which creates strong bottom multiples. In map regions of high subsurface geophysical data quality at deeper water depths, seismic facies are distinguished by acoustic amplitude and internal reflection-configuration pattern. Acoustically transparent intervals are thought to represent homogenous sediments lacking vertical changes in character (i.e. composition, texture, and density), while acoustically laminated intervals reflect textural and/or compositional variances with depth. Stratigraphic superposition, geometry, and the character and association of bounding surfaces are additional criteria for characterizing seismic units, some of which contain more than one facies (i.e. reflection configuration) type. Units are bound by regional unconformities that exhibit high amplitude and relief, truncate underlying seismic reflectors, and/or are characterized by onlap of overlying seismic surfaces. Mapped unconformities form the basis of the proposed stratigraphic framework model. Core locations intersecting the seismic grid provide lithologic constraint and an environmental context for established seismic facies, facilitating correlation to onshore stratigraphic framework models (Ramsey, 1999 and 2010).

Seismic Units, Bounding Surfaces, and Facies

A total of three seismic units (U1-U3, in order from oldest to youngest based on superposition) are imaged within the study area subsurface before signal attenuation/obscuration by the bottom multiple (BM) restrict analysis (Figure 5; Table 3). These units are bound by prominent unconformities B1 and B2 and their amalgam, B3. The stratigraphically oldest unit mapped across the region is bound above by B1, which is imaged at depths of up to ~40 m. The middle seismic unit, U2, sits above this surface and is bound above by B2, similar in character to B1, but not exceeding depths of 30 m. Unlike U1, which extends across the entire study area, its lower bounding surface is not resolved anywhere (Figure 5). U2 distribution is localized and it pinches out where bounding surfaces B1 and B2 amalgamate into B3 (Figure 5). The youngest unit, U3, represents strata mapped between B2/B3 and the modern seafloor. While other erosional surfaces are imaged, the ones creating this tripartite subdivision of the shallow subsurface of the inner continental shelf of Delaware provide the basis for the stratigraphic framework. Table 1 lists seismic facies recognized and associated lithologies, which are discussed in the following section.

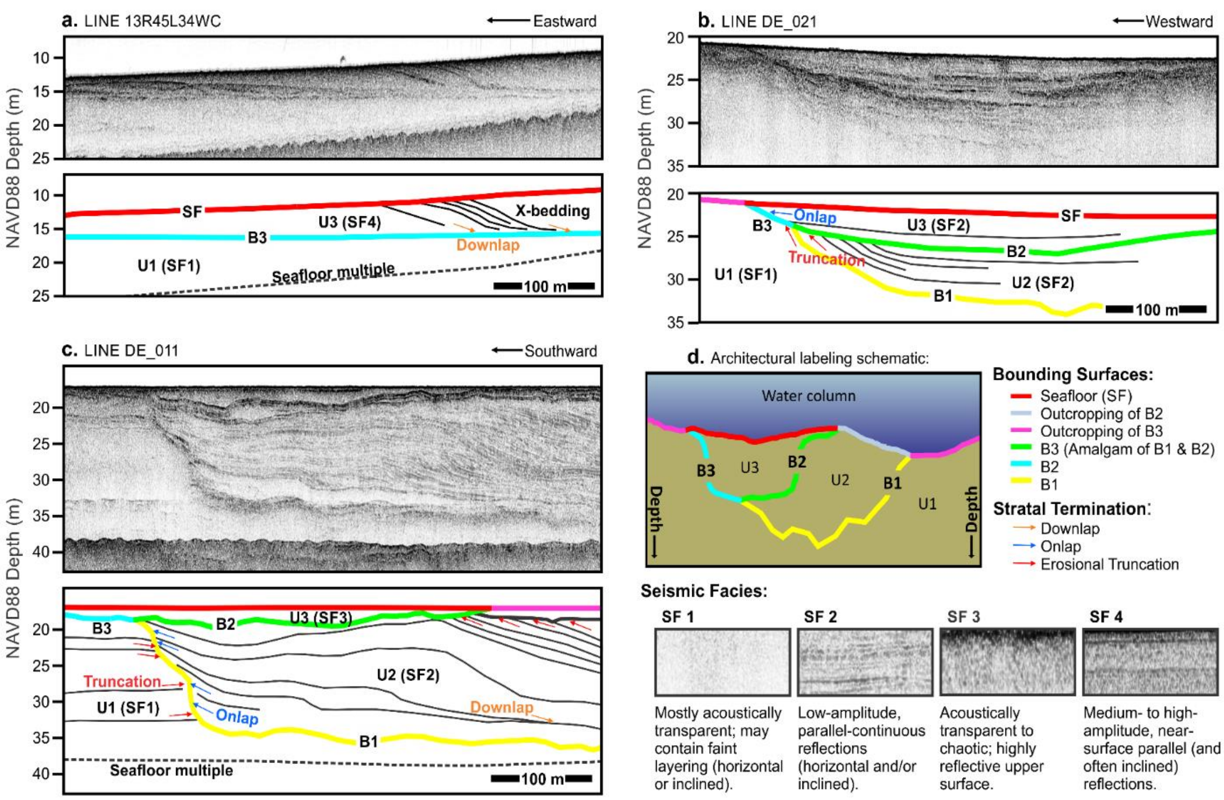

***Figure 5** – Seismic examples (a-c) showing the distinction between different seismic units (U1-U3) and seismic facies (SF1-SF4), based on key stratigraphic principles of erosional truncation, depositional onlap and downlap, and cross-cutting relationships and inner reflection configuration type (e.g. acoustically transparent versus layered).*

Table 3 *– Table of seismic facies, bounding surface characteristics, and associated lithologies. Abbreviations are defined in Figure 5.*

Unit	**Associated Seismic Facies (not mutually exclusive)**	**Lower Bounding Surface**	**Upper Bounding Surface**	**Stratigraphic Age**	**Correlative Onshore Unit or Offshore Unit Lithologic Description**
U1	SF1	Unknown/not imaged	B1, B3, or SF	late Pliocene to early Pleistocene	Fluvio-deltaic Beaverdam Formation (Tbd)
U2	SF2, SF3	B1	B2 or SF	Pleistocene	Lagoonal Omar (Qo) and Sinepuxent (Qsi) Formations
U3	SF2, SF3, SF4	B2 or B3	SF	Holocene	Lagoon (Ql), marsh (Qm), transgressive shelf (Qrl), sheet sand (Qss), intershoal (Qis) and shoal (Qsl) deposits

Lithologic Mapping

Geologic map units are established for offshore Delaware based on textural characteristics of sedimentary deposits, mineralogy, color, fossil content, and chronologic constraint (C-14 ages and AAR age estimates). Many of these are adapted from existing templates of coastal plain units (Ramsey, 2010), while others have been newly established. The following paragraphs describe the geologic units of the DE shelf at the surface and in the subsurface, in no particular stratigraphic order. They also relate lithology to mapped seismic facies. Photographs of type sections are shown in Figure 6 while a map of surface distribution across the DE shelf seafloor, based on stratigraphic picks in the DGS core database and seismic interpretations, is depicted in Figure 7. Figure 8 shows select lithologic and seismic cross-sections, which offer insight into the stratigraphic framework of the shelf.

Sheet sand (Qss)

This unit ranges from fine- to coarse-grained, well-sorted and interbedded to cross-bedded sands containing scattered shell fragments (e.g. *Spisula, Mercenaria, Anomia, Crassostrea*), heavy mineral laminae, and occasionally few scattered granules (particularly along the base; Figure 6). The unit commonly fines upwards or contains beds that are fining upwards. Silt-lined burrows are sometimes observed. Shell abundance is highly variable, but generally restricted to small scattered fragments <1 cm in diameter. Pebbles are sometimes encountered, mostly occurring in basal sections. Colors vary, depending on water content, from light-dark gray to yellowish-brown/light olive-brown. Holocene in age based on AAR data and stratigraphic position: This unit occurs exclusively at the seafloor surface and blankets other units, including other Holocene ones. This unit is largely absent across the northern portion of the study area, where finer and siltier sands associated with the distal reaches of the Hen and Chickens Shoal define the sediment-water interface (Figure 7). Its distribution across the central portion of the survey area is patchy; it comprises shore-oblique (SW to NE-trending) bedforms that extend into the western study area portion, where Qss either overlies the Beaverdam Formation directly or sits atop a transgressive lag unit.

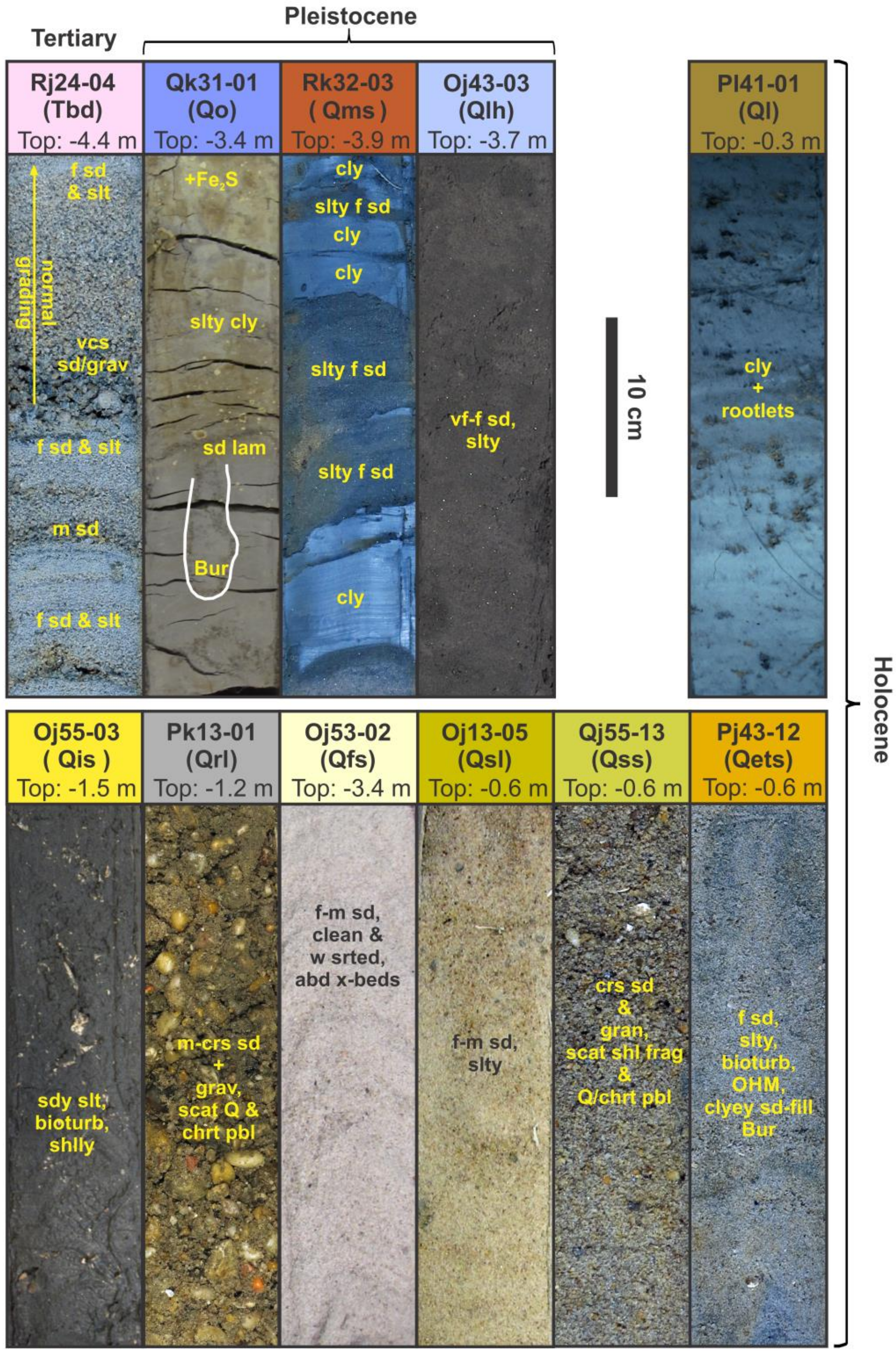

Figure 6 *– Photographs of 30 cm vertical core reference sections of defined lithologic map-units (color-coded to conform to subsequent Figure 7). Locations of reference cores are listed in Table 4. Abbreviated descriptions are as follows: vf = very fine, f = fine, m = medium, c = coarse, vc = very coarse, cly = clay, slt = silt, sd = sand, grav = gravel, gran = granule(s), pbl = pebble(s), slty = silty, lam = laminae, bioturb = bioturbated, scat = scattered, Q = quartz, chrt = chert, srted = sorted, w = well, Bur = burrow(ed), OHM = opaque heavy mineral(s), shl = shell, frag = fragment.*

Shoal sand (Qsl)
The northern portion of the map area contains the distal portion of the Hen and Chickens Shoal, a NW to SE oriented shoal body of around 20 km in length that extends offshore from the Cape Henlopen area (Figures 1 and 7). The water depth across this feature is around 12 m while the surrounding area is approximately 17 m. The Qsl unit is dominated by very fine to medium-grained sands of gray to pale yellowish-gray color (Figure 6). These deposits mostly lack internal structure (exhibiting cross bedding on occasion), but often contain scattered heavy minerals, chert pebbles, shell fragments (e.g. *Spisula*), and clay/silt laminae. Echinoderm fragments (e.g. sand dollars) are also occasionally encountered. Silty burrows may occur within the unit. Qsl interfingers with Qis, which is darker colored and finer due to an increase in silt and clay.

Intershoal (Qis)
Formerly termed 'quiet-water deposits (Qis)'. Black to very dark gray, silty, very fine to fine-grained sands and silt define this unit (Figure 6). Shell fragments, organic materials, and burrows (generally sand-filled) are common in the overall bioturbated sediments. This unit is found at the sediment-water interface surrounding the distal end of the Hen and Chickens Shoal, but also occurs within the shoal complex interbedded with coarser shoal sands/Qsl (Figure 7).

Ravinement lag deposits (Qrl)
This unit is highly variable in distribution and thickness, but generally comprises fine- to medium-grained silty sand containing traces of clay, pockets of shell fragments, wood, and gravel (e.g. quartz and chert pebbles; Figure 6). It is commonly dark-gray to olive-gray in color given organic and clay/silt content, but can show orange/yellowish discoloration. The unit ranges from poorly sorted to subtly interbedded, generally displaying normal grading at the base. The unit is enriched in pebble-sized clasts, which are common throughout, but also occur as interbedded deposits. These deposits are interpreted to represent the early phase of shelf inundation and heavy remixing of Pleistocene (e.g. Omar Formation) and older (e.g. Beaverdam Formation) units cropping out at the seafloor along the outer portion of the inner shelf (Figure 7). Unit occurrence is restricted to the outer portion of the mapped area, where it covers paleovalley interfluves. Unit thicknesses here can reach several m, particularly if directly above the Beaverdam Formation (Tbd), presumably the source of the coarse clasts. It is locally draped by sheet sand deposits (Qss), easily distinguished by their high degree of sorting, color (yellowish-brown instead of dark-gray), and absence of silt and clay (Figure 8). In seismic data the unit displays little to no internal reflection and is characterized by either sonic transparency or a chaotic pattern. Its base generally represents a high-amplitude, high relief seismic surface that is mapped regionally. The Qrl unit covers large areas of the central study region (Figure 7), which is noted for its lower seafloor elevations (generally <20 m) and absence of the shore-oblique bedforms found just to the west where low seafloor elevations are on the order of 16 m.

Lagoonal/Estuarine (Ql, Qlh, Qsi, Qo)
Several muddy litho-types are encountered, associated with offshore-trending paleovalleys. Paleovalley fills are distinguished as those belonging to the Omar Formation (Qo), a mid-Pleistocene estuarine unit mapped landward and beneath the town of Bethany Beach, and Holocene-aged fill deposits associated with the paleo-Indian River and Rehoboth Bay systems (Ql), which traverse the northern portion of the offshore study area. The Omar Formation is characterized by interbedded dark-gray clay to light-gray silty clay interbedded with very fine to

fine silty sands. Holocene valley-fill units range from bluish-gray, organic-rich clays to gray clayey silts with fine sand laminae. Other fine-grained estuarine units include the Sinepuxent Formation (Qsi), a shore-parallel lagoonal complex in State waters, and deposits belonging to the Lynch Heights Formation (Qlh), a bay-margin estuarine unit mapped along the Delaware Bay-proximal coastal plain. The former comprises gray, laminated, silty, very fine to fine micaceous sand to sandy silt. It can be interbedded with fine to medium sand and contain abundant *Mulinia* shells. The latter is described as a clean, white to pale-yellow well-sorted fine to coarse sand with scattered pebble laminae and silty clay laminae. The Qsi and Qlh are not discussed any further in this text given their absence across the BOEM ASAP study area.

Marine sand (Qms)

This unit is medium to very dark-gray in color and is typified by interbedded clay and silt and sands of varying texture (Figure 6). Silty sand laminae are common within the muddy beds; sand beds may be fine to coarse. The unit is micaceous and shell content is sparse. The unit underlies the surficial Qss deposits of the Fenwick Shoal region and overlies the fluvio-deltaic sediments of the Beaverdam Formation (Figure 7). This tripartite stratigraphic division is exemplified in cores Ql51-02, Rk23-05, and Rl11-01, which were collected where the surficial sand unit is thin. Seismic images show that the lithologic boundaries captured here (B1 and B2) extend across the Fenwick Shoal area with little topographic variance (i.e. changes in unit thickness; Figure 8). Unit thickness varies, but is generally on the order of 2-3 m.

Fluvio-deltaic Beaverdam Formation (Tbd)

The Beaverdam Formation consists of fine to coarse interbedded sands that are slightly to moderately silty and contain varying amounts of gravel-sized clasts (Figure 6). Quartz and chert pebbles are generally found scattered throughout and also occur as interbeds. Light-gray is the typical color, but greenish, yellow, and orange discolorations are common. Graded bedding and cross-bedding are commonly observed. The unit is devoid of shell material and vertical sand- and clay-filled burrows are commonly encountered, whose dark-gray/dark olive-gray color (clay and silt content) offer a stark color contrast to the overall light-colored strata. Heavy mineral laminae are common. It is late Pliocene to early Pleistocene in age.

Table 4 *- Information for lithologic reference sections in offshore cores.*

Core ID	Map Unit	Depth range (m)	Defining Unit Characteristics	Unit Age	Environmental Interpretation	Formation Name	Resource Potential
Pj43-07	Qets	8.2-12.7	White to light-gray, fine to very fine mud-laminated sand.	Holocene	Ebb-tidal delta	NA	Poor
Pk32-05	Ql	16.5-22.2	Dark olive-gray, slightly silty clay with sandy burrows.	Holocene	Estuarine central basin	NA	None
Qk33-02	Qo	16.2-21.9	Interbedded dark-gray silty clay and fine-medium clayey to silty sand.	Pleistocene	Estuarine central basin	Omar	None
Qk24-01	Qrl	19.4-23.6	Gray, poorly-sorted sands and gravels.	Unknown	High-energy, shallow shelf during inundation	NA	Poor
Rk25-03	Qss	12.0-17.2	Light yellowish-brown medium sand with scattered quartz and chert pebbles, shell fragments, and heavy minerals	Holocene	Mid-shelf shoal	NA	Excellent
Oj34-06	Qlh	15.3-16.8	Shell-rich, mottled and slightly oxidized brown to dark gray silt and very fine sand with heavy mineral laminae.	Pleistocene	Subtidal to intertidal lagoon	Lynch Heights	None
Rj24-04	Tbd	14.1-19.0	Light-gray, interbedded silty sands ranging from fine to very coarse with scattered Q and chert pebbles and heavy mineral laminae.	Pliocene-Pleistocene	Fluvio-deltaic braid plain	Beaverdam	Poor to Excellent
Ql51-02	Qms	17.3-21.2	Interbedded and burrowed very dark gray to black fine silty sands, clays, and gravels.	Pleistocene	Estuarine/marine	NA	None
Oj35-02	Qsl	12.9-16.6	Well sorted, pale yellowish-gray fine to medium sands with zones of abundant dark gray clay-lined burrows.	Holocene	Shoal	NA	Excellent
Pk13-01	Qis	17.5-18.0	Greenish-black, bioturbated and silty, very fine to fine sand containing organic debris.	Holocene	Low-energy marine/inter-shoal	NA	Poor to good
Oj53-02	Qfs	12.8-17.1	Tan to yellowish, well-sorted fine to medium sands, shelly, heavy minerals and few silty burrows.	Holocene	Inner shelf shoals	NA	Excellent

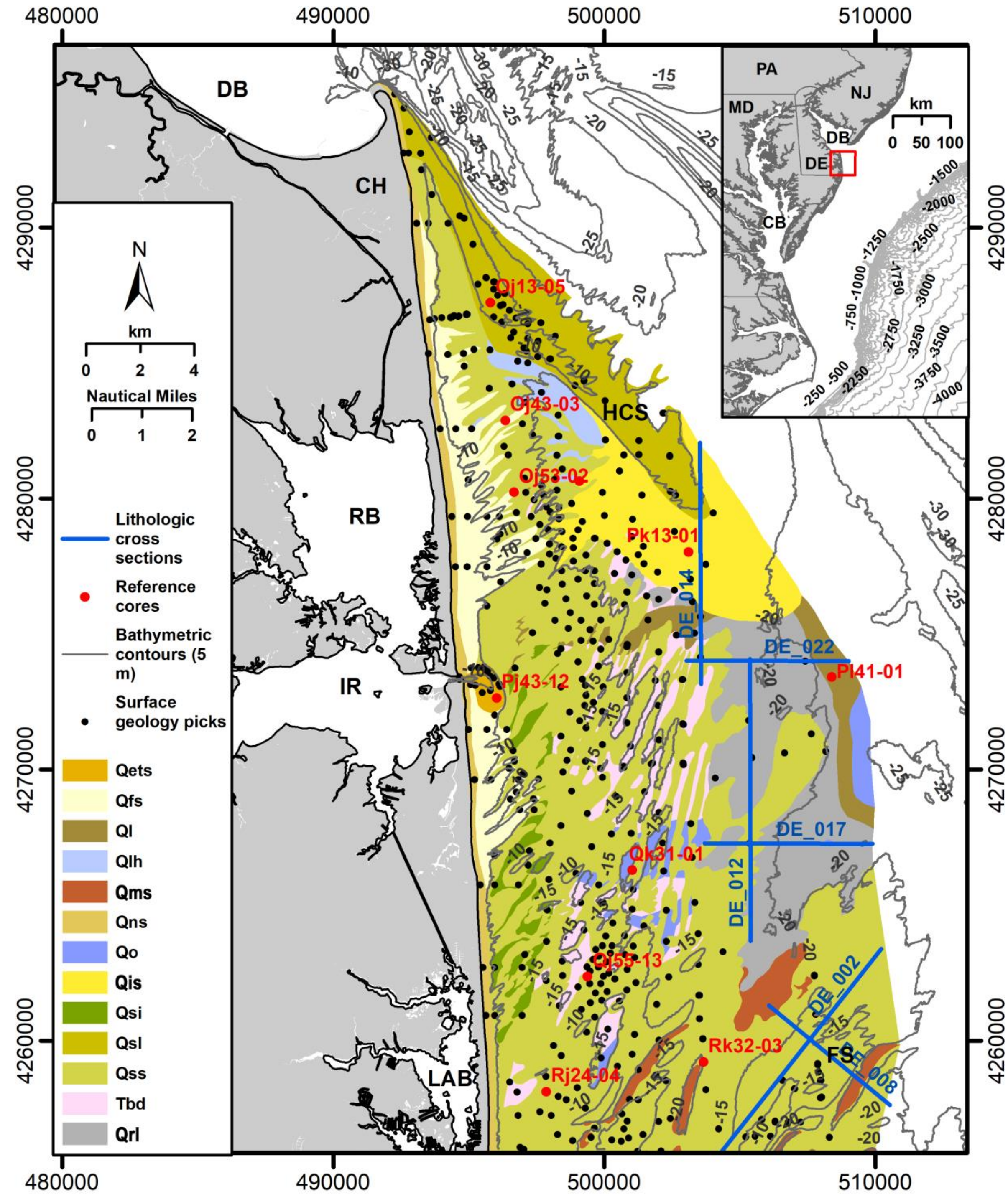

Figure 7 *– Surface geology map based on core information, seismic mapping, and seafloor topography (based on a 2015 USGS DEM built from 2007 NOAA data). Minimum unit thickness is 1 foot. If, for example the surface unit was a 0.5 foot gravel lag deposit overlying the Beaverdam Formation, the latter was used as the map unit. Reference cores are plotted (red) as are the locations of seismic cross sections shown in Figure 8.*

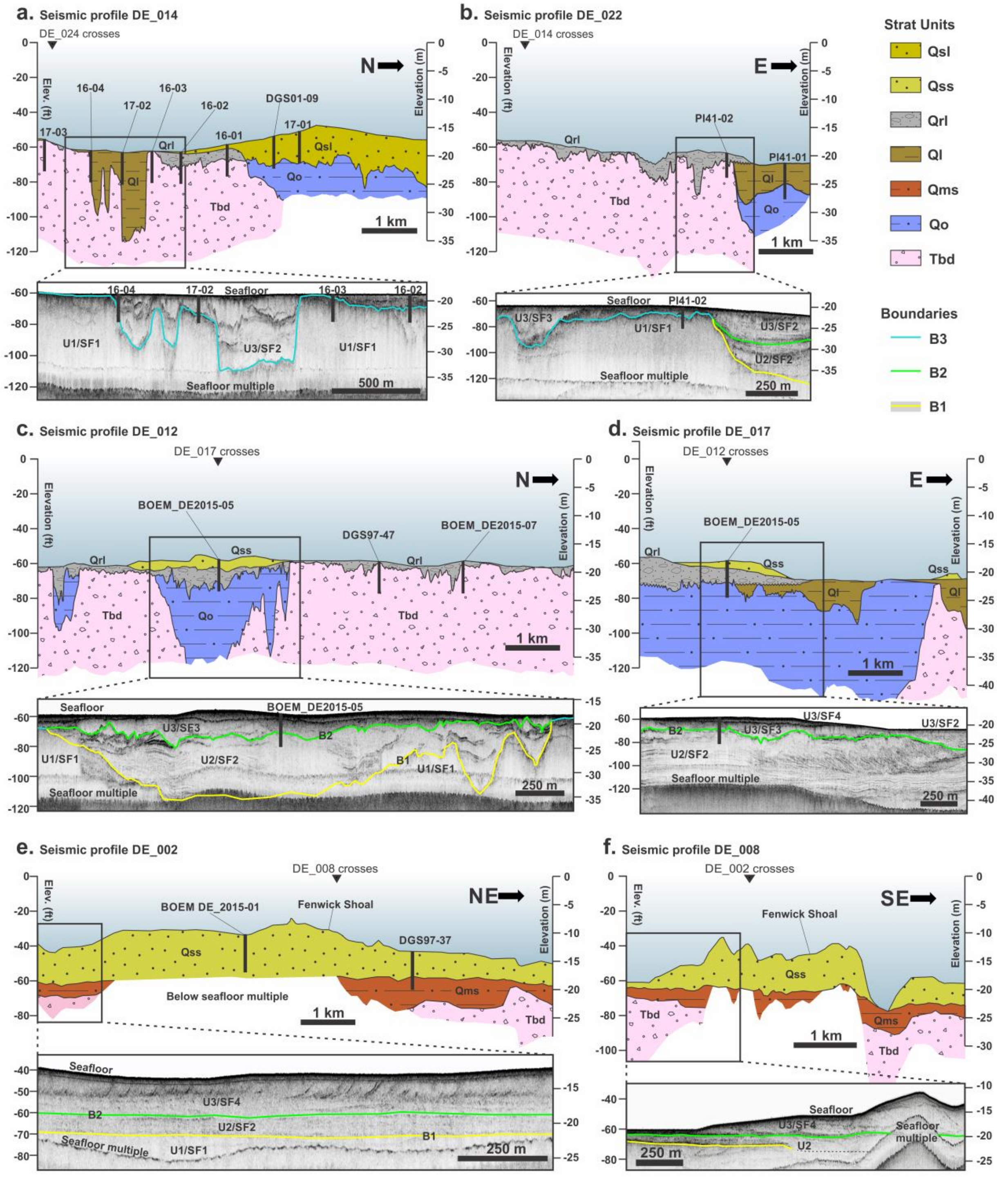

__Figure 8__ – Lithologic cross sections based on the integration of core and seismic data with accompanying excerpts of corresponding seismic images. Units are color-coded to match Figures 6 and 7. The Qsl unit comprising the Hen and Chickens Shoal in seismic profile DE_014 is comprised of interbedded Qis and Qsl, but is shown as Qsl at this scale given that lithologies prominence.

SEDIMENT TEXTURE RESULTS

Resource Mapping

Offshore Delaware seafloor stratigraphic units are primarily sand and are texturally heterogeneous (Figures 6 and 7). Previous work classifying resource potential (McKenna and Ramsey, 2002) did not have the benefit of stratigraphic unit identification or distribution of the stratigraphic units at the seafloor. Sediments from core sites were classified for resource potential using a stack-unit classification method (Berg et al., 1984; Kempton and Cartwright, 1984; Andres, 1991). Resource ratings of Excellent, Good, Fair, or Poor were assigned for each core site based on thickness of textural units (e.g., gravel, sand, mud) down core. Resource rating maps were drawn by mapping contiguous areas of each resource rating. The stack-unit methodology proved to be useful for identifying potential sand resource areas but the classification itself is tedious and is not likely to be implemented by anyone other than the original authors. As a part of this study, a simpler classification methodology was explored using standard textural statistics from sediment samples and a classification scheme already adopted for use by Federal agencies. This classification scheme is evaluated in the context of the geologic framework of the Delaware offshore (e.g., association of texture and stratigraphic units; Figure 8). Textural analyses from cores from two pilot areas were chosen that correspond approximately with the BOEM ASAP areas (Figure 9).

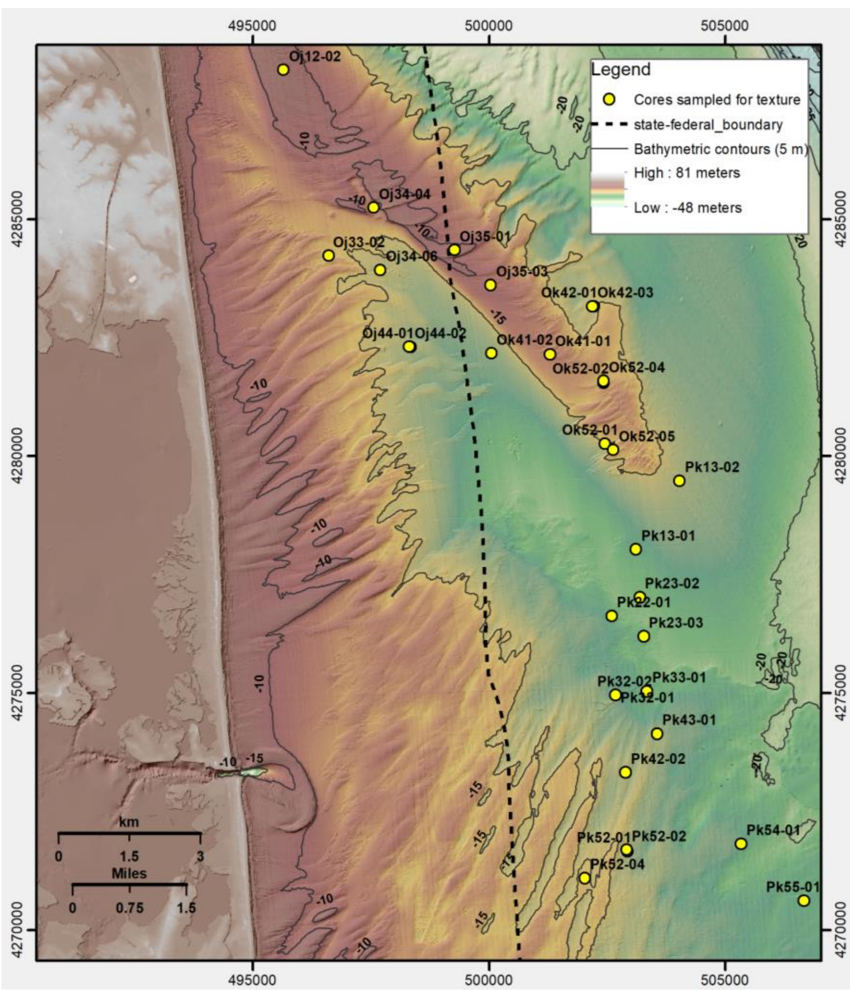

Figure 9 – Topobathymetric map based on 2007 NOAA/USGS multibeam data, showing the locations of cores for which texture samples were analyzed for this portion of the project. They are centered on the Hen and Chickens Shoal and proximal areas to the south, where finer and coarser deposits occur at the seafloor (Figure 7).

CMECS Classification

The Coastal and Marine Ecological Classification Standard (CMECS) is a catalog of terms developed for the classification of ecological units that includes both biological classifications (biogeographic units, systems, and settings) as well as classification of the geologic substrate upon and in which coastal and marine biota live (FGDC, 2012).

CMECS uses standard geologic sediment grain-size descriptors such as gravel, sand, and mud with qualifying size names (e.g., fine, medium, coarse sand; Wentworth, 1922) and is widely used in the geologic community. Because sediments always contain a range of grain sizes across the descriptor categories, CMECS uses Folk's (1954) Sand-Gravel-Mud (S-G-M) ternary diagram and threshold values with a few modifications. Mud is a term used for the combination of silt and clay particle sizes. None of the samples used in this study were analyzed to determine of silt and clay percentages, so the Sand-Silt-Clay classifications of CMECS are not used. Sediment textures are divided into classes based on the percentages of gravel. Greater than 80% gravel constitutes a true gravel. Sediment with percentages of gravel between 30 and 80% are termed gravel mixes, and between 5 and 30% as gravelly. Sediment with 1 to 5% gravel is termed as slightly gravelly. Gravel is a combination of granules (2 to 4 mm diameter or -1 to -2 phi) and pebbles (4 to 64 mm diameter or -1 to -6 phi).

Texture Database

This study uses sediment texture data from the ASAP project as well as historical data. The texture data were generated by multiple projects in multiple labs using several different methodologies and reporting protocols. In order to work from a standard data set, the DGS Texture Database was created. The database uses an Access platform. Raw weights for phi sizes were tabulated, or in some cases, weight percentages where the raw weights were not available. The database calculates the class percentages (e.g., fine, medium, coarse sand) and percent of mud-sand-gravel using the CMECS classifications. The percentages were checked against those originally reported by the labs doing the texture analyses and were found to be consistent (varying by $< 1\%$). Statistics such as mean grain size and sorting were input into the database from the original lab reports or where calculated from analyses done in the DGS lab using publically available software such as GRADISTAT. QA/QC was conducted on the data after import into the database in order to make sure there were no import errors.

Samples that have data reported only as statistical results (sorting, skewness, etc.) or only as Sand-Gravel-Mud (SGM) percentages have also been entered into the database but are not used for this study. The majority of grain size data and associated textural analyses from offshore cores come from three sources: U.S. Army Corps of Engineers (USACE), DGS projects funded by the Minerals Management Service (MMS), and DGS projects funded by the Bureau of Ocean Energy Management (BOEM). Data from USACE were generated by sieve analyses. Data funded by MMS were generated by rapid size analyses (RSA). Data funded by BOEM were generated by sieve analyses.

Data synthesis

The northern BOEM ASAP area and an area closest to Rehoboth Beach (Hen and Chickens Shoal area) were selected as the pilot areas for testing new resource classification analysis

(Figure 9). Eighty-nine texture data samples (Appendix 3) from the top six feet of 28 cores were compiled. The samples were restricted to those with complete texture data from which grain size parameters were calculated. The sand-gravel-mud percentages from samples from the top six feet of the cores were plotted on the CMECS classification triangle (Figure 10). The restriction to the top six feet is dictated by the general depth to which offshore bottom dredging is likely to penetrate in any given area. Primarily muddy cores were not sampled for textural analyses because they were not candidates for sand resources.

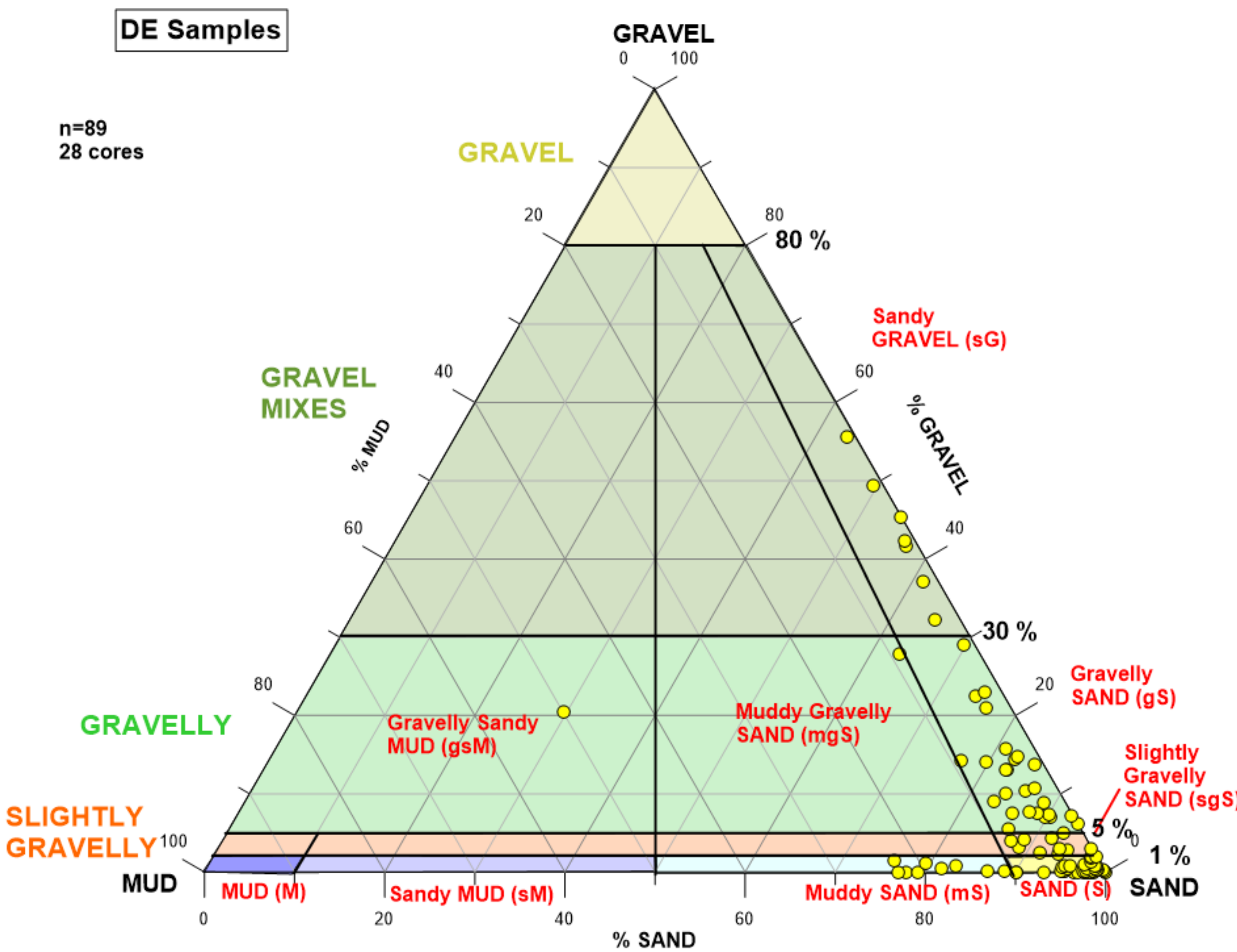

Figure 10 *– CMECS Ternary diagram plotting texture results from the top six feet of 28 sediment cores (locations are shown in Figure 9).*

Five percent by weight pebbles is used as an arbitrary boundary for determination of resource potential. Samples that have above five percent pebbles tend to break into two groups of between five and ten percent by weight pebbles and greater than 20 percent by weight. Beach design parameters will determine the tolerance for percentages of pebbles. Visually, samples that have greater than five percent pebbles look like they have a much higher percent.

Because muddy cores were not sampled, the samples plot primarily along the Sand-Gravel axis (Figure 10). Figure 11 shows the number of samples in each CMECS class. Of the 89 samples, 35 are in the gravelly classes and 53 in the sandy classes. Plotting the S-G-M percentages on the CMECS triangle gives a visual first approximation of sediment suitable for sand resources. Of the 89 samples, 14 contain gravel percentages above 20% with another 28 above 5%, and 11 above 1%. Thirty-one samples had less than 1 percent gravel.

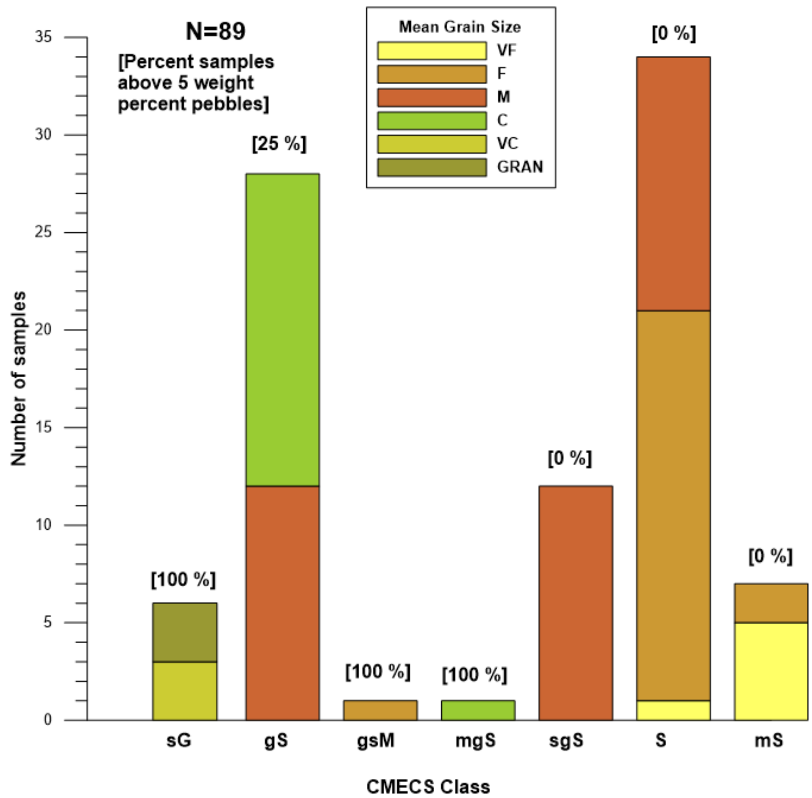

Figure 11 *- Bar chart of the CMECS classes showing the distribution of the number of samples by CMECS class; about a third of the samples fall in the gravelly sand (gS) class and a third in sand (S) class.*

As would be expected, the more gravelly the sediment, the coarser the sand size (Figure 11). Samples that fell in the sand class were primarily fine to medium sand. Samples in the gravelly sand class were primarily medium to coarse sand. Also indicated in Figure 11 are the percent of samples that have greater than 5 weight percent pebbles. The sandy gravel class had samples with weight percent pebbles between 32 and 46 percent of the sample. The gravelly sand class had 25% of the samples with pebble weight percentages between 6 and 20% but 57% of the samples had no pebbles. The reason that the other 75% of the samples were classified as gravelly is that they had up to 32% by weight granules. Muddy sand (mS) samples have very fine to fine sand. From other data, the mud component of these deposits is more silt than clay and could be used for sand resources if no other resources are available.

A large component of this study was geologic mapping of the offshore with the hope that the offshore stratigraphy can be used in identification of potential sand resources. Stratigraphic units have as a component of their definition sediment texture. As with subdividing the samples by their CMECS class, a bar chart was constructed subdividing the samples by their designated stratigraphic unit and mean sand sizes (Figure 12). Seven stratigraphic units were sampled. The Lynch Heights Formation (Qlh), sheet sands (Qss) and ravinement lag deposits (Qrl) are heterogeneous in their mean grain sizes. Intershoal deposits (Qis) are fine to very fine sands and shoal deposits (Qsl) are fine to medium sands. The Beaverdam Formation is the coarsest of the units with mean sizes ranging from medium sand to granule. The percent of samples with pebbles by weight greater than 5% shows that the shoal sands (Hen and Chickens Shoal) and intershoal deposits (Qis) do not contain significant amounts of pebbles. Only one sample out of seven in the sheet sands deposits (Qss) contained significant amounts of pebbles. This sample was from a thin sheet sand overlying the Beaverdam Formation that contained pebbles reworked from the underlying unit. Relict lag deposits have the highest percentages with almost half of the samples containing greater than 5% by weight pebbles. The Beaverdam Formation has 19% of the sample with greater than 5% by weight pebbles but 50% of the samples in the Beaverdam have no pebbles. Only one sample was in lagoonal deposits (Ql) and is a mix of pebbles and mud. From other cores, it can be determined that lagoonal deposits are muddy and not a potential resource.

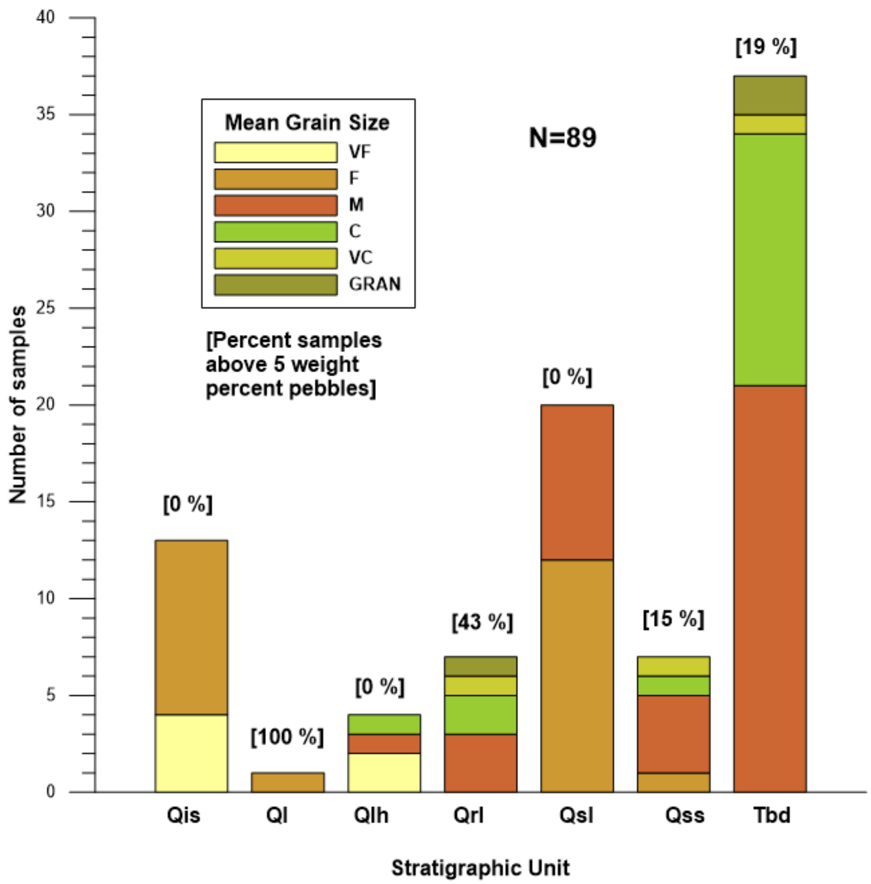

Figure 12 *- Bar chart of the CMECS classes showing the distribution of the number of samples by CMECS class; about a third of the samples fall in the gravelly sand (gS) class and a third in sand (S) class.*

DISCUSSION

Surface geology and subsurface architecture

The lithologic cross sections, constructed from seismic data and core constraint, depict the general tripartite structure of the shallow shelf (Figure 8). While sheet sand bodies (Qss) are extensive across the surface of the Delaware shelf, they are thin and discontinuous in places; underlying Pleistocene units (Qo, Qsi, Qms, Qlh), the late Pliocene Beaverdam Formation (Tbd), and basal transgressive lag deposits crop out here (Figure 7). This is common in Federal waters as the majority of sand ridges are confined to the inner shelf platform, in water depths <15 m (Figures 1 and 7). In Federal waters (where water depth generally >15 m), there are three distinct sandy lithosomes of significant volume and topographic prominence. The surface interval in the northern portion of the study area is dominated by the distal end of the Hen and Chickens Shoal, which is comprised of finer sand here than along its more shore-proximal section. The Qsl unit is up to 5 m thick here (based on seismic profiling) and thins as well as fines to the S/SE, where it grades into Qis. The latter eventually gives way to a gravel lag deposit (Qrl), which blankets much of the seafloor across the outer, most seaward portion of the map area. It is locally draped by Qss. Closer to shore, isolated NE-SW trending Qss ribbons are interspersed with areas where Tbd crops out. Figures 7b and 7c show how thin surficial Qss sands and other Holocene units are atop the fluvio-deltaic Tbd, which underlies the entire study area. Thicker Quaternary sections are only found in association with extensive shoal fields (e.g. Fenwick; Figures 7e and 7f) and/or where paleovalley fills are encountered (Figures 7a-7d).

Recommendations based on Sediment Texture

The purpose of this portion of the study was to identify sand resources using grain size data in a relatively simple and straightforward manner. A primary consideration in this process is to focus on resources that do not have significant pebble percentages. Pebbles present both technological issues, such as screening at the dredge source, which creates a lag armor that precludes re-use of the dredge site, and mobilization of sediment from the dredge to the beach, as well as cultural issues relating to use of the beach and nearshore by those enjoying the shore environment. This is a pilot study and does not have a significant number of samples to be statistically rigorous. Some general conclusions are made.

1. The CMECS classification system using the Sand-Gravel-Mud percentages provides a simple first look at a potential resource.
    a. Sites with multiple samples in the sandy Gravel class are likely to have large percentages of pebbles and can be considered a poor resource for sand for beach replenishment.
    b. Sites with gravelly sand deposits may or may not be a good resource. It is important to look at the gravel fraction to determine whether the weight percent is largely pebbles or granules.
    c. Sites that fall in the slightly gravelly sand or sand classes have few to no pebbles. The slightly gravelly sand gravel component is comprised of granules (<2 mm diameter)

2. Distribution of offshore stratigraphic units (Figure 7) can be used as a resource exploration tool.
    a. Shoal and intershoal deposits are not gravelly. Intershoal deposits may be on the finer end of what can be used for beach replenishment.
    b. Ravinement lag deposits can be ruled out as a potential resource.
    c. Sheet sands are a good to excellent resource with pebbles only occurring close to the underlying Beaverdam Formation.
    d. The Beaverdam Formation contains good to excellent resources but also contains beds that are gravelly. Detailed coring in a potential resource area will be required to avoid the coarsest zones.
    e. The Lynch Heights Formation may be a possible source for sand, but too few samples were analyzed to make any conclusions.
3. A resource need is a sand source as close to Rehoboth Beach as possible. Shoal deposits that are an excellent resource are nearby but are likely not accessible due to conflict of interest. The area west of the shoal in the area of intershoal deposits may hold potential, especially in areas adjacent to sheet sands or shoal deposits where the sands may be coarser.
4. In terms of resource ratings, the following schema using CMECS classifications is proposed.

a. Sand (S) and slightly gravelly sand (sgS)	Excellent
b. Gravelly sand (gS) depending on the % of pebbles	Good
c. Muddy sand (mS) depending on the % of mud	Good-Poor
d. Sandy gravel (sG)	Poor

Volumetric Analyses

Lithologic mapping based on seismic and core data has resulted in the isolation of three distinct sand bodies for volumetric analysis (from south to north): 1) the Fenwick Shoals, 2) the central region shoal, and 3) the tip of Hen and Chickens Shoal (Figure 13). Sand volumes were assessed as follows: Isopach models were generated as the difference between seafloor elevation and the first high-amplitude bottom reflector in areas of verified sheet sand occurrence (Seafloor elevation minus base of sheet sand elevation = thickness). The map area of the sand body, assessed from seismic data interpretations and seafloor topography (2015 USGS dataset), was calculated in ArcMap and multiplied by the mean pixel value of the corresponding isopach model, yielding m^3 of volume. The metrics presented are raw and adapted from the outputs of this procedure. Volumes represent an estimate or approximation based on the data at hand. Negative pixel values for the central shoal region and the Fenwick Shoal suggest some issues involving interpolation and raster subtraction, likely related to differences in age of the datasets (cores collected from 2015-2017 versus seafloor elevation data from 2007).

The following sections discuss the volume models for each of the three areas of interest, describing insights from core and seismic data.

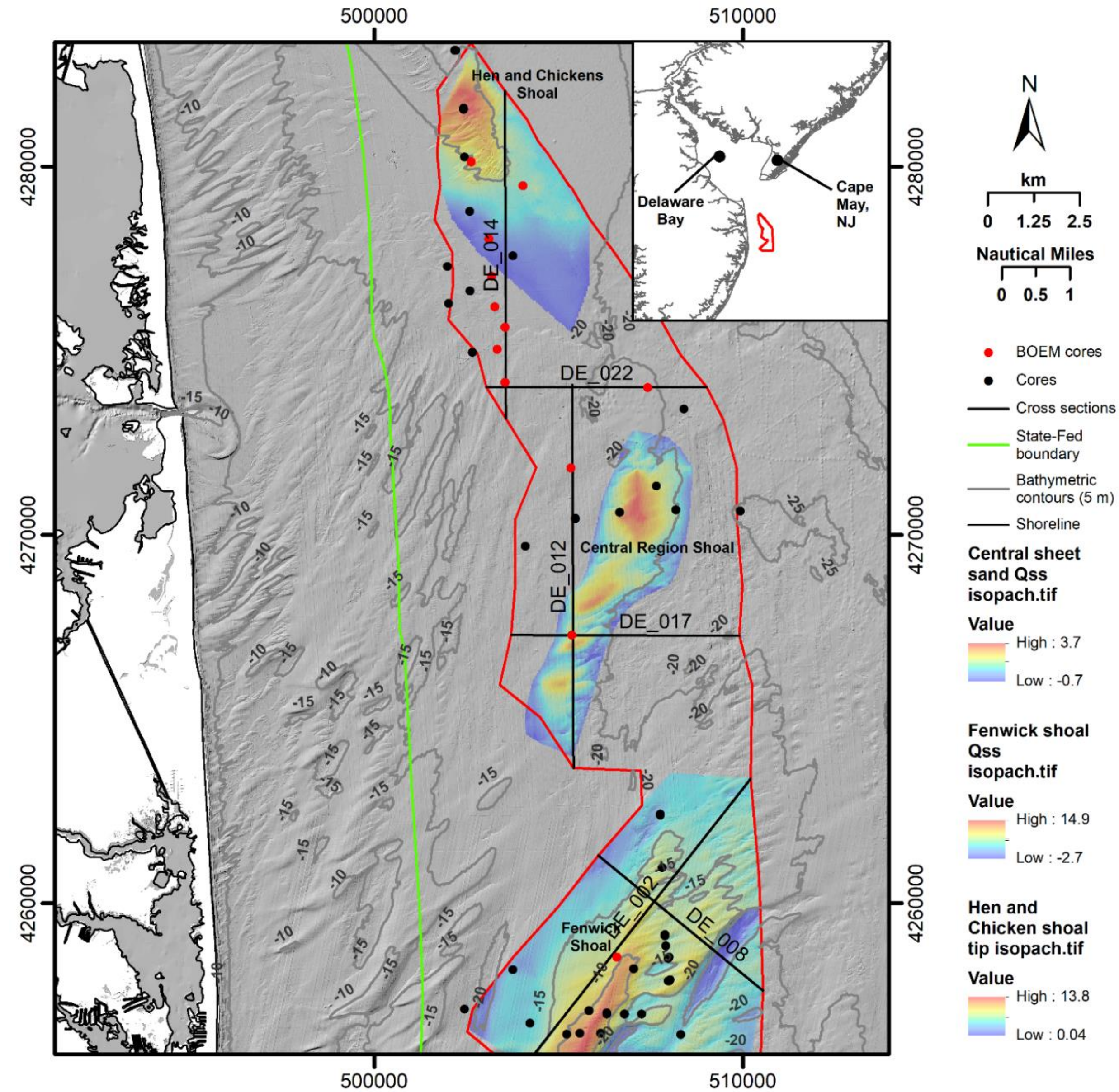

Figure 13 *– Isopach models of three sand bodies fitting the textural criteria for beach nourishment. The thicknesses are based on the 2015 USGS bathymetric dataset and the stratigraphic picks at the base of the surficial unit (from seismic and core). Negative isopach values are a product of the gridding process of the lower bounding surface and its subtraction from the much higher resolution 2015 USGS DEM. They correspond to isolated groupings of pixels and should have minimal influence on the overall analysis of sediment volumes.*

Fenwick Shoal Sand Volume

A total of 29 core logs exist in the DGS database for this part of the survey area (Figure 14). They provide litho-stratigraphic constraint for the interpretation of mapped subsurface seismic reflections, which map a tripartite unit sub-division across this area (Figure 8). Of all DGS cores, most penetrate only into a sheet sand body, representing the surficial unit. It consists of clean, fine to coarse sands and variable amounts of shell debris (see unit description for Qss; Table 4). A newly-acquired core (BOEM DE_2015-01), collected from central shoal body (at high elevation) typifies unit Qss across this area (Appendix 1). Only three DGS cores, which are situated along the perimeter of the sand body, penetrate through the surficial unit, into the underlying substrate (Qss). All three sample the Beaverdam Formation in the bottom-most core intervals (beneath Qms, an interstitial estuarine/lagoonal unit of Pleistocene age; Figures 8e and 8f). These cores are: Rl11-01 (DGS97-37), Ql51-02 (DGS97-38), and Rk23-05 (DGS97-43). The estimated volume of Qss, based on the 2015 USGS bathymetric dataset and seismic surface B2 (characterized by a lithologic contact between lagoonal/estuarine deposits below and Qss above in the aforementioned cores), is on the order of 297,200,000 yd^3 , reaching a maximum thickness of around 14 m (with a statistical mean of 5.2 m).

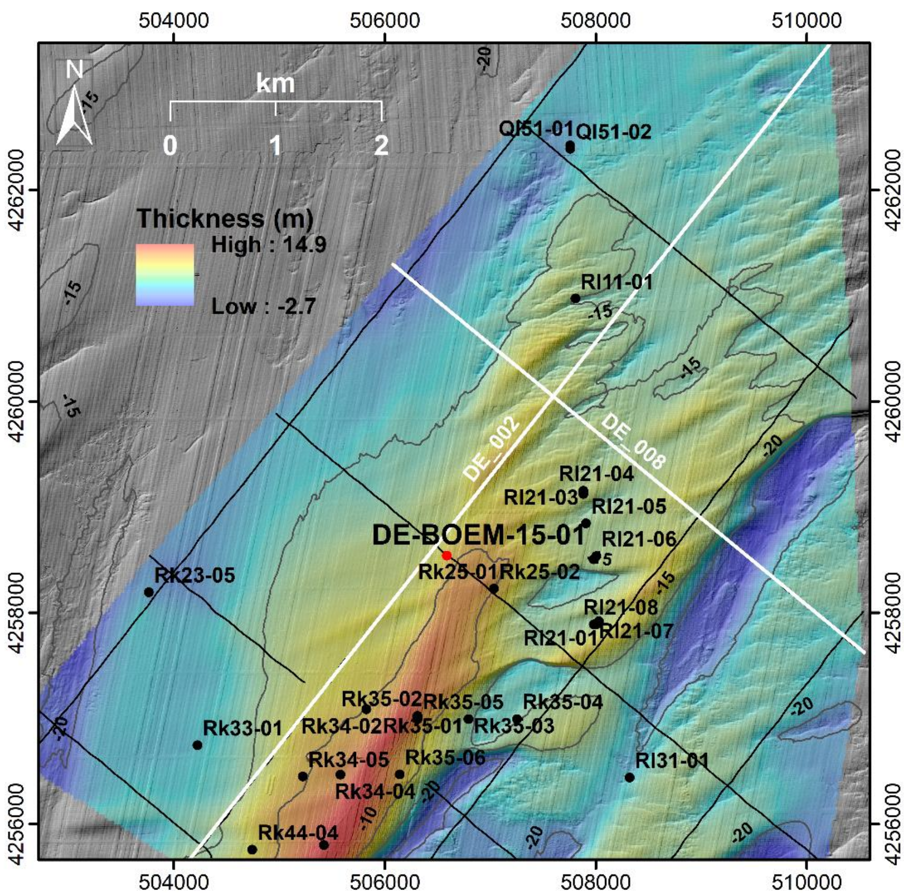

Figure 14 – *Isopach model of Fenwick Shoal sand body, which fits the textural criteria for beach nourishment. The thicknesses are based on the 2015 USGS bathymetric dataset and the stratigraphic picks at the base of the surficial unit from seismic and core. The isopach grid model is unmodified. Negative isopach values are a product of the gridding process of the lower bounding surface and its subtraction from the much higher resolution 2015 USGS DEM. They correspond to isolated groupings of pixels and should have minimal influence on the overall analysis of sediment volumes.*

Central region shoal volume

Subsurface lithologic constraint for the central region is provided by ten cores, two collected as part of the BOEM initiative (DE-BOEM-15-05 and DE-BOEM-15-07; Figure 15; Appendix 1). Seismic penetration in this area is excellent given deeper water depths and thus a longer time interval before interference and obscuration by the seafloor multiple (Figures 8c and 8d). Cores and seismic data suggest that the surface unit across this area is dominated by a transgressive lag unit (Qrl), defined by an enrichment of coarse clasts derived from the reworking of the underlying Beaverdam Formation. Highly variable in texture and poorly sorted, this unit is characteristically coarse-grained, but is commonly interbedded with fine-grained and organic-rich silty sands. This lag deposit can reach several m in thickness, which is highly variable across the area. The unit's lower bounding surface is recognized in seismic data as a high amplitude reflector of high local relief. It is subsequently interpreted to represent an erosional surface (transgressive surface or amalgamation of erosion surfaces). The unit's internal reflection pattern is characterized by acoustic transparency or chaotic patterns. The Qrl unit is capped by a sheet sand body of up to 3.6 m in thickness, recognized easily from a recent (2015 USGS) bathymetric dataset (Figure 11). Its volume is estimated at 26,400,000 yd^3, based on the aforementioned bathymetry information and the boundary between units Qss (sheet sand) and Qrl, captured in several cores and recognized/delineated across the seismic dataset. The seaward extent of the seismic data coverage captures a deepening of the interpreted base of the Pleistocene (i.e. top of the Beaverdam Formation).

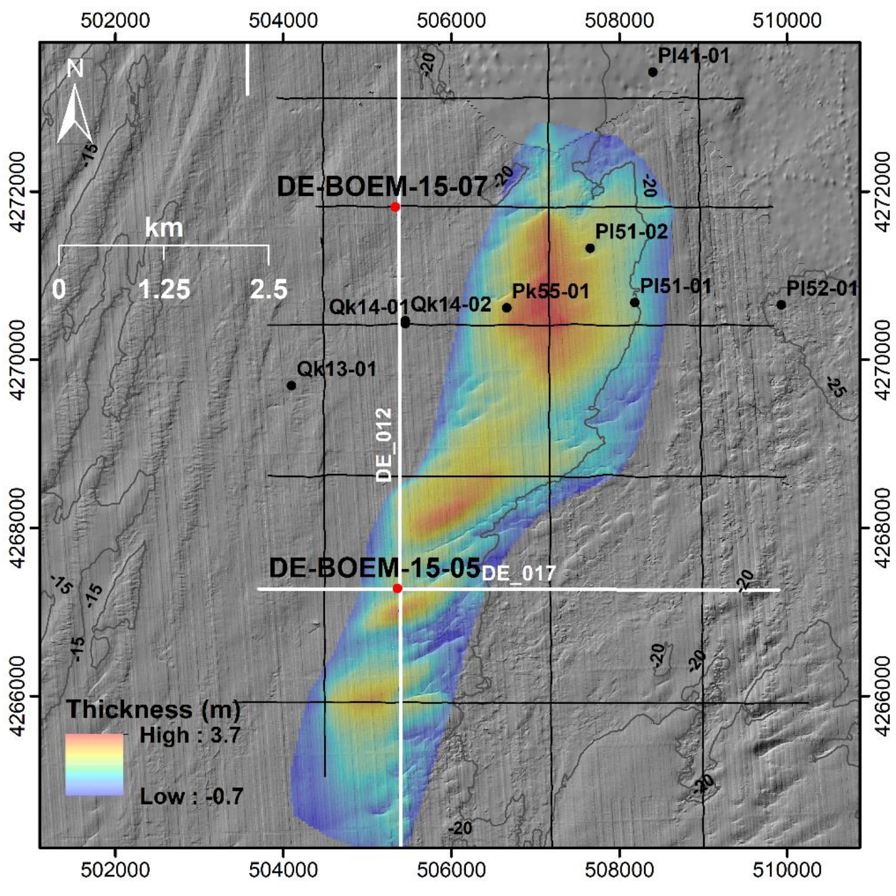

Figure 15 – *Isopach model of a sheet sand body within the central portion of the study area, which fits the textural criteria for beach nourishment. The thicknesses are based on the 2015 USGS bathymetric dataset and the stratigraphic picks at the base of the surficial unit (from seismic and core). The isopach grid model is unmodified. Negative isopach values are a product of the gridding process of the lower bounding surface and its subtraction from the much higher resolution 2015 USGS DEM. They could also correspond to isolated groupings of pixels and should have minimal influence on the overall analysis of sediment volumes.*

Tip of Hen and Chickens Shoal

Subsurface lithologic constraint for the central region is provided by seventeen cores, six collected as part of the BOEM initiative (DE-BOEM-15-03 and DE-BOEM-16-01, DE-BOEM-16-02, DE-BOEM-16-03, DE-BOEM-17-01, and DE-BOEM-17-02; Figure 16; Appendix 1). Seismic penetration here is poorest among the three sites; Figures 8a and 8b). Surface sands (Qsl), while thick, contain trace silts and are occasionally interbedded with silty deposits (Qis). The volume estimate is on the order of 108,500,000 yd^3, based on USGS bathymetry and the mapped contact between Qsl and Qo/Qrl (Figure 8a). Mean thickness is around 5 m.

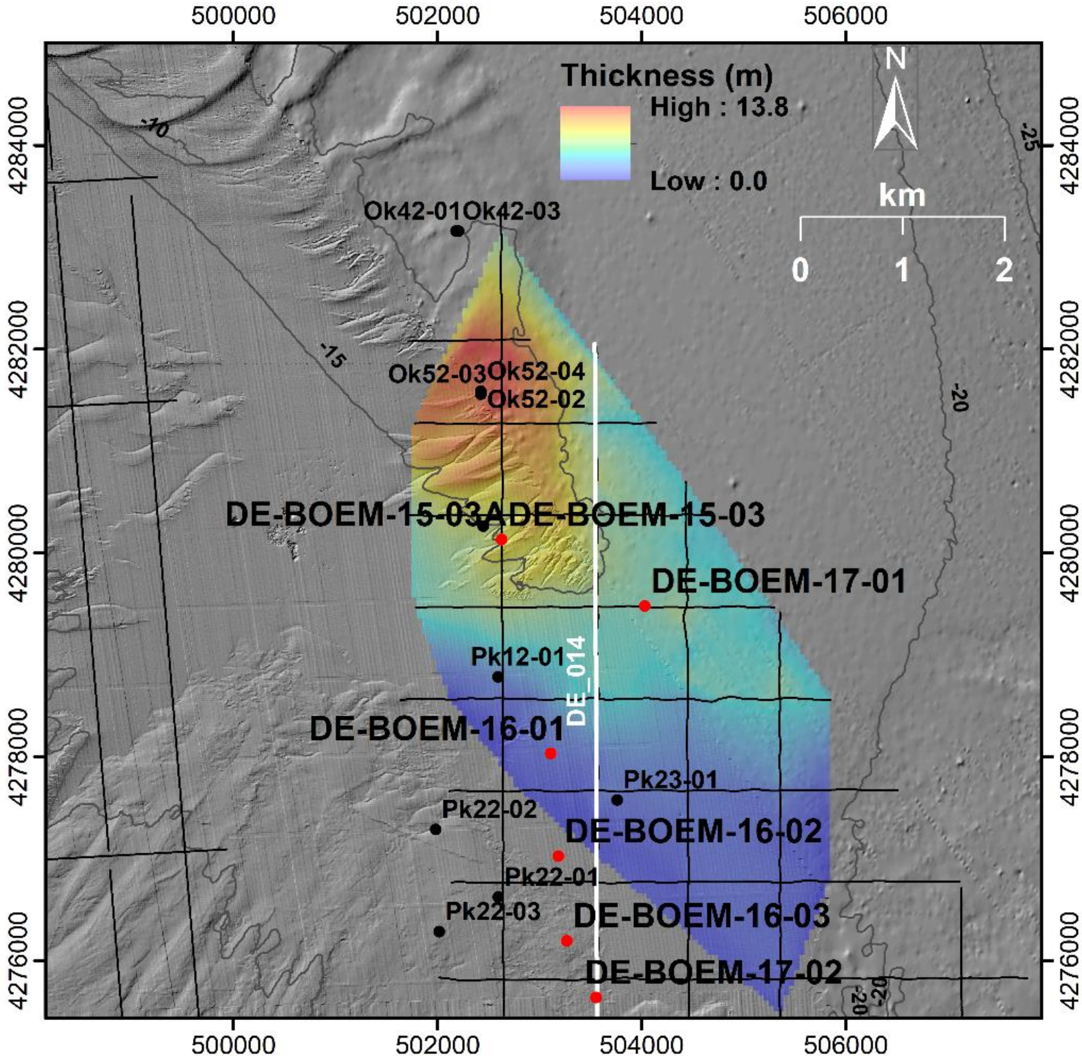

Figure 16 – Isopach model of the tip of the Hen and Chickens Shoal, which fits the textural criteria for beach nourishment. The thicknesses are based on the 2015 USGS bathymetric dataset and the stratigraphic picks at the base of the surficial unit (from seismic and core). The isopach grid model is unmodified. Negative isopach values are a product of the gridding process of the lower bounding surface and its subtraction from the much higher resolution 2015 USGS DEM. They could also correspond to isolated groupings of pixels and should have minimal influence on the overall analysis of sediment volumes.

CONCLUSIONS

1. An updated geologic map for offshore Delaware (Figure 7) provides a geologic framework for sand resource exploration in Federal waters, based ,in large part, on newly acquired core and geophysical data from the ASAP project.
2. The geologic map is useful for distinguishing areas of high resource potential from those of low resource potential.
3. The general architecture of the DE shelf subsurface is characterized by a tripartite stratigraphic division.
4. Outcroppings of the fluvio-deltaic Beaverdam Formation and/or pebbly transgressive lag deposits in areas of patchy or absent sheet sand distribution are areas to avoid, based on the enrichment in gravel-sized clasts of respective deposits.
5. Three potential resource areas are identified in mapped Federal waters; the rest of the area is largely blanketed by deposits that are too coarse or too muddy.
6. Sand volumes are calculated as follows:
    - **a.** Fenwick Shoal contains on the order of 297.2 million yd^3
    - **b.** The central region shoal is estimated to contain around 26.4 million yd^3 of sand
    - **c.** The volume of the distal Hen and Chickens Shoal is approximately 108.5 million yd^3

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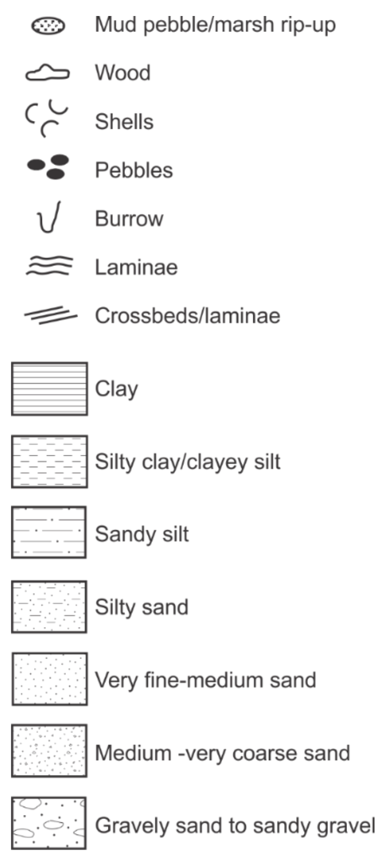
APPENDIX 1 – BOEM ASAP DE CORE LOGS

The following pages contain vibracore logs for the DE BOEM cores collected in 2015-2017, based on in-house core descriptions. They do not incorporate the results of texture analysis (i.e., are based solely on core descriptions made prior thereto), which are provided in Appendix 2.

LEGEND FOR CORE LOGS



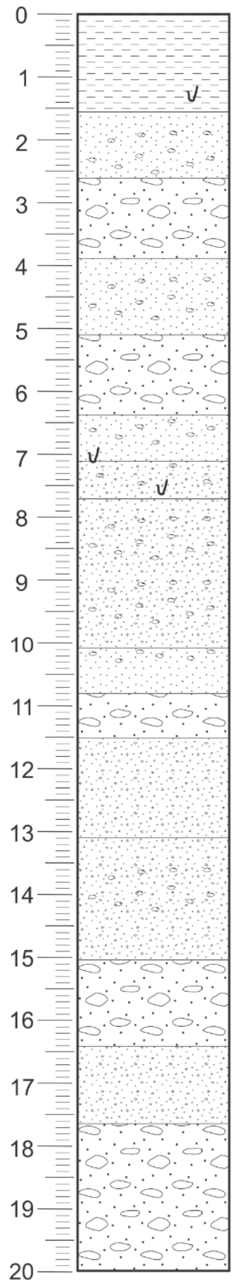
DGSID Pk13-01 DATE DESCR. 11/14/17 WATER DEPTH (FT) 57.4

LOCAL ID. BOEM-16-01 DESCR. BY CRM

DEPTH (FT)

LITHOLOGIC DESCRIPTION

SAMPLE #



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115277

SAND: vf-f, slty, dk gn gry (2.5/10Y), completely bioturb, sd-fill burr @ 1.3'.

SAND: m-crs, gn gry (5/10Y), bioturb, cly-fill burr, scat pbl.

GRAVEL: sndy, gry (1 GLEY 5/10Y), rnded Q & chrt pbl.

SAND: m-crs, gry (1 GLEY 7/10Y), scat pbl (rnded Q & chrt).

GRAVEL: sndy (m-crs), gry (1 GLEY 7/10Y), rnded Q & chrt pbl, matrix-supported.

SAND: m-crs, gry (1 GLEY 7/10Y), normal grading, scat pbl (<1 cm), cly-fill burr @ 7.0'.

SAND: crs-vcrs, gry (1 GLEY 7/5GY), scat pbl, cly-fill burr @7.6' (1 GLEY 5/10GY).

SAND: crs-vcrs, gry (1 GLEY 1/10Y), grav @8.1-9.0'.

SAND: m-grav, gry (1 GLEY 7/10Y), upwrd-crsening.

GRAVEL: sndy (crs-vcrs), gry (1 GLEY 7/10Y).

SAND: crs-vcrs, gry (1 GLEY 7/10Y)

SAND: crs-grav, gry (1 GLEY 7/10Y)

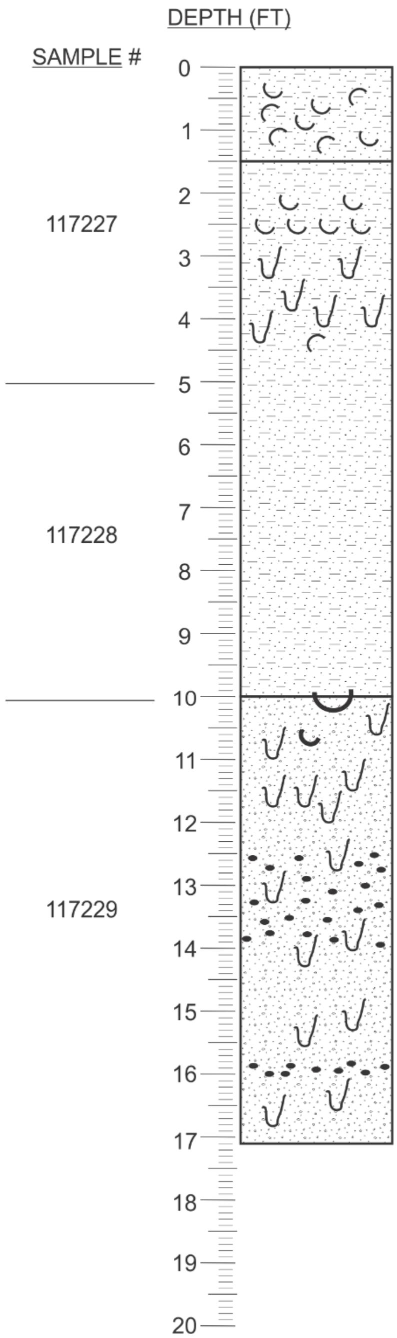
GRAVEL: sndy, gry (1 GLEY 7/10Y)

SAND: crs-vcrs, olv gry.

SAND: m-vcrs, grav interbed @ 17.6-17.7', 17.9-18.2', 18.5-18.6', and 18.7-18.9.

DGSID Pk13-02 DATE DESCR. 02/01/18 WATER DEPTH (FT) 54.07

LOCAL ID. DE-2017-01 DESCR. BY CRM



LITHOLOGIC DESCRIPTION

SAND: v slty-clyey, bioturb, abd scat shl frags, blck clr (1GLEY 2.5/N) to dk olv gry (1GLEY 4/10Y), grad cntct @ 1.5'.

SAND: f-m, v slty-clyey, bioturb, dk olv gry (1GLEY 4/10Y), few scat shl frag, gran & cly-fill Bur; v clayey zn @5-7.6', m clyey-slty sd zn @7.6-10', 2 cm diam pbl @9.8-10', mod slty f sd zn @1.5-2.6, abd shl frags @2.5-2.6' & 3'.

SAND: m-vcrs, slty, bioturb (strless), few interbeds (sd), abd clyey sd-fill Bur (lt blsh gry - 1GLEY 6/5G), scat gran; abd gran zn @ 12.5-14.1' & 15.8-16'; lg shl frag (8 cm diam conch) @ 10-10.4', lg shl frag (~2 cm diam) @ 10.6-10.7.

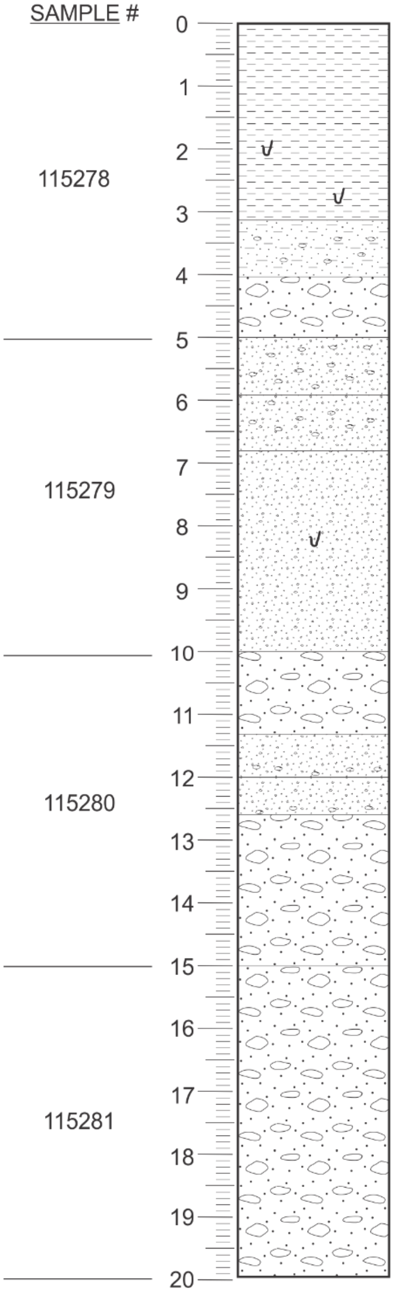
DGSID Pk23-02 DATE DESCR. 11/15/17 WATER DEPTH (FT) 60.0

LOCAL ID. BOEM-16-02 DESCR. BY CRM

DEPTH (FT)

LITHOLOGIC DESCRIPTION

SAMPLE #



CLAY: slty-sdy (f), crsening upcore, sd-fill bur @ 0.4', oxidized @ 0.6-0.7' and 0.9-1.0', sd-fill bur @ 2.0' and 2.8'.

SAND: f-crs, slty, rdsh (7.5 YR 4/6), Fe-stain, possible bioturb.

SAND: f-m, scat vcrs sd & gran, Fe-stain, rdsh (7.5YR 4/6).

SAND: crs-vcrs, scat gran, Fe-stain, rdsh (7.5YR 4/6).

SAND: vcrs, grav, or-gry (7.5 YR 6/6) to gry (1 GLEY 7/10Y), ~1 cm diam pbl @ 6.1-6.2'. Q, chrt, lith.

SAND: crs-vcrs, vcrs/gran-fill bur @ 8-8.3'.

SAND: m-crs, ylsh-gry (10YR 6/3), scat pbl. Q, chrt, lith.

SAND: vcrs-gran, dncore crsening, ylsh-gry (10YR 6/3).

SAND: vcrs-gran, dncore crsening, rdsh (2.5 YR 4/4), scat pbl. Q, chrt, lith.

SAND: f-vcrs, slty, scat pbl, ol-gry (2.5Y 7/4), Q, chrt, lith.

SAND: f-vcrs, scat pbl (Q, chrt, lith), vcrs sd @15.8 - 16.3'.23-03

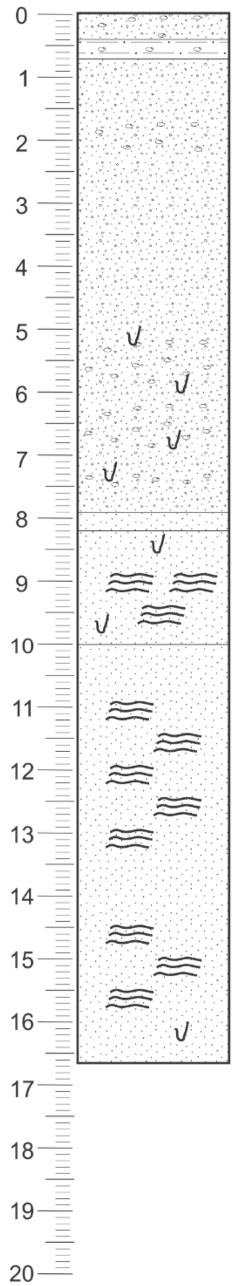
DGSID Pk23-03 DATE DESCR. 11/15/17 WATER DEPTH (FT) 59.4

LOCAL ID. BOEM-16-03 DESCR. BY CRM

DEPTH (FT)

LITHOLOGIC DESCRIPTION

SAMPLE #



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SAND: crs-vcrs, lt olv gry (1 GLEY 8/10Y), scat pbl, scat shl, cly-fill bur, dwncre

CLAY: slty-sdy, dk gry (1 GLEY 3/10Y), scat pbl.

SAND: crs-vcrs, lt olv gry (1 GLEY 8/10Y), scat pbl, scat shl, cly-fill bur, dwncre crsening.

SAND: f-m, lt gry (1 GLEY 8/5G), srted, Q, clean.

SAND: f, ylsh-gry (2.5Y 7/2), OHM lam @9-9.2', 9.3-9.5', and 9.8-9.9', sd-fill bur (m-crs).

SAND: f, ylsh-gry (2.5Y 7/2), crs sd lams @11-11.1' and 12.7-13', OHM laminae at 11.4-11.9' and 15-16', sdy cly (dk gry - 2.5Y 4/1) bur @ 12.5-12.6'.

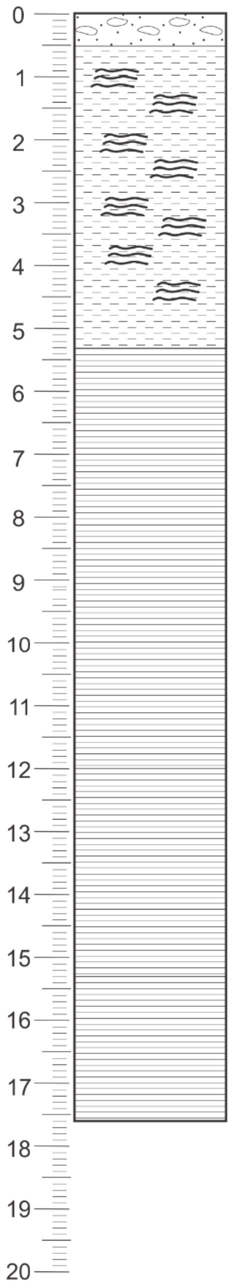
DGSID Pk33-01 DATE DESCR. 11/15/17 WATER DEPTH (FT) 58.2

LOCAL ID. BOEM-16-04 DESCR. BY CRM

DEPTH (FT)

LITHOLOGIC DESCRIPTION

SAMPLE #



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GRAVEL: gran & pbl (lith, Q, chrt), sdy (m-crse).

CLAY: slty, mott, or (10 YR 4/6) to dk gry (1 GLEY 13/5G), sdy lam, scat orgs @ 4.1', 4.8-5.3'.

CLAY: dk gry (1 GLEY 4/5G), interbed brnsh-blk (1 GLEY 1N to 10 YR 2/1) org-rich (fibrous peat); cly-rich @6.8-7.2', 7.8-8.6', and 9.5-10.2'.

CLAY: blsh-gry (1 GLEY 5/5G), scat orgs, clr change to dk brwnsh-gry (10YR 3/1) w/ incr orgs @12.7-13.2.

CLAY: blsh-gry (1 GLEY 5/5G).

DGSID Pk33-02 DATE DESCR. 01/31/18 WATER DEPTH (FT) 63.69

LOCAL ID. DE-2017-02 DESCR. BY CRM

DEPTH (FT)

LITHOLOGIC DESCRIPTION

SAMPLE #

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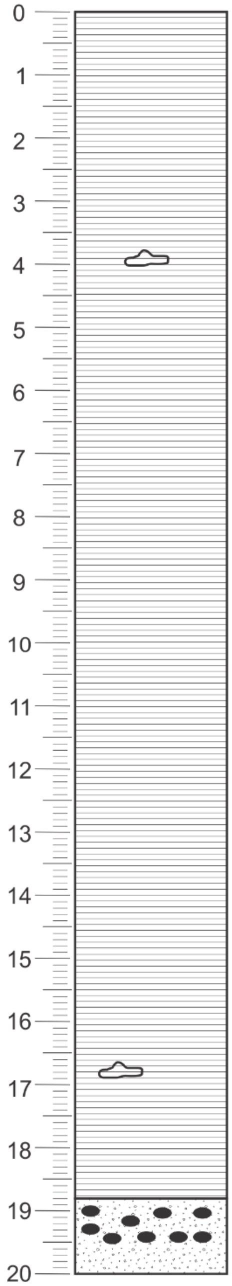
117232

117233



CLAY: dk olv gry (1GLEY 4/5GY), motts, scat orgs; wood @3.9-4' (sampled for C-14), slty/sdy cly-fill Bur (clr AA) @ 4.8-4.9', wood @ 16.8’ (sampled for C-14).

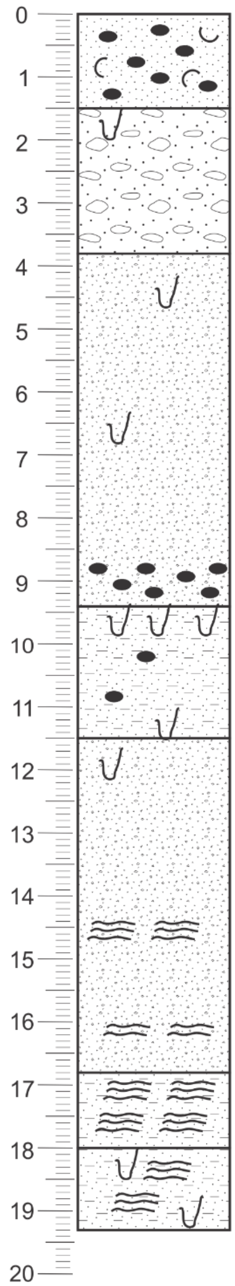
SAND: m-crs, slty, dk gry (1GLEY 4/N), abd Q pbl @ 19-19.6', v slty @ 18.8-19.1 (matrix), m sd zn (sltly slty) @ 19.7-20.

DGSID Pk43-01 DATE DESCR. 02/01/18 WATER DEPTH (FT) 58.83

LOCAL ID. DE-2017-03 DESCR. BY CRM

DEPTH (FT) | LITHOLOGIC DESCRIPTION

SAMPLE #



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SAND: f-m, lt tan clr (2.5Y 7/2); abd Q, abd Q & chrt pbl (rnded, up to 4 cm diam) in crs sd matrix w/ few scat shl frags @ 0.4-1.2'; orgs @ 0-0.2' (blk clr); shrp cntct @ 1.5'.

SAND: slty slty, dwncre crsning from m/crs to vcrs & pbly; scat Q & chrt pbl (rnded), yllsh clr (2.5Y 7/4); clyey sd-fill Bur (lt gry - 2.5Y 7/1) @ 1.6-1.7', lg rnded (~3 cm diam) Q pbl @ 1.8-1.9', abd gran & pbl (rnded, Q & chrt) @ 2.5-3.8', shrp cntct @3.8'.

SAND: crs (m-vcrs), few scat gran, Q & chrt, few OHM, lt gry clr (2.5Y 7/1), clyey sd-fill Bur (lt gry - 2.5Y 6/1) @ 4.3-4.5', cly-fill Bur (dk olv gry - 1GLEY 4/10Y) @6.6-6.7', clr chng to olv gry (1GLEY 6/10Y) @ 8.2-8.6', abd rnded Q pbl (up to 3 cm diam) @8.7-9.4', shrp cntct @ 9.4'.

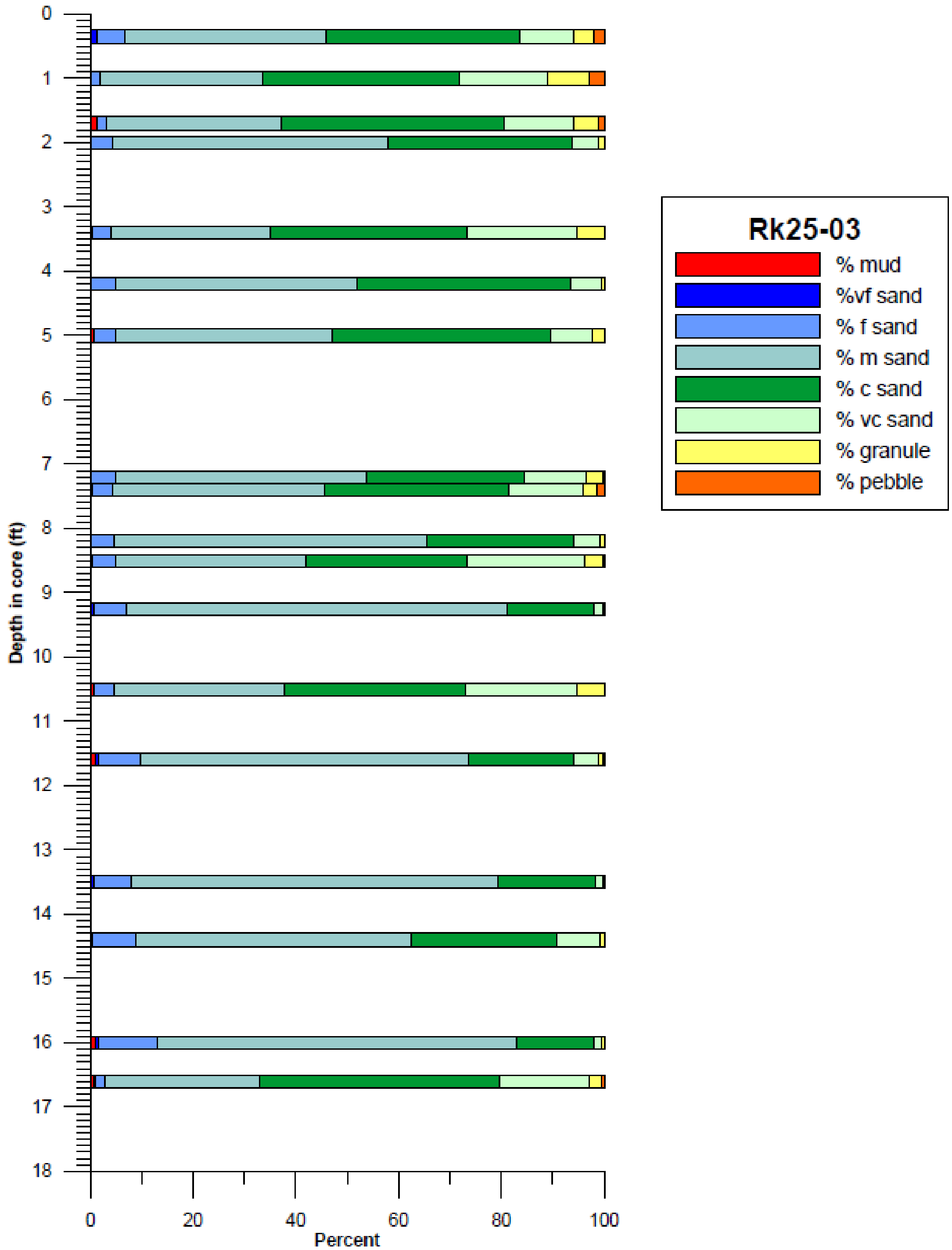
SAND: f-m, slty, bioturb, lt blsh-gry (2GLEY 7/10BG), OHM & mica, few scat Q pbl (rnded); crs sd/grav-fill Bur @9.4-10.4', dk olv-gry (AA) sd-fill Bur @11.4', grad cntct @ 11.5'.

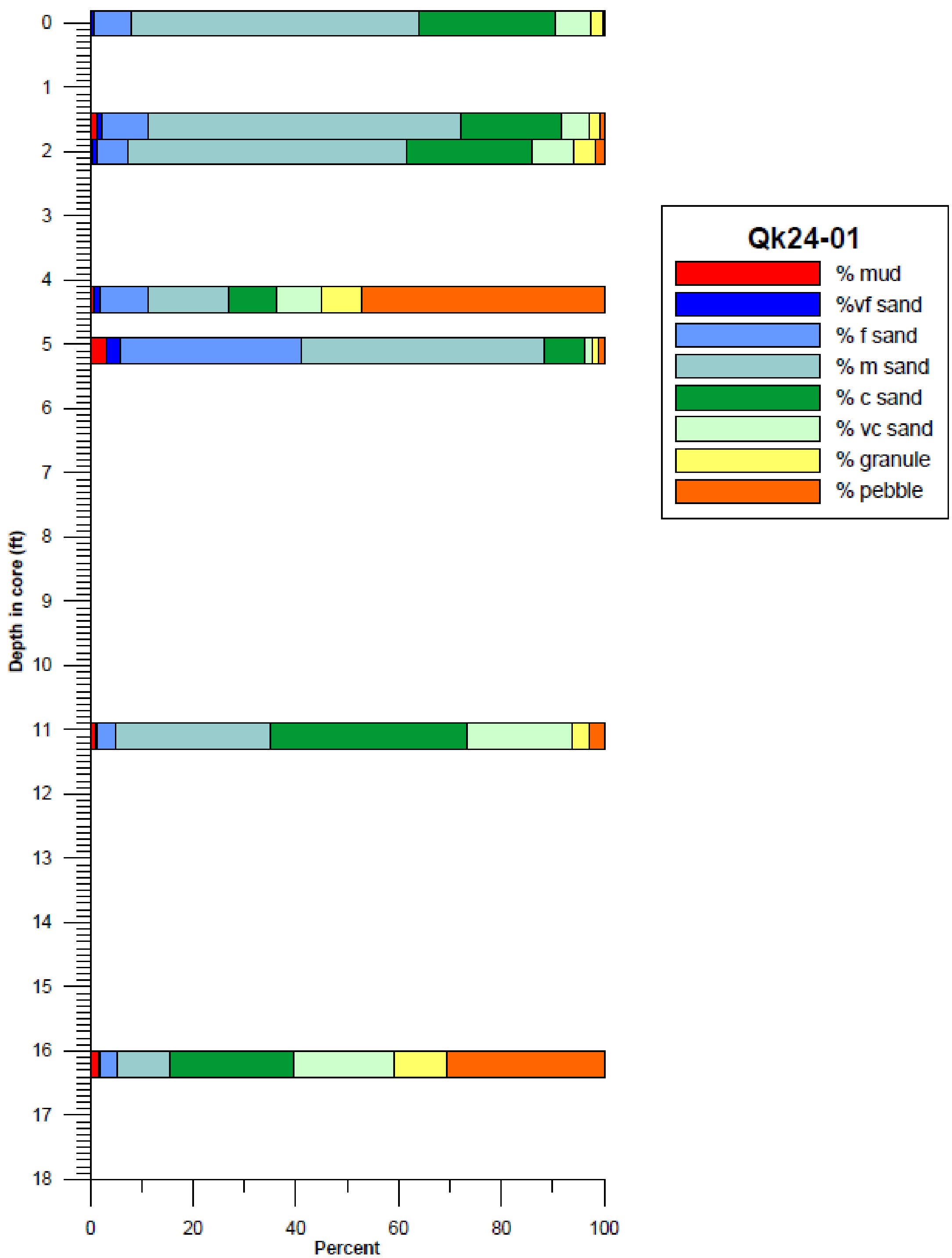
SAND: m-crs, interbed, slty slty, lt gry (1GLEY 7/5GY); crs sd zn @ 12.3-13.1' & 13.6-14', OHM lams @ 14.4-14.7' & 16.1-16.2', m sd zn @ 14.4-16.8', dk olv gry clyey sd-fill Bur (AA) @ 11.8-11.9', shrp cntct @ 16.8'.

SAND: vf, slty, abd OHM (lams) & mica, lt gry (1GLEY 7/5GY) w/yllsh lams (2.5Y 7/6), grad cntct @ 18'.

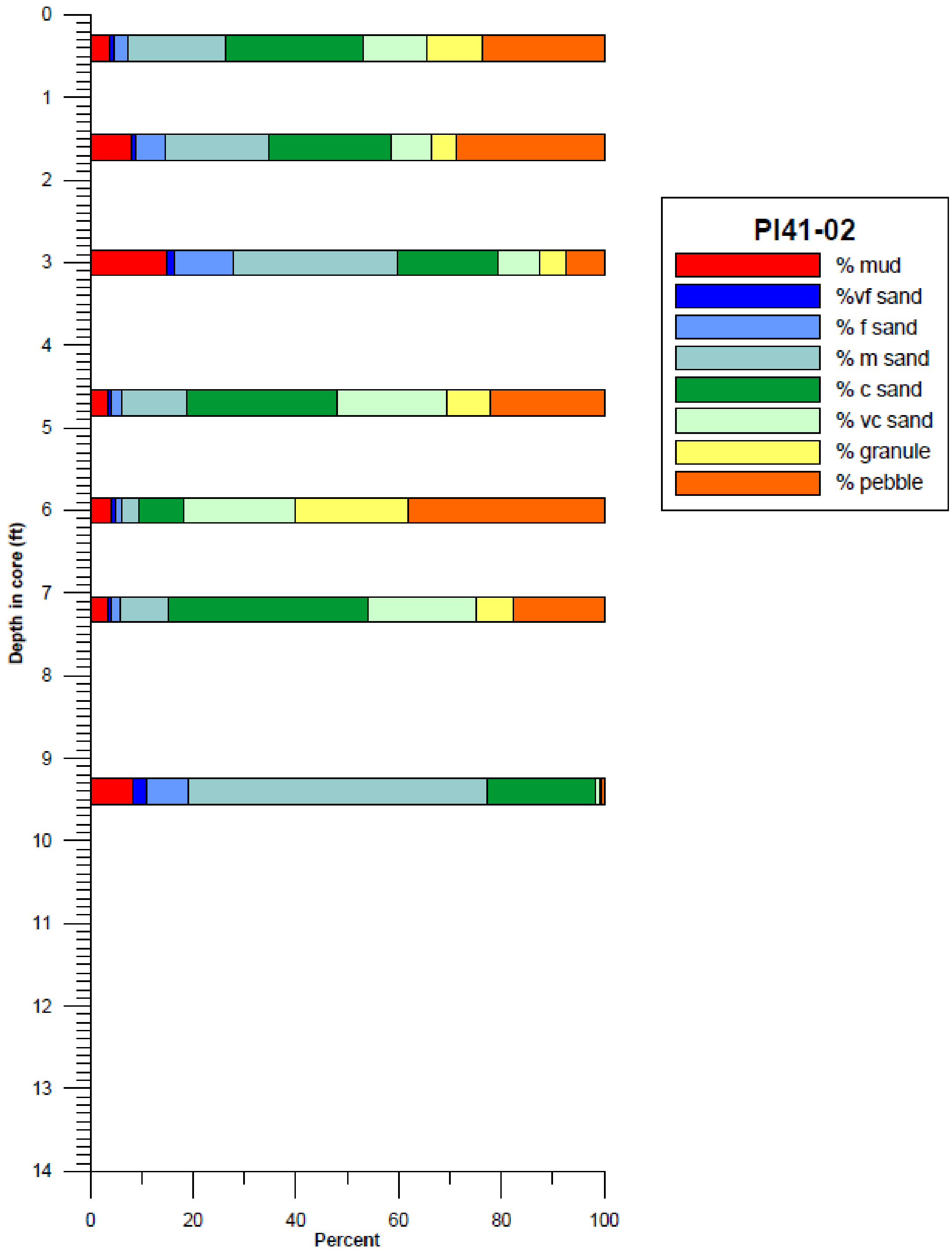
SAND: f, slty, OHM lams, few scat mica, few Bur (cly-rimmed, sd-fill, clr AA) @18.2-18.5', 19-19.3'.

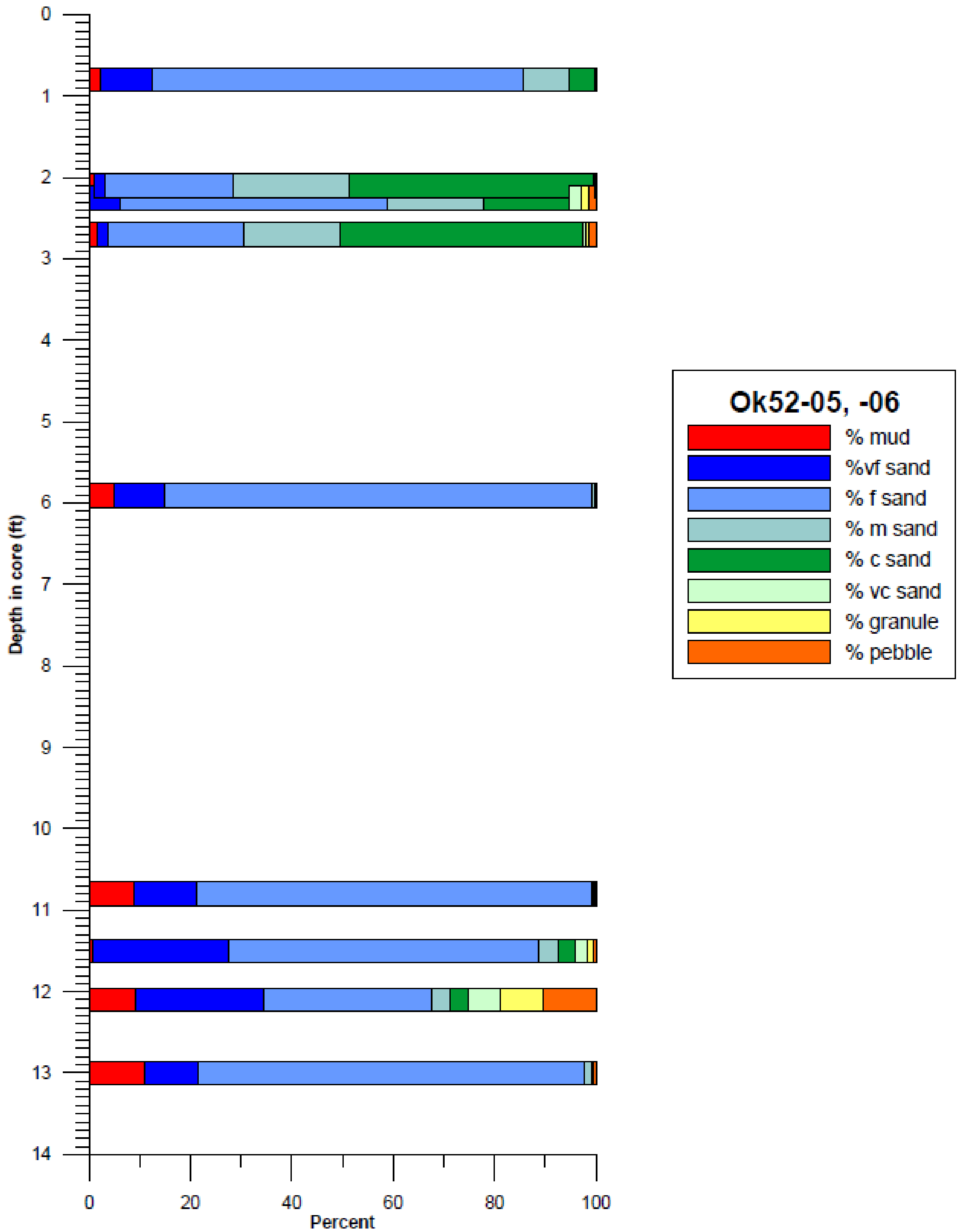
APPENDIX 2 – BOEM CORE TEXTURE DATA



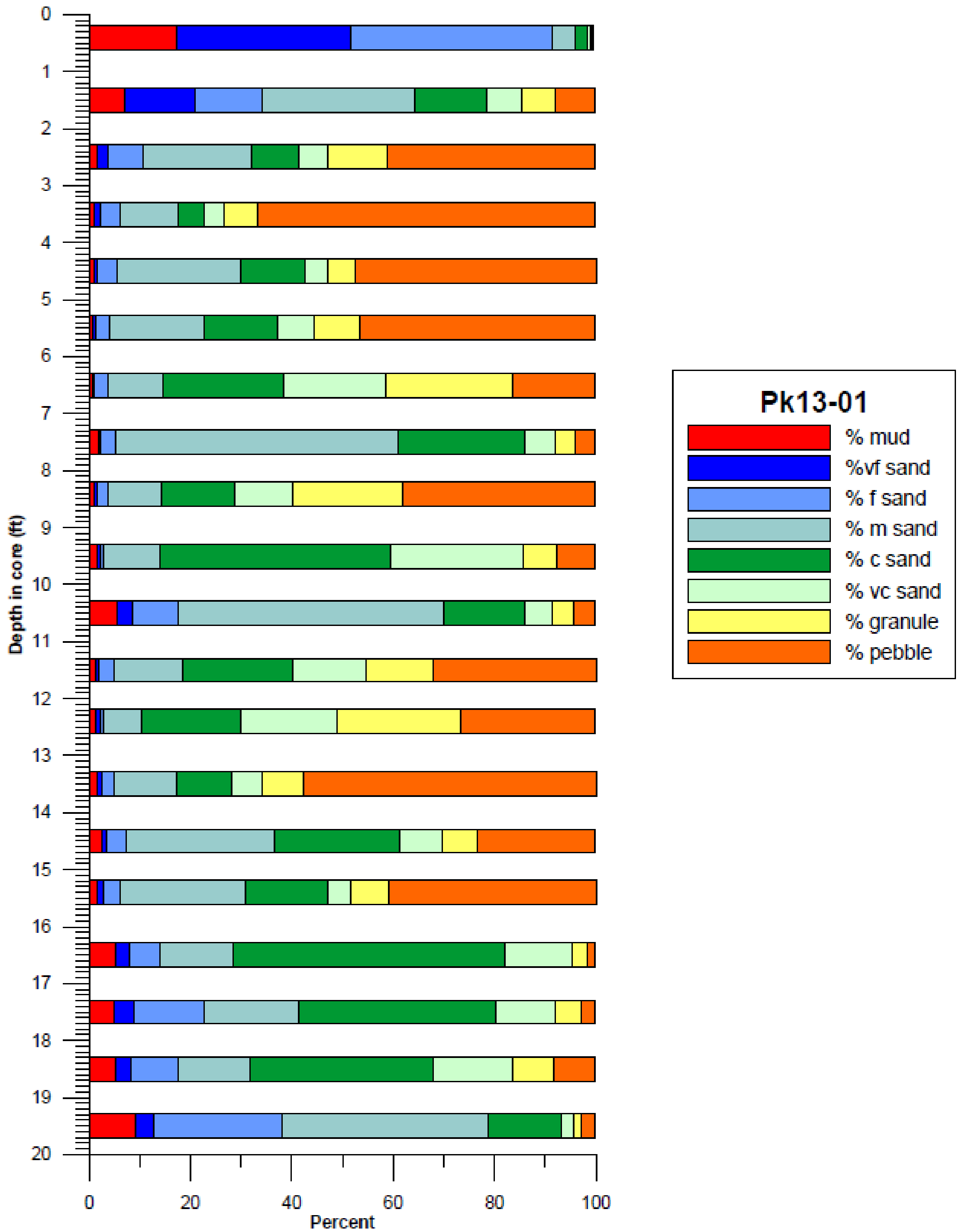


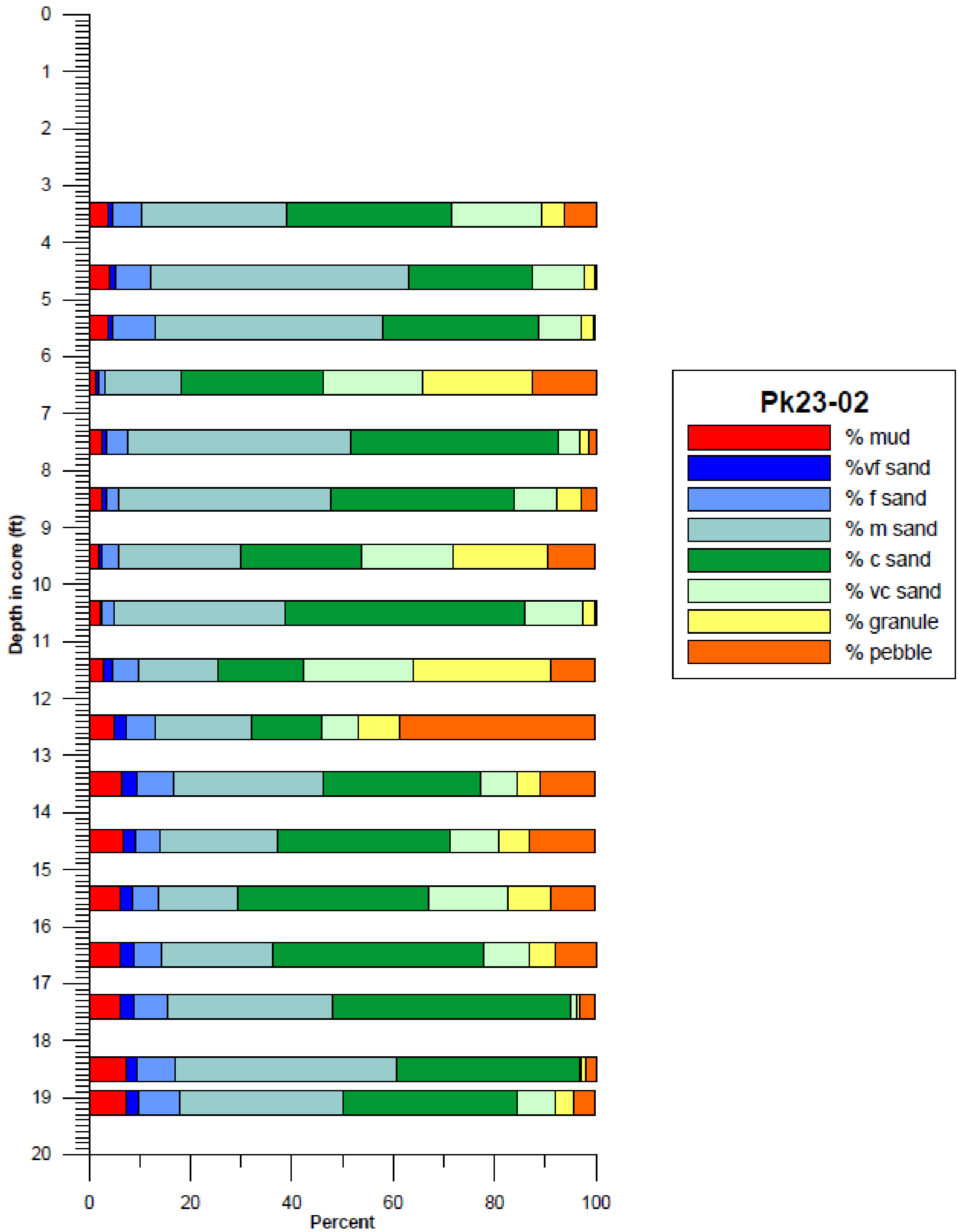
Qk24-01
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
Percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
20
40
60
80
100


PI41-02
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
Percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
20
40
60
80
100

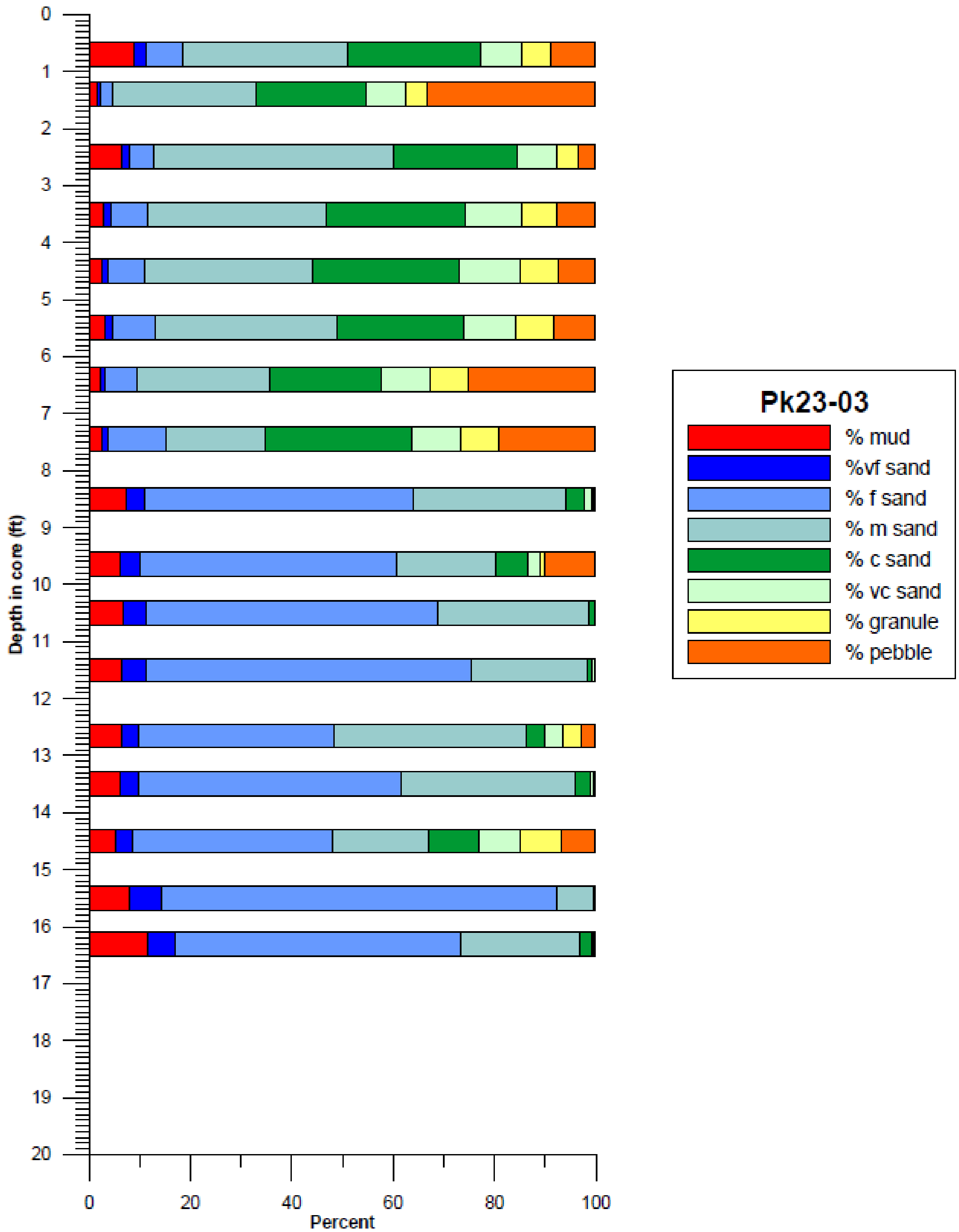


0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Depth in core (ft)
0
20
40
60
80
100
Percent
Ok52-05, -06
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble

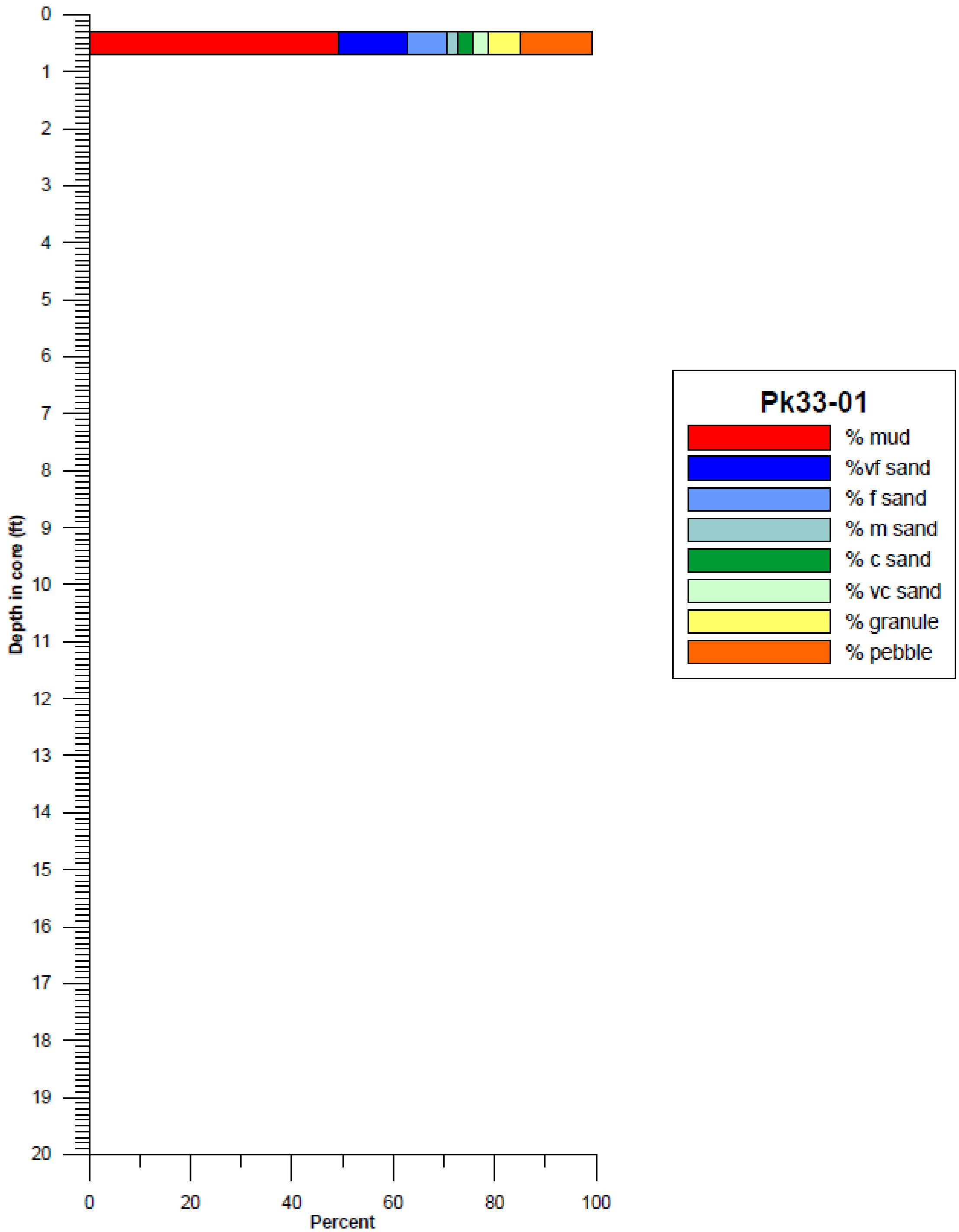

Pk13-01
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
Percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
20
40
60
80
100



Pk23-02
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
20
40
60
80
100
Percent



Pk23-03
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
Percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
20
40
60
80
100


Pk33-01
% mud
%vf sand
% f sand
% m sand
% c sand
% vc sand
% granule
% pebble
Depth in core (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
20
40
60
80
100
Percent

APPENDIX 3 – TEXTURE ANALYSIS DATA

Sample ID	DGS ID	Start depth	Stop depth	% gravel	% sand	% mud	% pebble	% granule	% vc	% c	% m	% f	% vf
104496.1	Oj12-02	2	2.2	0	98.69	1.31	0	0	0	1.61	38.41	57.86	0.81
104496.2	Oj12-02	4	4.2	0	97.62	2.37	0	0	0	1.32	26.96	68.02	1.32
104475.1	Oj33-02	2	2.2	0	98.37	1.61	0	0	0	5.4	53.36	34.31	5.3
104475.2	Oj33-02	4	4.2	5.45	86.53	8.01	3.74	1.71	3.74	8.33	29.7	38.25	6.51
104479.1	Oj34-04	0	0.2	0	98.26	1.73	0	0	0	1.41	41.91	53.78	1.16
104479.2	Oj34-04	2	2.2	0	97.86	2.12	0	0	0	0.45	25.93	69.43	2.05
104479.3	Oj34-04	4	4.2	0	93.16	6.82	0	0	0.79	2.3	9.52	74.84	5.71
104501.6	Oj34-06	4	4.2	1.12	79.52	19.37	0	1.12	1.4	2.89	14.43	29.98	30.82
104501.4	Oj34-06	0	0.2	0.76	95.09	4.16	0	0.76	5.49	11.64	16.65	54.4	6.91
104501.5	Oj34-06	2	2.2	27.82	63.24	8.94	19.88	7.94	8.19	7.18	14.95	27.07	5.85
104509.4	Oj44-01	2	2.2	0	96.5	3.49	0	0	1.16	11.99	31.2	45.75	6.4
104509.3	Oj44-01	0	0.2	0	96.99	3.01	0	0	0	14.68	42.46	34.21	5.64
104510.1	Oj44-02	4	4.2	0	79.16	20.84	0	0	0	1.66	7.44	46.48	23.58
61321.3	Ok42-01	3.5	4	0.16	86.85	12.99	0	0.16	0	0	0	0	86.85
61321.1	Ok42-01	0.5	1	0.24	99.49	0.24	0	0.24	0	0	0	0	99.49
61320.1	Ok42-01	0.5	1	0.29	98.95	0.74	0	0.29	0	0	0	0	98.95
61320.2	Ok42-01	2	2.5	0.32	98.74	0.94	0	0.32	0	0	0	0	98.74
61321.2	Ok42-01	2	2.5	0.77	98.41	0.81	0	0.77	0	0	0	0	98.41
61320.3	Ok42-01	4	4.5	1.82	97.4	0.78	0	1.82	0	0	0	0	97.4
61215.2	Ok42-03	3.5	4	0.02	76.98	23.01	0	0.02	0	0	0	0	76.98
61215.1	Ok42-03	2	2.5	0.86	83.02	16.12	0	0.86	0	0	0	0	83.02
61331.2	Ok52-01	2	2.5	0.06	97.42	2.52	0	0.06	0	0	0	0	97.42
61331.3	Ok52-01	4	4.5	0.17	94.87	4.96	0	0.17	0	0	0	0	94.87
61331.1	Ok52-01	0.5	1	0.43	95.5	4.07	0	0.43	0	0	0	0	95.5
61325.1	Ok52-02	1.5	1.5	0.1	88.77	11.13	0	0.1	0	0	0	0	88.77
61326.1	Ok52-02	5.5	6	0.14	95.32	4.54	0	0.14	0	0	0	0	95.32
61311.3	Ok52-04	4	4.5	0.04	90.03	9.93	0	0.04	0	0	0	0	90.03
61311.1	Ok52-04	0.5	1	0.06	97.83	2.11	0	0.06	0	0	0	0	97.83
61311.2	Ok52-04	2.5	3	0.06	95.49	4.46	0	0.06	0	0	0	0	95.49
114915.3	Ok52-05	5.9	5.9	0.06	99.7	0.21	0	0.06	0.03	0.08	0.51	88.88	10.19
114914.3	Ok52-05	2.1	2.1	0.04	99.82	0.01	0	0.04	0.27	5.2	9.5	75.39	9.65
114914.2	Ok52-05	0.8	0.8	0.13	98.48	1.28	0.03	0.1	1.44	48.34	22.62	25.43	1.96
114915.1	Ok52-05	2.7	2.95	0.5	98.61	0.88	0.26	0.24	1.56	21.71	23.84	44.26	7.24
114915.2	Ok52-05	2.7	2.7	0.98	96.1	1.88	0.51	0.47	4.22	48.03	18.8	26.74	2.08

114914.1	Ok52-05	2.25	2.7	2.9	96.87	0.23	1.35	1.55	2.27	16.86	19	52.89	5.85
115274.1	Pk13-01	0.4	0.55	0.49	81.61	17.93	0.09	0.4	1.18	2.34	4.67	39.66	34.29
115275.1	Pk13-01	5.5	5.65	55.64	43.46	0.91	46.53	9.11	9.3	14.4	18.64	2.87	0.41
117227.5	Pk13-02	4	4.2	0	77.82	22.17	0	0	1.1	2.41	3.95	10.32	60.04
117227.3	Pk13-02	2	2.2	0	90.09	9.9	0	0	0	1.73	2.35	45.79	40.22
117227.4	Pk13-02	3	3.2	1.55	75.81	22.63	1.22	0.33	0.45	1.34	2.34	17.95	53.73
117227.2	Pk13-02	1	1.2	4.06	87.48	8.44	1.42	2.64	2.34	2.03	2.54	52.7	27.87
61211.1	Pk22-01	1	1.5	7.43	90.05	2.52	0	7.43	0	0	0	0	90.05
61211.2	Pk22-01	2.5	3	7.5	88.71	3.79	0	7.5	0	0	0	0	88.71
61211.3	Pk22-01	4	4.5	20.92	76.33	2.75	0	20.92	0	0	0	0	76.33
115278.2	Pk23-02	4.6	4.75	2.29	93.72	4.07	0.07	2.22	20.12	24.59	50.94	6.89	1.04
115279.1	Pk23-02	5.5	5.65	3.01	93.64	3.62	0.53	2.48	20.98	30.87	44.84	8.48	1.04
115278.1	Pk23-02	3.5	3.65	10.58	87.27	3.75	6.08	4.5	29.18	32.62	28.69	5.5	0.97
115282.3	Pk23-03	2.5	2.65	7.57	85.68	6.59	3.35	4.22	14.61	24.43	47.2	4.84	1.45
115282.5	Pk23-03	4.5	4.65	14.85	83.51	2.46	7.51	7.34	21.24	28.88	33.21	7.3	1.16
115282.4	Pk23-03	3.5	3.65	14.56	83.17	2.91	7.65	6.91	19.77	27.26	35.36	7.19	1.4
115283.1	Pk23-03	5.5	5.65	15.68	80.42	3.13	8.35	7.33	17.92	25	35.7	8.58	1.46
115282.1	Pk23-03	0.7	0.85	14.49	77.79	8.92	8.87	5.62	15.76	26.13	32.47	7.21	2.5
115282.2	Pk23-03	1.4	1.55	37.53	61.84	1.7	33.25	4.28	14.16	21.64	28.23	2.39	0.65
61327.2	Pk32-01	2.5	3	13.69	85.21	1.1	0	13.69	0	0	0	0	85.21
61327.3	Pk32-01	4	4.5	29.07	69.69	1.24	0	29.07	0	0	0	0	69.69
61328.1	Pk32-01	5.5	6	0	97.63	2.37	0	0	0	0	0	0	97.63
61327.1	Pk32-01	1	1.5	4.92	92.9	2.16	0	4.92	0	0	0	0	92.9
61203.1	Pk32-02	1	1.5	6.93	90.43	2.64	0	6.93	0	0	0	0	90.43
61203.3	Pk32-02	4	4.5	22.55	74.26	3.2	0	22.55	0	0	0	0	74.26
61204.1	Pk32-02	5.5	6	22.95	75.09	1.96	0	22.95	0	0	0	0	75.09
61203.2	Pk32-02	2.5	3	3.19	88.74	8.06	0	3.19	0	0	0	0	88.74
115285.1	Pk33-01	0.5	0.65	20.55	29.68	50.07	14.13	6.42	2.82	2.96	1.95	7.98	13.36
61283.1	Pk42-02	4	4.5	13.09	82.49	4.42	0	13.09	0	0	0	0	82.49
61341.1	Pk42-02	1	1.5	14.03	79.71	6.25	0	14.03	0	0	0	0	79.71
61342.1	Pk42-02	5	5.5	0.78	95.68	3.54	0	0.78	0	0	0	0	95.68
61284.1	Pk42-02	5.5	6	2.55	91.46	6	0	2.55	0	0	0	0	91.46
61341.3	Pk42-02	3.5	4	4.13	88.92	6.95	0	4.13	0	0	0	0	88.92
61341.2	Pk42-02	2.5	3	4.28	91.93	3.79	0	4.28	0	0	0	0	91.93
117234.1	Pk43-01	0	0.2	6.95	89.82	3.22	2.19	4.76	15.44	35.26	30.89	7.72	0.51
117235.1	Pk43-01	5	5.2	10.75	86.8	2.45	2.99	7.76	19.73	45.58	20.41	0.94	0.14
117234.3	Pk43-01	2	2.2	8.8	88.69	2.5	4.2	4.6	16.3	50.4	19.7	2.09	0.2
117234.4	Pk43-01	3	3.2	49.43	49.53	1.03	32.07	17.36	21.61	18.51	6.43	2.53	0.45
117234.2	Pk43-01	1	1.2	41.61	57.09	1.28	36.92	4.69	9.14	19.11	21.69	6.45	0.7

117234.5	Pk43-01	4	4.2	42.34	56.54	1.09	37.24	5.1	12.83	26.62	13.79	2.9	0.4
61334.1	Pk52-01	0.5	1	7.72	87.66	4.62	0	7.72	0	0	0	0	87.66
61334.3	Pk52-01	3	3.5	10.08	83.87	6.05	0	10.08	0	0	0	0	83.87
61334.2	Pk52-01	2	2.5	13.12	82.36	4.52	0	13.12	0	0	0	0	82.36
61335.1	Pk52-01	5	5.5	0.58	94.93	4.49	0	0.58	0	0	0	0	94.93
61316.3	Pk52-02	4.5	5	9.05	83.07	7.87	0	9.05	0	0	0	0	83.07
61316.1	Pk52-02	1	1.5	32.15	65.04	2.8	0	32.15	0	0	0	0	65.04
61316.2	Pk52-02	2	2.5	2.8	94.31	2.89	0	2.8	0	0	0	0	94.31
114922.2	Pk54-01	3	3	2.02	97.77	0.09	1.37	0.65	4.57	25.62	49.58	17.82	2.99
114923.1	Pk54-01	4	4	6.1	93.39	0.04	2.86	3.24	13.01	37.55	29.35	16.68	2.98
114922.1	Pk54-01	1.6	1.6	7.22	92.05	0.15	4.17	3.05	19.38	39.34	28.57	12.72	2.04
114923.2	Pk54-01	5.2	5.2	45.03	54.18	0	35.78	9.25	14.07	18.87	17.17	4.44	1.11
61275.2	Pk55-01	3	3.5	0.72	98.58	0.7	0	0.72	0	0	0	0	98.58
61276.1	Pk55-01	5	5.5	0.48	97.77	1.75	0	0.48	0	0	0	0	97.77
61275.3	Pk55-01	4.5	5	1.36	97.69	0.93	0	1.36	0	0	0	0	97.69
61275.1	Pk55-01	1.5	2	1.93	97.38	0.69	0	1.93	0	0	0	0	97.38

Sample ID	mean	median	sorting	skewness	kurtosis	sorting type	skewness type	mean class	CMECS class	strati pick
104496.1	2.10	2.17	0.63	-0.16	0.77	moderately well	negative	F	S	Qsl
104496.2	2.23	2.32	0.60	-0.25	0.93	moderately well	negative	F	S	Qsl
104475.1	1.92	1.84	0.75	0.21	0.90	moderately	positive	M	S	Qlh
104475.2	1.95	2.07	1.40	-0.17	1.59	poorly	negative	M	gS	Tbd
104479.1	2.08	2.12	0.64	-0.10	0.75	moderately well	negative	F	S	Qsl
104479.2	2.26	2.34	0.58	-0.24	0.99	moderately well	negative	F	S	Qsl
104479.3	2.50	2.50	0.72	0.10	2.00	moderately	near symmetrical	F	S	Qsl
104501.6	3.10	3.01	1.34	0.04	1.04	poorly	near symmetrical	VF	mS	Qlh
104501.4	2.01	2.28	1.14	-0.31	1.28	poorly	strongly negative	F	S	Qis
104501.5	0.66	1.46	2.74	-0.27	0.94	very poorly	negative	C	mgS	Qlh
104509.4	2.03	2.12	0.97	-0.11	1.09	moderately	negative	F	S	Qss
104509.3	1.88	1.83	0.94	0.09	1.06	moderately	near symmetrical	M	S	Qss
104510.1	3.09	2.88	1.13	0.29	1.09	poorly	positive	VF	mS	Qlh
61321.3	2.92	0.00	0.28	0.09	1.42	v well	near symmetrical	F	mS	Qsl
61321.1	1.70	0.00	0.32	0.16	1.04	v well	positive	M	S	Qsl
61320.1	1.97	0.00	0.41	0.18	1.00	well	positive	M	S	Qsl
61320.2	1.91	0.00	0.40	0.18	1.02	well	positive	M	S	Qsl
61321.2	2.01	0.00	0.37	0.27	1.00	well	positive	F	S	Qsl
61320.3	1.92	0.00	0.39	0.17	1.05	well	positive	M	sgS	Qsl
61215.2	2.90	0.00	0.34	-0.16	1.95	v well	negative	F	S	Qis
61215.1	2.73	0.00	0.44	-0.98	1.25	well	strongly negative	F	S	Qis
61331.2	2.75	0.00	0.26	0.00	1.12	v well	near symmetrical	F	S	Qis
61331.3	2.80	0.00	0.25	0.00	1.09	v well	near symmetrical	F	S	Qis
61331.1	2.74	0.00	0.39	-0.46	2.06	well	strongly negative	F	S	Qsl
61325.1	2.95	0.00	0.39	-0.56	2.24	well	strongly negative	F	mS	Qis
61326.1	2.48	0.00	0.58	-0.48	1.48	moderately well	strongly negative	F	S	Qis
61311.3	2.93	0.00	0.26	0.07	1.18	v well	near symmetrical	F	S	Qsl
61311.1	2.84	0.00	0.22	-0.03	1.20	v well	near symmetrical	F	S	Qsl
61311.2	2.93	0.00	0.24	0.17	1.27	v well	positive	F	S	Qsl
114915.3	2.64	2.67	0.33	-0.06	1.42	v well	near symmetrical	F	S	Qis
114914.3	1.38	1.02	0.81	0.59	0.69	moderately	strongly positive	M	S	Qsl
114914.2	2.54	2.66	0.56	-0.44	2.61	moderately well	strongly negative	F	S	Qsl
114915.1	1.84	2.05	1.04	-0.23	0.86	poorly	negative	M	S	Qsl
114915.2	1.35	0.98	0.85	0.53	0.72	moderately	strongly positive	M	S	Qsl
114914.1	1.88	2.17	1.04	-0.39	0.90	poorly	strongly negative	M	sgS	Qsl
115274.1	3.22	3.04	0.83	0.11	1.29	moderately	positive	VF	mS	Qis
115275.1	-1.19	-1.62	1.96	0.31	0.55	poorly	strongly positive	GRAN	sG	Qrl

117227.5	3.59	3.54	1.04	0.05	2.10	poorly	near symmetrical	VF	mS	Qis
117227.3	3.04	3.00	0.72	0.07	0.75	moderately	near symmetrical	VF	S	Qis
117227.4	3.46	3.49	1.07	0.05	1.83	poorly	near symmetrical	VF	mS	Qis
117227.2	2.86	2.74	1.11	-0.02	1.66	poorly	near symmetrical	F	S	Qis
61211.1	0.70	0.00	0.71	0.19	1.23	moderately	positive	C	gS	Tbd
61211.2	1.00	0.00	0.78	0.34	0.81	moderately	strongly positive	M	gS	Tbd
61211.3	0.60	0.00	0.56	0.09	1.22	moderately well	near symmetrical	C	gS	Tbd
115278.2	1.10	1.27	1.03	-0.16	1.16	poorly	negative	M	gS	Tbd
115279.1	1.10	1.21	1.01	-0.13	1.10	poorly	negative	M	sgS	Tbd
115278.1	0.54	0.53	1.46	-0.06	1.33	poorly	near symmetrical	C	gS	Tbd
115282.3	1.02	1.15	1.32	-0.08	1.96	poorly	near symmetrical	M	gS	Tbd
115282.5	0.57	0.76	1.45	-0.23	1.08	poorly	negative	C	gS	Tbd
115282.4	0.62	0.87	1.50	-0.26	1.21	poorly	negative	C	gS	Tbd
115283.1	0.64	0.95	1.59	-0.32	1.25	poorly	strongly negative	C	gS	Tbd
115282.1	0.81	1.03	1.87	-0.17	1.73	poorly	negative	C	gS	Qrl
115282.2	-0.53	0.21	1.98	-0.41	0.52	poorly	strongly negative	VC	sG	Tbd
61327.2	0.72	0.00	0.92	0.35	0.67	moderately	strongly positive	C	gS	Tbd
61327.3	0.70	0.00	0.76	0.08	1.25	moderately	near symmetrical	C	gS	Tbd
61328.1	1.84	0.00	0.47	0.01	1.16	well	near symmetrical	M	S	Tbd
61327.1	1.66	0.00	0.60	-0.23	1.22	moderately well	negative	M	sgS	Tbd
61203.1	1.39	0.00	0.66	-0.09	1.26	moderately well	near symmetrical	M	gS	Tbd
61203.3	1.09	0.00	0.76	-0.01	0.81	moderately	near symmetrical	M	gS	Tbd
61204.1	0.76	0.00	0.77	0.19	0.87	moderately	positive	C	gS	Tbd
61203.2	1.82	0.00	0.51	-0.14	1.62	moderately well	negative	M	sgS	Tbd
115285.1	2.21	3.99	2.67	-0.88	0.80	very poorly	strongly negative	F	gsM	Ql
61283.1	1.27	0.00	0.71	-0.20	0.84	moderately	negative	M	gS	Tbd
61341.1	1.22	0.00	0.89	-0.18	0.98	moderately	negative	M	gS	Tbd
61342.1	1.63	0.00	0.59	-0.07	0.96	moderately well	near symmetrical	M	S	Tbd
61284.1	1.64	0.00	0.44	-0.01	1.54	well	near symmetrical	M	sgS	Tbd
61341.3	1.62	0.00	0.46	-0.14	2.37	well	negative	M	sgS	Tbd
61341.2	1.15	0.00	0.68	-0.05	0.91	moderately well	near symmetrical	M	sgS	Tbd
117234.1	0.74	0.78	1.21	-0.04	1.17	poorly	near symmetrical	C	gS	Qss
117235.1	0.36	0.43	1.09	-0.14	1.20	poorly	negative	C	gS	Tbd
117234.3	0.46	0.49	1.08	-0.14	1.57	poorly	negative	C	gS	Tbd
117234.4	-1.14	-0.97	1.81	-0.06	0.83	poorly	near symmetrical	GRAN	sG	Tbd
117234.2	-0.83	-0.08	2.52	-0.33	0.62	very poorly	strongly negative	VC	sG	Qss
117234.5	-1.22	-0.40	2.42	-0.37	0.57	very poorly	strongly negative	GRAN	sG	Tbd
61334.1	0.98	0.00	0.63	-0.07	1.09	moderately well	near symmetrical	C	gS	Tbd
61334.3	1.17	0.00	0.79	-0.08	1.03	moderately	near symmetrical	M	gS	Tbd

61334.2	1.01	0.00	0.72	0.05	0.94	moderately	near symmetrical	M	gS	Tbd
61335.1	1.22	0.00	0.65	0.10	1.03	moderately well	positive	M	S	Tbd
61316.3	1.58	0.00	0.74	-0.17	1.15	moderately	negative	M	gS	Tbd
61316.1	0.94	0.00	0.66	-0.04	0.96	moderately well	near symmetrical	C	gS	Tbd
61316.2	1.15	0.00	0.53	0.01	1.10	moderately well	near symmetrical	M	sgS	Tbd
114922.2	1.40	1.30	0.77	0.16	1.11	moderately	positive	M	sgS	Qrl
114923.1	1.10	0.98	1.12	0.03	1.47	poorly	near symmetrical	M	gS	Qrl
114922.1	0.90	0.87	1.17	-0.07	1.57	poorly	near symmetrical	C	gS	Qrl
114923.2	-0.45	-1.09	1.04	1.12	0.33	poorly	strongly positive	VC	sG	Qrl
61275.2	1.46	0.00	0.56	-0.22	1.06	moderately well	negative	M	S	Qrl
61276.1	1.36	0.00	0.69	-0.20	0.95	moderately well	negative	M	S	Qss
61275.3	1.45	0.00	0.55	-0.21	1.05	moderately well	negative	M	sgS	Qss
61275.1	1.61	0.00	0.46	-0.01	0.95	well	near symmetrical	M	sgS	Qss