Delaware Offshore Sand Resource Investigation

Technical Report for Cooperative Agreement M14AC00003

Kelvin W. Ramsey, Trevor L. Metz, John F. Wehmiller, Jaime L. Tomlinson
Delaware Geological Survey
University of Delaware

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ABSTRACT

Geologic mapping is a valuable tool for offshore sand resource investigation and identification of target areas for beach replenishment material. Identifying the sediment characteristics of each unit and the unit's geographic proximity to replenishment sites with geologic mapping can significantly streamline the process of targeting sand resources, constrain their distribution, and determine volumes available for future nourishment projects. Onshore Delaware, mapping of surficial deposits is well established with published 1:24,000-scale geologic maps for the entire Delaware Atlantic Coast region. Surficial deposits onshore Delaware are extended to five miles offshore through analysis of 415 offshore vibracore records, samples, and descriptions representing over 40 years of surveys. Geochronology using radiocarbon (RC) dating and amino acid racemization (AAR) age estimates was employed to correlate onshore and offshore map units and provide stratigraphic age resolution. RC dating helped determine whether deposits are Holocene, late Pleistocene (MIS-2 to MIS-3), or older (beyond limits of RC dating). AAR analyses on shells (mollusk) allows for separation of Holocene, late Pleistocene (MIS-3 or MIS-5), and middle Pleistocene (MIS 9-11) deposits. RC and pollen data compiled from published and unpublished sources, supplemented by new RC dating funded by this project, indicates the presence of previously unrecognized, non-marine, late Pleistocene (MIS-2 to MIS-3), periglacial eolian and bog deposits offshore. Holocene sediments, ranging from very thin (<0.5 ft) to very thick (>20 ft), overlie Late Pliocene and Pleistocene offshore deposits. In places, no Holocene sediments are present, and older deposits outcrop at the sea floor. The middle Pleistocene Lynch Heights Fm. and Omar Fm. are muddy, lagoonal deposits restricted to paleovalleys. The high percentage of silt and clay and only intermittent presence of sand preclude these units from being beach nourishment resources. The late Pliocene Beaverdam Fm. occurs over a large area offshore, commonly at the sea floor, or with only a thin Holocene cover. This unit is primarily sand and has been used as a source for beach replenishment material. The unit, however, contains a significant amount of pebbles which creates problems both at the dredge site and post-emplacement on the beach. Of the offshore units, Holocene age sheet sands and ridge deposits have the greatest potential for sand resources. Both of these units, however, are variable in thickness and distribution and require detailed, site-specific mapping for sand resource evaluation. In summary, geologic mapping, bolstered by geochronologic analyses, provides a framework for future detailed sand resource investigations offshore Delaware.

INTRODUCTION

Background

Identification of offshore sand resources that are suitable for beach nourishment is important for continued success of Delaware's Atlantic shore protection program. Beach nourishment is Delaware's preferred method for mitigation the effects of coastal erosion. It has become a means of protecting life and property during hurricanes and northeasters (Wunsch et al., 2012). Finding sand resources involves understanding the regional geologic history to identify those areas where the combination of geologic source material, wave and currents to sort the material, and accommodation space for the material to be deposited produced a sand body of the proper texture for beach replenishment. Ramsey (1999) reported on historical Delaware beach sand textures from pre-nourishment beaches and determined that the "native" beach sand texture is coarse to medium, well-sorted sand (grain size- 1.5 to 0.5 phi; sorting- 0.5 or less phi). This study was used as a benchmark for the texture preferred for nourishment sand on Delaware's beaches.

From 1990 to 2010, the Delaware Geological Survey (DGS), through a cooperative agreement with the Minerals Management Service (MMS), conducted a mapping project to determine the location of sand resources in Federal waters suitable for beach nourishment. Initial work included collection of a grid of single-channel 3.5 kHz seismic data (325 km total length) and 17 vibracores in 1992 and 1993. The cores were described and analyzed in context of the seismic data and a stratigraphy was developed for the offshore (Williams, 1999). Additional vibracores were collected in 1997, 2001, 2004, and 2007, primarily by the U.S. Army Corps of Engineers in State waters (McKenna and Ramsey, 2010). Textural analyses were conducted on a total of 362 vibracores in order to determine their suitability for beach nourishment (Figure 1). Of these cores, 61 were collected from Federal waters and 301 from State waters. The core material was rated using a stack-unit resource rating method (Kempton, 1981; McKenna, 2000; McKenna and Ramsey, 2002). Stack-unit mapping takes into account the vertical variability of texture and thickness of sand bodies within cores to determine suitability for beach nourishment. Each core site was rated as excellent, good, fair, or poor based on the sediment textures and thicknesses. Using GIS, the cores sites were mapped to determine areas where textures most suited for beach nourishment sand were present (Figure 1). Preliminary results of this work were published as a DGS Report of Investigations (McKenna and Ramsey, 2002) and updated in 2010 as a final report to MMS (McKenna and Ramsey, 2010). The work identified two possible borrow areas that extend from State to Federal waters--one off Rehoboth Bay, and the other off Indian River Inlet (Figure 1). Potential sand resources were calculated to be approximately 66 million cubic yards (51 million cubic meters) (McKenna and Ramsey, 2010).

In 2004, the USACE and the Delaware Department of Natural Resources and Environmental Control (DNREC), as the non-Federal sponsor, began nourishing the beaches along Delaware's Atlantic Coast using sand resources in State waters and that practice has continued to the present. Several permitted sand resource locations in State waters have either been depleted, not used due to textural issues (too much gravel), or are at a significant distance from the beaches which adds greatly to the cost. The texture of the sand used in the nourishment projects is important in the design of the project. Material that is too coarse (coarse sand to pebbles) leads to over-steepened beaches and can present hazards to recreational swimmers. Sand that is too fine is generally unstable in the Delaware beach wave climate and greatly shortens the life span of the beach nourishment. At present, sand used for replenishing Rehoboth Beach is being taken from a site in State waters off Fenwick Island and shipped 15 miles to the north. The shipping distance is greatly increasing the cost of the beach nourishment project. The goal of this and future cooperative agreements between the DGS and the Bureau of Ocean Energy Management (BOEM) is to identify and map the sand resources in Federal waters of optimal texture in Federal waters that are as close to the Delaware public beaches as possible.

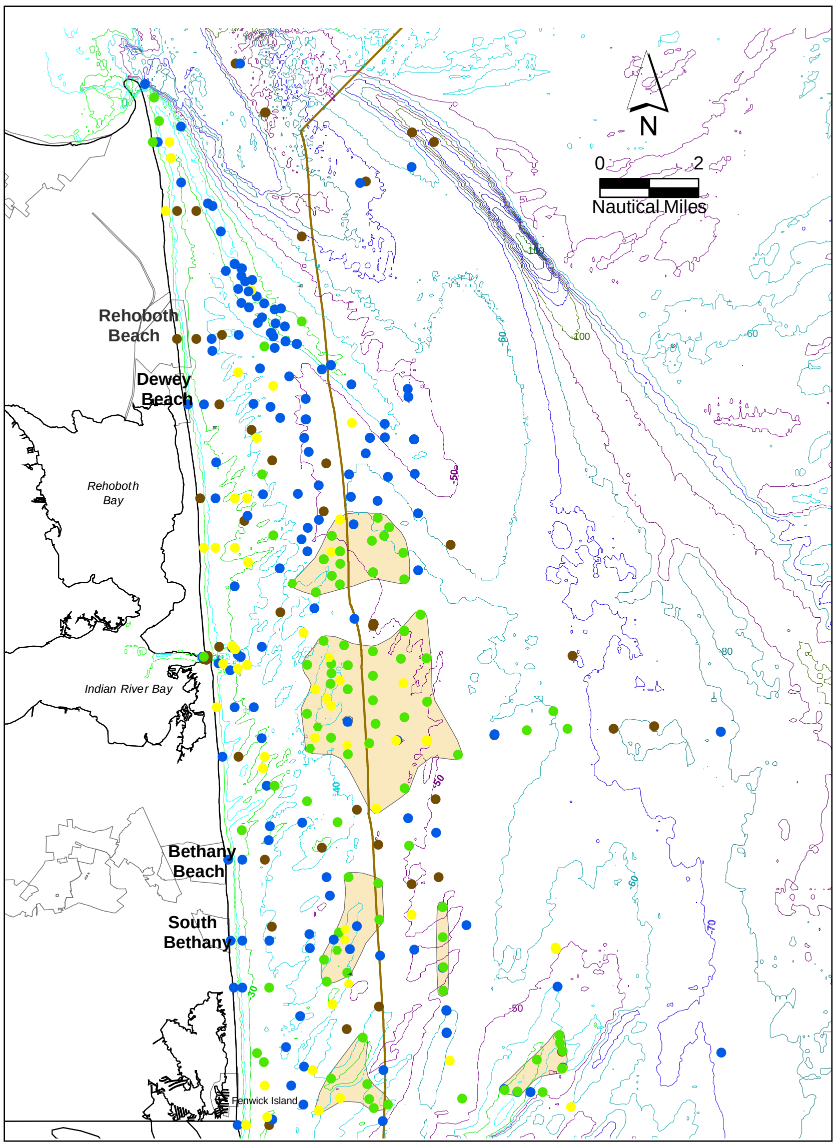

Figure 1. Resource ratings for offshore cores and areas of potential beach nourishment sand. Colored dots indicate quality of sand resources: Green-Excellent, Yellow-Good, Blue-Fair, Brown-Poor. Areas of best resources are indicated by the tan polygons (McKenna and Ramsey, 2010).

Offshore Geology

Geochronologic terminology

For this report, ages and dates are given in years before present (BP) and in kiloannum (ka) for a 1,000 year time span (e.g. 12,000 yrs BP is given as 12 ka BP). Glacial and interglacial periods are referred to using marine isotope stage (MIS) chronology because of the direct relationship between the deposits and Quaternary sea level fluctuations (Figure 2).

		Marine Oxygen Isotope Stage*		Age (ka BP)
HOLOCENE		1		0- ~12
PLEISTOCENE	Late	2	Wisconsinan glaciation	13-24
		3		24-64
		4		64-76
		5		76-128
		5a		71-85
		5b		85-93
		5c		93-105
		5d		105-113
		5e		113-128
	Middle	6	Illinoian glaciation	128-185
		7		185-245
		8		245-293
		9		293-339
		10		339-370
		11		370-425
		12-19		425-780
	Early			780-2600

*Stage 1: Walker et al., 2009; Stages 2-5, 5a-5e: Cutler et al., 2003; Stages 6-11: Tzedakis et al., 2001; early/middle Pleistocene boundary: Lisiecki and Raymo, 2005; early Pleistocene range: Walker and Geissman, 2009.

Figure 2. Quaternary marine isotope stages (MIS) (adapted from Ramsey, 2010).

Previous geologic mapping

Belknap and Kraft (1977; 1985) recognized the offshore Delaware geologic framework of older units being cut by a network of paleovalleys tributary to the incised Delaware River paleovalley. Subsequent publications have built upon that framework. The offshore geology of Delaware is influenced by three geologic factors: (1) the deposition of the fluvial to estuarine Beaverdam Formation in the Pliocene, (2) migration of the valley of the Delaware River across the inner Continental Shelf (3) incision and filling of tributary streams during the glacioeustatic rises and falls of sea level during the middle to late Pleistocene (MIS-11,-9,-5,-3) and (4) the ongoing rise of sea level during the last 12 ka (Ramsey, 2010). Ramsey (2011) and Ramsey and Tomlinson (2012) reviewed the stratigraphic context of offshore cores in the Rehoboth Beach, Bethany Beach and Little Assawoman Bay 1:24,000 quadrangles (Figure 3). Pre-Holocene onshore geologic units were mapped offshore and Holocene-age marine sedimentary units (lithofacies) were identified, mapped, and published as part of the geologic maps (Figures 3 and 4) for these quadrangles. Although the maps covered areas only in State waters, the geology can readily be extended into Federal waters. The stratigraphic units are in part defined on the basis of sediment texture which can then be related to the potential for use as beach nourishment sand. The mapping units will be used as a geologic framework for this project.

Middle to late Pleistocene geology

The Delaware River has been located near its present position since the early Pleistocene when glacial meltwater flooding carved a channel across the Coastal Plain and inner Shelf (Ramsey, 2010; Jengo et al, 2013). The location of the channel valley has migrated generally to the south during the middle to late Pleistocene with subsequent falls and rises of sea level from a position underneath the modern Cape May, NJ to its present position (McGeary et al, 1991, Krantz et al., 1993, Murphy, 1996). During sea-level low stands, streams on Atlantic-facing side of the Delmarva Peninsula were for the most part tributaries to the Delaware River. During sea-level rise, these valleys became the location of barrier lagoons that filled with mud and very fine sand. These paleovalley fill deposits can be mapped across the inner Continental shelf and in some cases for miles onshore (Ramsey, 2010; Ramsey and Tomlinson, 2012). These lagoonal deposits found offshore are generally not suitable for beach nourishment.

Latest Pleistocene to Holocene geology

The latest Pleistocene (MIS-3 and MIS-2) and Holocene geologic history of the region determined the present configuration of offshore sand bodies that are the focus of this study. The bathymetry and geology of the present shelf off Delaware is the product of sea-level rise during the Holocene (Miller et al, 2009). At approximately 12ka BP the shoreline was much closer to the modern continental shelf edge during sea-level low stand, about 100 feet lower than present, and the modern offshore area was sub aerially exposed. The Delaware River incised into underlying sediments with tributary incised streams draining the Delaware Atlantic coast and shelf. The bathymetric low concurrent with the latest Pleistocene Delaware River paleochannel is the dominant morphologic feature of the Delaware inner shelf. Figure 1 shows the late Pleistocene valley (northeast of Rehoboth Beach) that is being filled from the north as shoals from Cape May prograde south into the mouth of Delaware Bay.

From about 8 ka to 3 ka, sea level rose rapidly and the shoreline migrated westward (Ramsey, 2010). By 3 ka, the shoreline was near its present location (Belknap and Kraft, 1985). Stream valleys occupied by lagoons were transgressed by the barrier and filled with sand in the nearshore zone creating a sequence of sand over lagoonal muds (Belknap and Kraft, 1985). On interfluves between the stream valleys, the Beaverdam Formation was exposed and became the source for sheets of sand sorted by the offshore tidal currents (Figures 3, 4). Migration of sand along the shoreline to the nearshore zone produced finger shoals with a northeast-southwest orientation. Some of these shoals became detached as the shoreline moved landward and now exist as bathymetric highs offshore (Toscano et al, 1989). These finger shoals and detached shoals have been a primary source of nourishment sand for Maryland's Atlantic beaches (Conkwright and Gast, 1994; Wells, 1994). Another prominent bathymetric high, Hen and Chickens Shoal, developed at the mouth of Delaware Bay as ebb currents moved sand from Cape Henlopen offshore. Sands in portions of Hen and Chickens Shoal are good beach nourishment material. In areas landward of Hen and Chickens Shoal protected from offshore waves and currents, fine-grained sediment was deposited in quiet water (Figures 3, 4). These deposits are primarily very fine sand and silt and are not beach nourishment material.

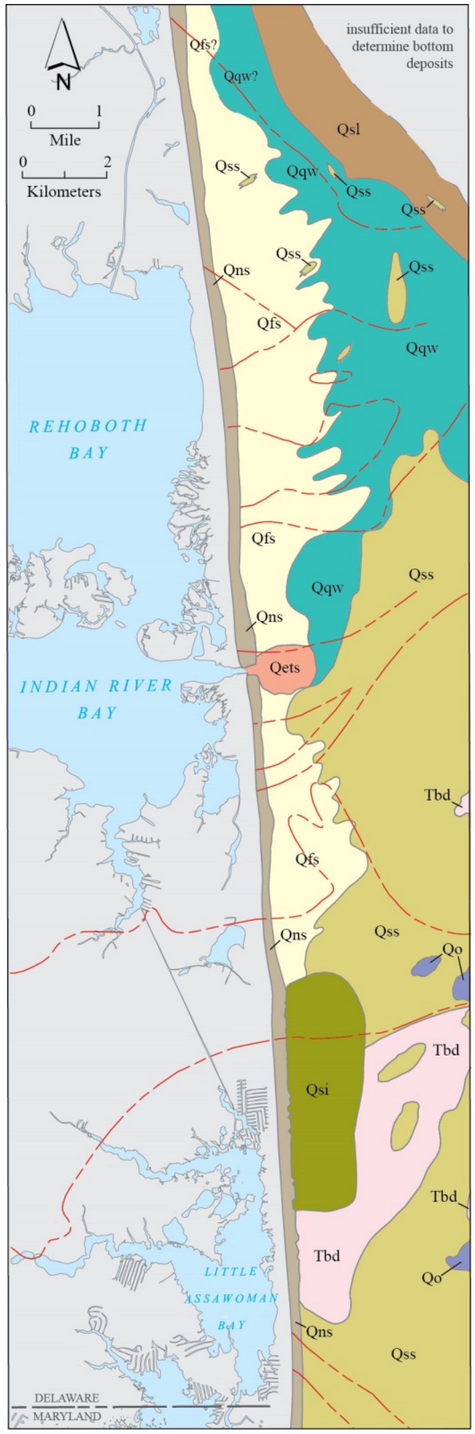

Figure 3. Geologic map offshore Delaware from off Rehoboth Beach to off Fenwick Island (adapted from Ramsey, 2011; Ramsey and Tomlinson, 2012). Map unit names are abbreviated: Qsl-shoal deposits, Qss-sheet sand deposits, Qns- nearshore deposits, Qfs-finger shoal deposits, Qqw-quiet water deposits, Qets-ebb tidal shoal deposits, Qsi-Sinepuxent Fm, Qo-Omar Fm., Tbd-Beaverdam Formation. Dashed red lines indicate possible boundaries of Quaternary and Holocene paleochannel-fill lagoon deposits.

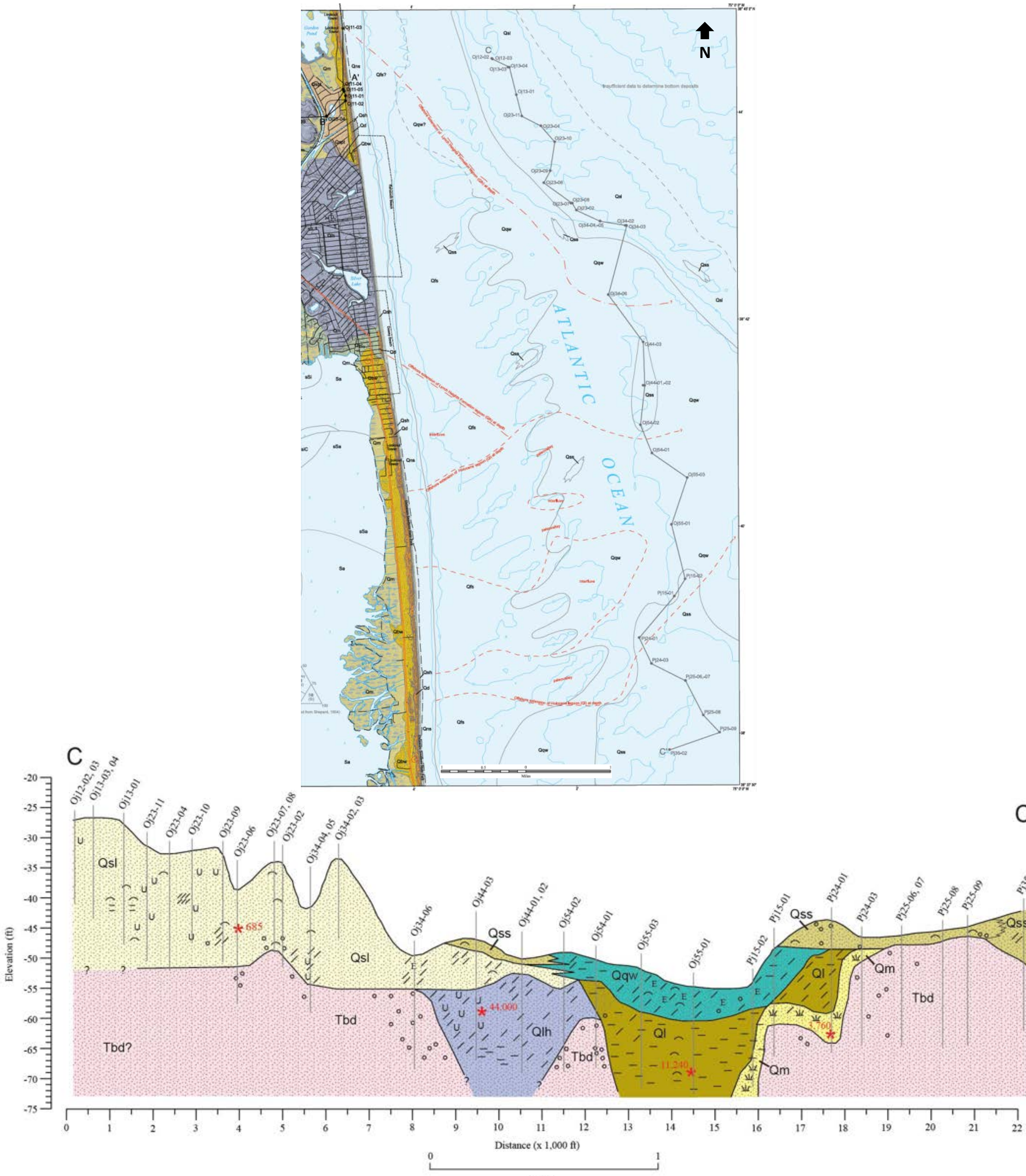

Figure 4. Geologic cross-section showing the relationship between some of the stratigraphic units found offshore Delaware (Ramsey, 2011). Map unit names are abbreviated: Qsl-shoal deposits, Qss- Sheet sand deposits, Qqw- quiet water deposits, Qm- marsh deposits, Ql- lagoon deposits Qlh- Lynch Heights Fm., Tbd- Beaverdam Formation. Dashed-red lines indicate possible boundaries of Quaternary and Holocene paleochannel-fill lagoon deposits. Radiocarbon dates indicated in red on cross-section.

METHODS AND DATA MANAGEMENT

This project concentrated on geologic data (cores, sediment texture, analog seismic records, and RC and AAR analyses) offshore Delaware from where either core had been collected or seismic surveys run. QA/QC of the data was conducted and relevant data were compiled into relational databases to be used for interpretation of offshore stratigraphy and for mapping in GIS. Cores in the DGS Core and Sample Repository (DGSCSR) were also examined where needed for stratigraphic interpretations and sampling for geochronology. Geochronologic data (RC and AAR) are an important component of stratigraphic interpretation. In order to have AAR data that were based on the most current analytic techniques, a reanalysis of shells from previously published sites from onshore and offshore Delmarva Peninsula sites was conducted (Belknap, 1979; Groot et al., 1990; Groot et al., 1995; Williams, 1999; Toscano et al, 1989). These samples were supplemented by additional samples primarily from offshore that had not previously been analyzed. Likewise, RC dating was conducted on organic material from offshore that had been dated using older techniques (Belknap and Kraft, 1985) along with undated material from cores. Select Holocene shells were also dated to provide calibration for the AAR interpretation. The following sections describe each of the data groups, the methodology employed in the QA/QC analysis and database construction, and the resulting databases that were used in the geologic mapping.

Geologic data

Vibracores

The first step in the project was to conduct quality analysis and quality control (QA/QC) of data records. The DGS WATSYS Oracle database contains all the primary data related to a core or sample site including a site identifier (DGSID), local identifier as assigned by the original data generator, geographic coordinates, sea floor elevation, core depth, and date drilled. The database also contains the basic information regarding samples including a DGS sample number and sample interval start and stop depths. Original data about offshore cores were re-examined to make sure the data were correct in the DGS WATSYS database and that no data had been missed since the most recent offshore resource project ended in 2010. A total of 415 cores are documented in WATSYS (Figure 5), of which 326 are in the Delaware Geological Survey Core and Sample Repository (DGSCSR). One set of vibracores had been collected since the last update by the Army Corps of Engineers (ACOE) in 2011. These cores had been obtained by the DGS and were in the DGSCSR but had not been examined. They were opened, described and sampled for this project. Table 1 is a summary of the 22 projects that produced core data used in this study. Additionally, 12 offshore bottom grab samples were collected in 2013 as part of a DNREC coastal mapping project and are now in the DGSCSR. The five cores collected as part of the Atlantic Sand Assessment Project (ASAP) are not included because pertinent data have not yet been made available.

Most vibracores were collected as 15 to 20 ft length cores. They were cut on shipboard into five ft sections and delivered to the contract agency. The cores in the DGSCSR are in sections split lengthwise to create halves for sampling and archival storage. The sampled half was inconsistently retained, but the archive half was nearly always preserved. When the cores were archived in the DGSCSR, each five ft section was assigned a unique number identifier (e.g., sample id 101766). Subsamples from each core segment were assigned the same sample id followed by a decimal and numbered in consecutive order as they were taken (e.g., sample id 101766.1, 101766.2). In addition to the QA/QC of the digital core data, a physical inventory was undertaken of the cores in the DGSCSR and QA/QC of correlative data in WATSYS. Priority was given to cores in Federal waters that had not been used in previous geologic mapping (Ramsey, 2011; Ramsey and Tomlinson, 2011, 2012). DGS employees compared the cores in the DGSCSR with their existing lithologic logs, verified IDs, and inventoried sample history. If missing, lithologic descriptions, stratigraphic interpretations, photographs, and shell or organic samples for geochronologic analyses were added to existing records. Once a vibracore record was complete, the sections were cut into 2.5 ft sections, sealed in plastic tubing, and placed in core boxes for permanent archiving. The process of permanent archiving the cores is time consuming, ongoing, and will be completed as time and resources are available.

Sediment Texture

Hundreds of sand texture (grain size, sorting, and other parameters) analyses have been run on samples from the offshore vibracores. These analyses were the basis for offshore sand resource assessment using a stack unit methodology of resource evaluation and a resource rating (McKenna, 2000; McKenna and Ramsey, 2002; McKenna and Ramsey, 2010). The initial assessment of the texture data and resource ratings during this project emphasized the need to update data records. Developing and managing a texture database would take considerable time and would diminish the focus on the offshore geologic mapping. In addition, personnel from the ACOE, Philadelphia District, and the Delaware DNREC Shoreline Management Section, who are the primary decision makers for beach replenishment projects in Delaware, were consulted regarding the resource ratings developed by the DGS (McKenna and Ramsey, 2010). It was determined that the resource rating system needs to be revisited. Specifically, an update to the ratings is needed to determine how to factor in the gravel fraction of the resources within the rating scheme. The gravel fraction has created issues both at the dredge site, by armoring the site with the pebbles not passed through screens, and on the beach by creating over steepened profiles and negative recreational perceptions. Therefore, the decision was made not to include texture data compilation and management as a part of the project. Sediment textures were used as a component in determining lithofacies and correlating stratigraphic units in the mapping project.

Year	Area	# Cores	Total Footage	Localids	Cores in DGSCSR	Data documentation
1970	Entire Offshore	13	221.5	SDK 1 to 16	No	Sheridan, Dill, and Kraft, 1974a, 1974b
1971	Mouth Delaware Bay	13	10.5	NSF-Station 16 to 22	Yes	Oostdam, 1971
1976	Entire Offshore	11	189.7	KHV-1 to KHV-11	No	ACOE, 1976, Phase 2 report
1979	Off Fenwick Island	1	10	1 to 13	No	Field, 1976, 1979
1984	Off IRI and Bethany Beach	11	229.8	KHV-12 to KHV-23	No	ACOE unpublished data
1987	Fenwick shoals	9	154.52	3-1, 3-2, 3-4, 3-9, 3-10, 3-11, 3-12, 8-3, 8-6	No	Underwood and Anders, 1987
1981	Nearshore along entire DE coast	36	880.6	JCK A to L 1 to 3 81	Yes	Unpublished core logs at DGS
1982	Indian River Inlet Ebb Tidal Shoal	4	53.5	JCK-IRI-1-81 to JCK-IRI-4-81	Yes	Collins, 1982
1992	Entire Offshore	17	251	DGS92-01 to DGS92-16	Yes	Unpublished core logs at DGS
1992	Fenwick shoals	5	82	MGS-WS-1 to WS-5	No	Unpublished core logs at DGS
1993	Off Rehoboth Bay to off Indian River Inlet	26	476.9	KHV-31 to KHV-58	No	ACOE, 1996
1997	Off Bethany Beach to off Fenwick Island	22	426.3	KHV-59 to KHV-80	Yes	Woodward-Clyde Federal Services, 1997
1997	Entire Offshore	24	129.6	DGS97-3 to DGS97-28	Yes	Unpublished core logs at DGS
1997	Entire Offshore	35	580.2	DGS97-29 to DGS97-60	Yes	Unpublished core logs at DGS
1999	Off Rehoboth Beach	15	225.3	KHV-81 to KHV-92	Yes	Duffield Associates, 1999 Contract Report
2000	Off Rehoboth Bay to off Indian River Inlet	30	496.3	KVH-93 to KHV-115	Yes	Duffield Associates, Inc., 2000 Contract Report for ACOE
2001	Off Dewey Beach to off Indian River Inlet	24	404	DGS01-1 to DGS01-20	Yes	Unpublished DGS data
2004	Off Bethany Beach	13	232.5	DGS04-01 to DGS04-12	Yes	Unpublished DGS data
2007	Off Cape Henlopen to off Rehoboth Bay	26	480.5	DGS07-01 to DGS07-25	Yes	DGS Contract Report April 2009
2007	Off entire coast	33	574.22	KHV-116 to KHV-145	Yes	2007 Schnabel Engineering data report
2008	Off Bethany Beach to off Fenwick Isl.	23	418.5	KHV-146 to KHV-168	Yes	2009 CH2MHill technical
2011	Off Rehoboth Beach	24	391.3	KHV-169 to KHV-186, BVC-1 to BVC-6	Yes	2011 O'Brien & Gere technical report
		415	6918.74			

Table 1. Summary of core data offshore Delaware.

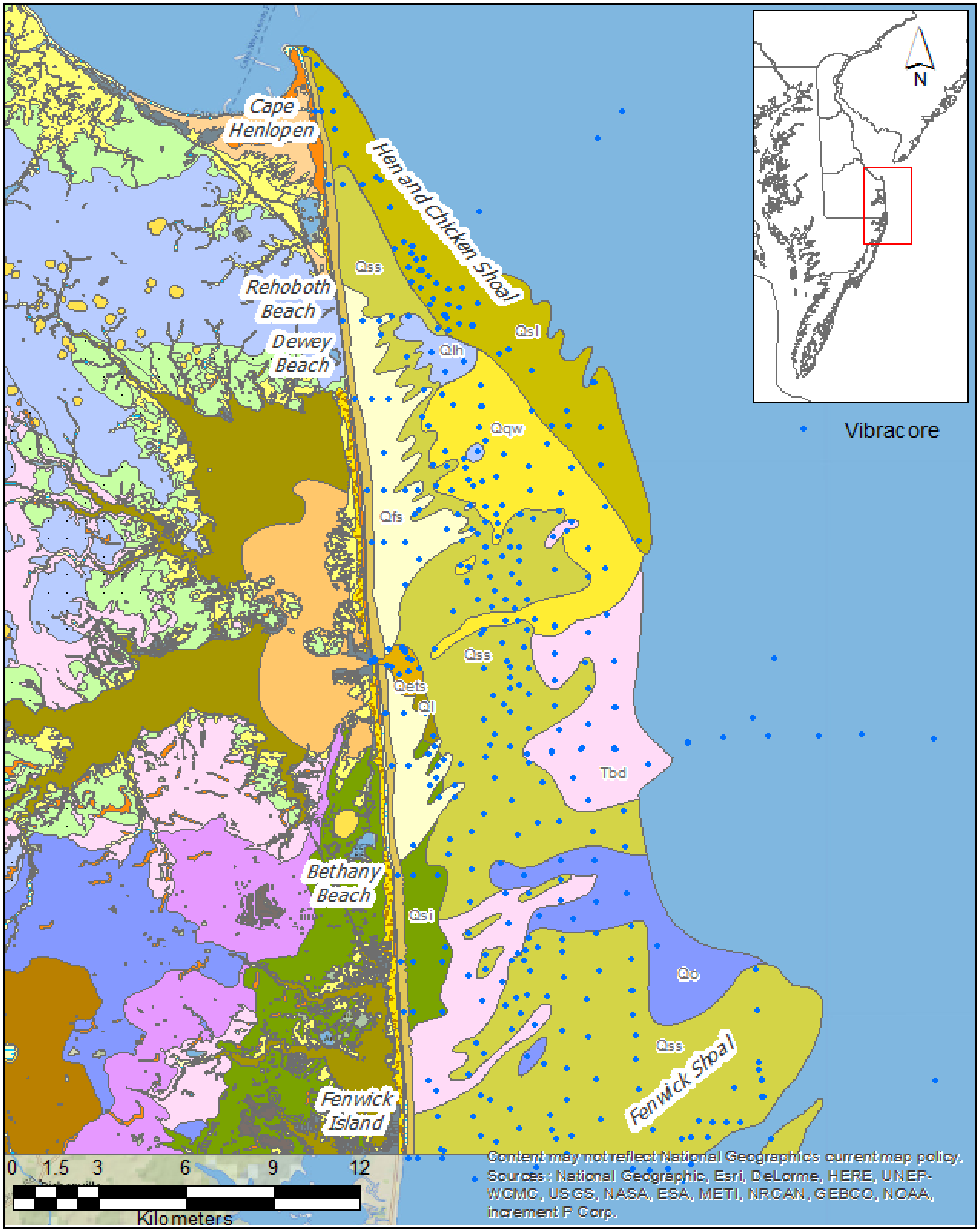

Figure 5. Location of 420 vibracores offshore Delaware. The color-shaded areas show both onshore and offshore surficial geologic units. Plate 1 shows the offshore units in more detail.

Amino Acid Racemization (AAR) Data

Aminostratigraphy is a method by which relative ages of stratigraphic units can be determined from the geochemistry of fossil mollusk shells found within those deposits. Wehmiller, in Groot et al. (1990, p. 10), summarized aminostratigraphy as follows.

> "Aminostratigraphy relies upon the observation that amino-acids contained in fossilized skeletal organic matter (in mollusks, for example) undergo racemization during diagenesis. Racemization produces D- (or right- handed) amino-acids from the original L- (left-handed) amino-acids that produce biomineralization protein. The degree of racemization is determined by measurement of D/L values for one or more amino-acids in the total amino-acid mixture of a fossil. The D/L value starts at 0 in modern samples and reaches an equilibrium value (1.0 in most amino-acids) in about 1 to 2 million years at temperatures like those of the mid-Atlantic region. The simplest approach to the use of amino-acid D/L data is as a stratigraphic tool, whereby relative ages are assigned to recognized clusters of D/L values (aminozones) from samples within a region of similar temperature histories."

For the middle to late Pleistocene deposits of southern Delaware, the use of AAR data provides a means of correlation between geologic units that is independent of the lithostratigraphy and geomorphology and is the primary method of age correlation. AAR is a low-cost alternative to radiocarbon dating ($60/sample vs $600/sample) to determine if a shell is Pleistocene or Holocene in age.

A QA/QC analysis was conducted on the existing AAR data and cross-referenced with Wehmiller and Pellerito (2015). Specific attention was given to verifying sample site locations and documenting sampling chronology. The Delaware Geological Survey Amino Acid Racemization Database (DGSAARDB) was constructed to manage AAR data relevant to, and generated by, this project and shell samples that are part of the DGS Quaternary Shell collection (QuatShl). This collection is comprised primarily of shells collected by John Wehmiller and his students that are now part of the DGSCSR.

AAR data from Delaware onshore sites (Belknap, 1979; Groot et al., 1995; Groot et al., 1990) and offshore sites (limited data in Belknap, 1979; Williams, 1999; Toscano et al., 1989 from adjacent Maryland) were generated by several different analytical methods yielding in some cases a limited suite of D/L values for a sample. Between 2005 and 2011, 131 shell samples from Delaware offshore and onshore sites were analyzed at Northern Arizona University (NAU) using the reverse phase liquid chromatography (RPLC) methodology (Kaufman and Manley, 1998). The RPLC data, in agreement with older data (Belknap, 1979; Groot et al., 1990), indicate several different clusters of D/L values, interpreted as aminozones, were present. Given that shells from Delaware, including the offshore, had already been analyzed by the RPLC method, it was determined for this project to use only RPLC data in order to have a common analytic methodology for the results. A regional approach to data collection and analysis was taken to provide an updated geochronologic framework based on AAR for the Delmarva Peninsula region, both onshore and offshore. Selected samples from Quaternary deposits previously analyzed (Belknap, 1979; Toscano, et al., 1989; Groot et al., 1995) were sent to NAU along with additional samples not previously analyzed. The goal of the sampling strategy is to develop better stratigraphic resolution between and within middle and late Pleistocene deposits. Another goal of the data analysis is to determine whether MIS-3 age highstand marine deposits can be separated from those of MIS-5 using AAR. If separation can be achieved, the new information can be used to clarify interpretations regarding MIS-3 regional sea-level history and glacial neotectonic history (Finkelstein and Kearney, 1988; Colman et al., 1989; Scott et al., 2010; DeJong et al., 2015). These data are also important for interpreting past and future rates of sea-level rise during the Holocene (Englehart et al., 2009).

For this project, 247 shell samples were sent to NAU for AAR RPLC analysis. These samples were from both onshore and offshore localities from Delaware, New Jersey, Maryland, and Virginia with the majority of the samples from offshore (Figure 6). Of these, 136 analyses have been received with the remaining 111 expected in June 2016. With the previous 131 samples from Delaware already analyzed, these 378 analyses will comprise one of the largest regional data sets anywhere for geochronologic interpretation. The AAR data are still being analyzed, but, a few preliminary results are presented in the following section.

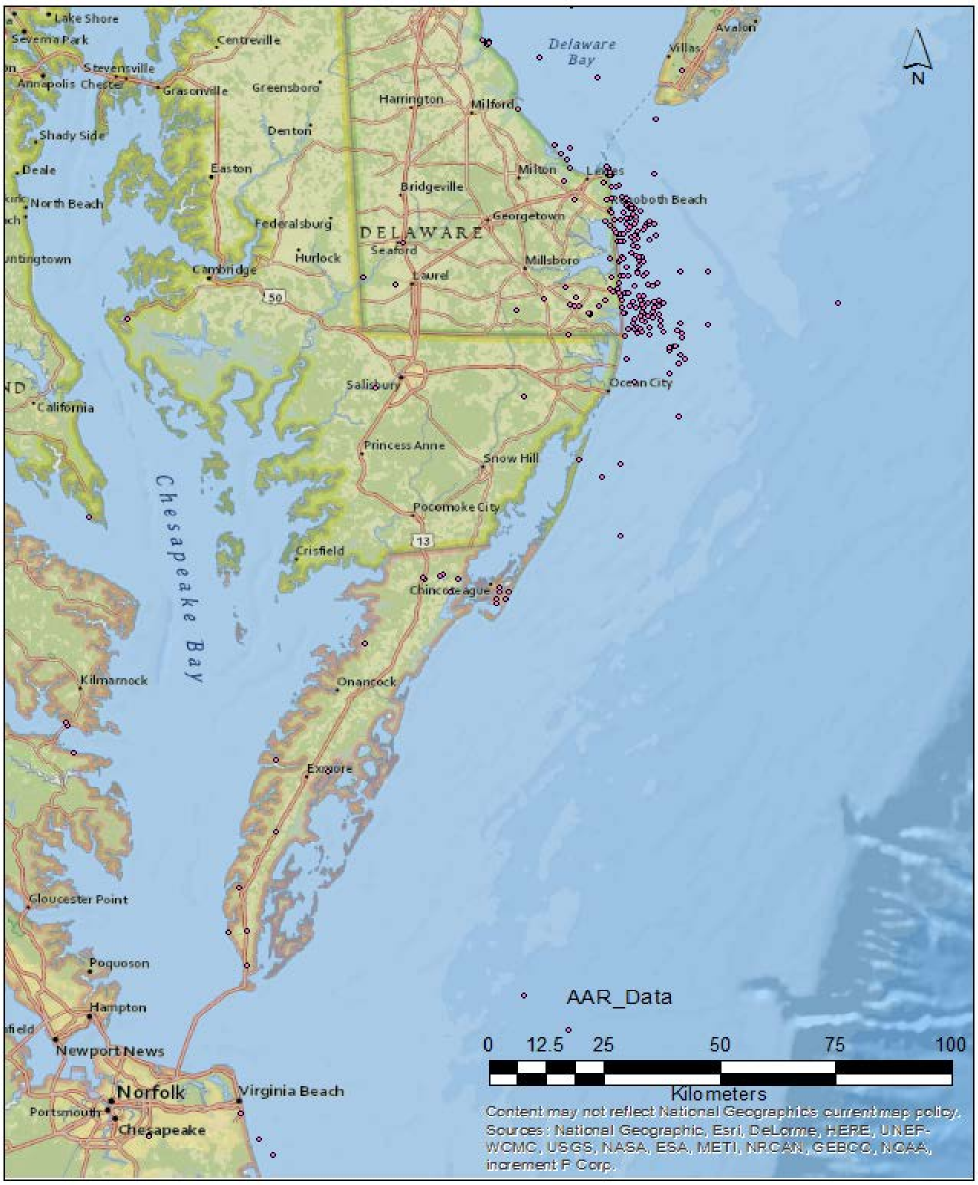

Figure 6. Locations for 251 of the amino acid racemization (AAR) data results in the Delaware Geological Survey Amino Acid Racemization Data Base (DGSAARDB). Locations for samples in processing are not shown.

Radiocarbon Data

Radiocarbon data from Delaware (Ramsey and Baxter, 1996) are now part of an Access database, the Delaware Geological Survey Radiocarbon Database (DGSRCDB). This database was upgraded for this project with additional queries and a QA/QC conducted on data that were not completely documented. The DGSRCDB includes 483 radiocarbon dates with the majority being from Delaware. These dates were supplemented by dates from Maryland and Virginia portions of the Delmarva Peninsula and offshore for this project. Of these dates, 51 are from offshore cores and 118 from the marsh and lagoonal deposits along the Atlantic Coast of the Delmarva Peninsula (Figure 7). A total of 27 dates were funded by this project of which the results of 16 dates from offshore shell samples are still pending (and will be added to the 483 dates in the DGSRCDB). These shell samples are being RC dated as a calibration for AAR data from the same Holocene shell samples to better understand intergeneric racemization rates for *Mercenaria, Mulinia, Ensis, Spisula,* and *Astarte*. Understanding the racemization rates is important for comparing D/L ratios from multiple genera from the same site.

Geophysical Data

An inventory was conducted of seismic surveys offshore Delaware limited to the study area of this project. At least 10 marine geophysical surveys were documented, but sub-bottom data existed for only four surveys. Of these four data sets, three were analog records from surveys conducted over 20 years ago. Figure 8 shows the location of survey tracklines including the data format. Interpretations of resulting sub-bottom profiles are missing or incomplete excluding the data collected in cooperation with the Maryland Geological Survey (MGS) in 1992/1993 (Williams, 1999). Through this project, the DGS has increased its geophysical data processing capacity by acquiring Chesapeake Technology, Inc.'s *ImageToSegy* software. Analog records can now be digitally scanned, geo-rectified based on tic mark data, and interpreted using digital processing software. Digital geophysical data was collected within Delaware State waters as part of a DNREC coastal mapping effort in 2013. This data set, along with the pending geophysical data collected as part of this project, has not been processed or interpreted. Data have been archived at the DGS until processing capacity is acquired. Given the limited data and the impending arrival of the ASAP geophysical data, it was decided not to conduct any detailed analysis of the existing geophysical data or conversion of analog to digital records. Once the ASAP data are available, the existing data will be examined to determine their utility for sub-bottom stratigraphic interpretation.

Data management (databases)

WATSYS was originally constructed to manage water well records and works well for spatial data and sample data. Analytic data from geologic samples and interpretive data such as stratigraphic picks are not part of the WATSYS database. For management of these data, Access relational databases were used. An existing DGS databases for stratigraphic picks was used for stratigraphic contact interpretations. An existing DGS radiocarbon database (DGSRCDB) (Ramsey and Baxter, 1996) was restructured and updated for radiocarbon analysis results. A new database for amino acid racemization data (DGSAARDB) was constructed. A database for all the offshore core data was constructed to link all of the DGS databases (WATSYS, DGSRCDB, DGSAARDB, and stratigraphic picks). This design allows for the combined display

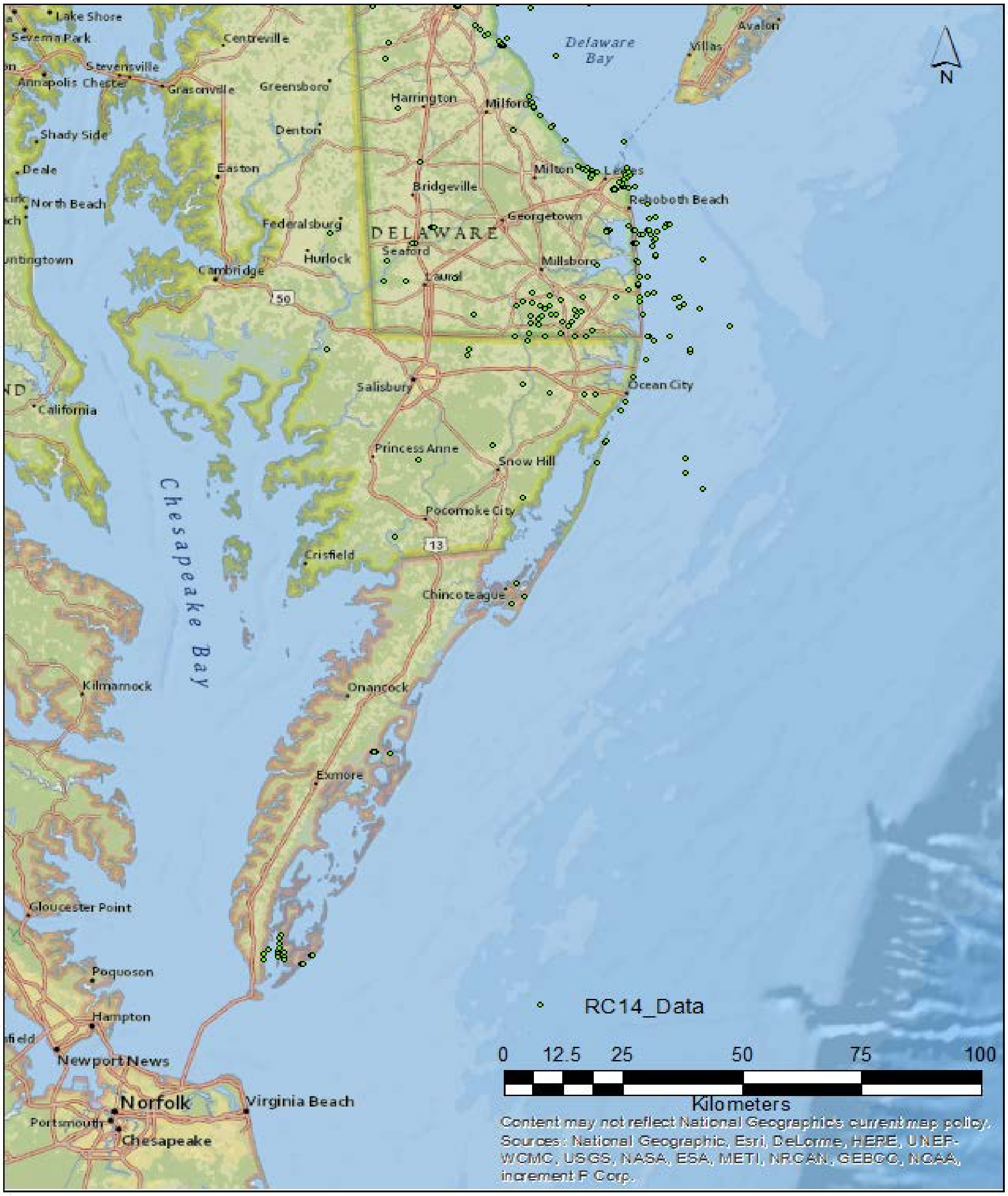

Figure 7. Location of 322 radiocarbon (RC) data results in the Delaware Geological Survey Radiocarbon Data Base (DGSRCDB). Location of additional samples in processing is not shown.

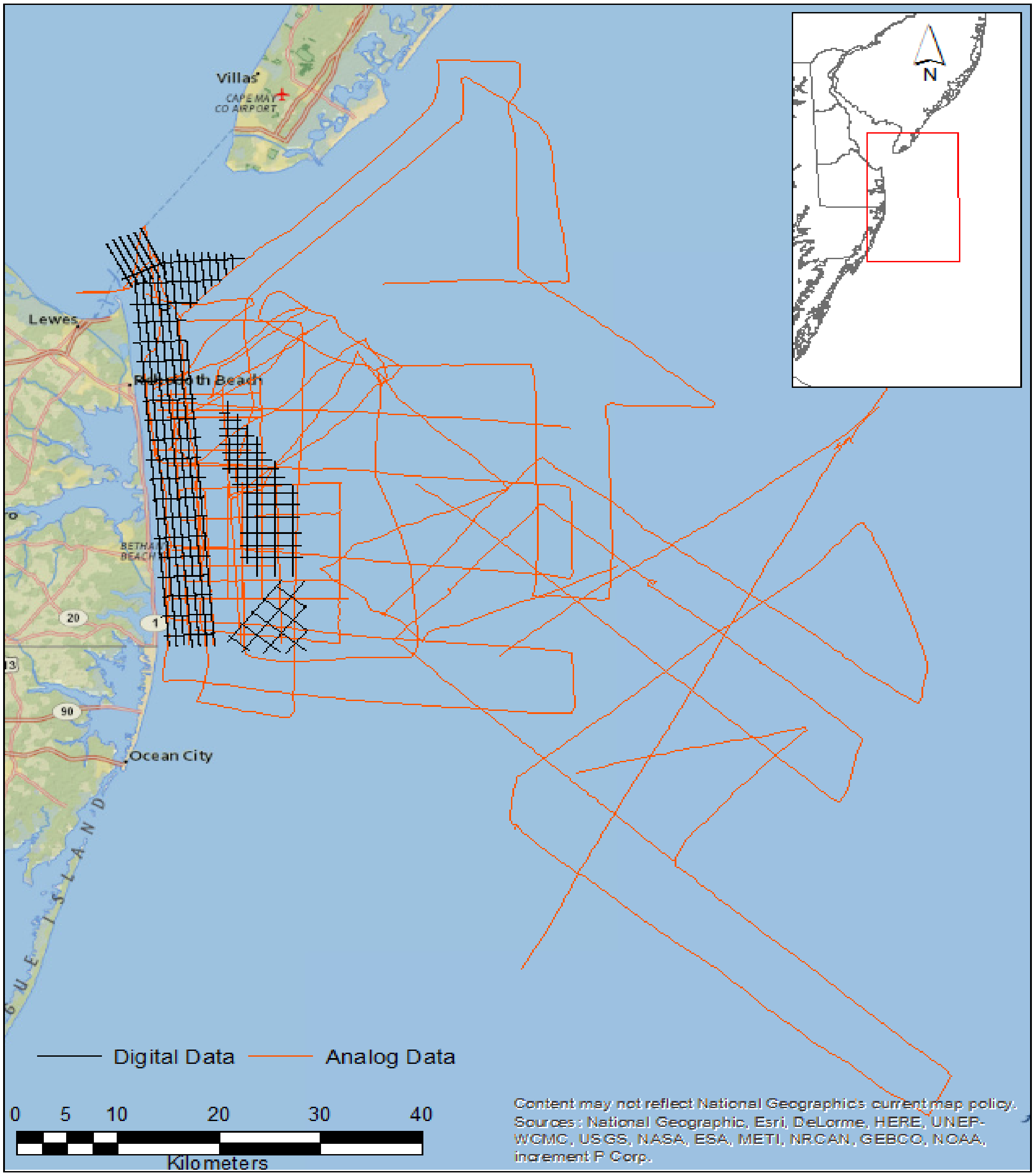

Figure 8. Location of geophysical survey coverage offshore Delaware. Analog data exists for the three separate surveys that are represented in orange. Digital data only exists for one survey (within Delaware state waters), with data resulting from this project pending delivery.

of all the data associated with a particular core or sample. Queries were written for the databases that create tables which can be tied to ESRI ARCGIS projects for spatial analysis, mapping, or graphical display. Metadata related to the databases can be found in Appendix I.

Delaware Geological Survey Radiocarbon Database (DGSRCDB)

The DGSRCDB database contains radiocarbon dates from geologic samples collected onshore and offshore Delaware. The database has been expanded to include the Maryland and Virginia portions of the Delmarva Peninsula, both onshore and offshore. As of May 1, 2016, 483 radiocarbon dates are included in the database. All dates are related to a sample locality with geographic coordinates and land surface (or sea floor) and sample elevation, as well as the type of sample dated (e.g. peat, shell, organic sediment). The database record includes all data received from the analytical lab including any calibration of the dates (e.g. INTCAL13, InterCal09.14C). Data can be queried by age, sample type, geographic coordinates or region, and other parameters and geographically displayed in GIS. These data are instrumental for understanding the sea-level history of the region over the past 45ka years and in predicting future rates and effects of sea-level rise.

The Delaware Geological Survey Amino Acid Racemization (DGSAARDB) Database

All AAR data for geologic samples from the Delmarva Peninsula have been combined in the DGSAARDB. These data have been collected by Dr. John Wehmiller, Professor Emeritus of the Dept. of Geological Sciences at the University of Delaware, and his students over the last 35 years. As of May 1, 2016, 282 localities from which mollusk shells have been collected and over 600 data analyses are included in the database. AAR data are used as a tool for approximation of age based on racemized (D/L) ratios of amino acids from shell material. These data are the primary tool available for age estimates of estuarine and marine Quaternary deposits in the U.S. mid-Atlantic region. The age estimates are important for mapping the geology offshore of the Delmarva Peninsula and correlating it with the onshore geology. The usefulness of the data in mapping offshore deposits is that the samples which are Holocene (D/L ratios less than 0.2 and independently dated by radiocarbon) can be readily differentiated from older deposits. In addition to the database, the samples from which the data were generated are now in the DGSCSR as a separate collection called the Quaternary Shell Collection (QuatShl).

Delaware Geological Survey Offshore (vibra)Core Database (DGSOCDB)

In order to organize all the geologic data associated with vibracores collected offshore of Delaware the Access DGSOCDB was constructed. This database allows for organization and analysis of multiple data sets in a single relational database rather than having separate files, spreadsheets, and folders. The database links to WATSYS, the DGSRC, the DGSSP, and DGSAAR databases, as well as supplemental core information (e.g. core photographs, texture analysis data, lithologic descriptions, interpretations of depositional environments). Combining all of the data associated with cores enables users to search, sort, and query a wide range of attributes as they pertain to QA/QC, stratigraphic interpretations, and surface geologic mapping.

Delaware Geological Survey Stratigraphic Pick Database (DGSSPDB)

The DGSSPDB was developed to manage stratigraphic picks that were the result of surficial geologic mapping projects sponsored by the StateMap Program. A stratigraphic pick is defined as an interpretation of a stratigraphic contact, the depth and elevation of the contact, and the stratigraphic units above and below the contact. The database links to WATSYS for the primary data related to the site (e.g., outcrop, boring, hand auger). Queries have been written to create tables for specific contacts, surficial geologic units, and other necessary data. Beginning with the mapping of the central and southern Delaware Atlantic Coast, offshore vibracores were included in the database (Ramsey, 2011, Ramsey and Tomlinson, 2012). As of May 1, 2016, 6,048 sites are included in the DGSSPDB, of which approximately 300 are offshore vibracores.

Geologic Map Construction

Surficial geologic map units previously recognized and mapped both onshore and offshore (Ramsey, 2011; Ramsey and Tomlinson, 2012) were extended farther offshore into Federal waters and revised from previous geologic maps. Cores were re-examined and stratigraphic units reinterpreted based on additional geologic or geochronologic data. The area offshore Cape Henlopen was previously mapped (Ramsey, 2003) only as sediment textures. All cores for this area were examined and stratigraphic picks made. Because the primary mission of this project is to identify sand resources, solely mapping the surficial unit may be misleading, especially where a thin sand veneer which may look like a viable resource on a map overlies a muddy unit that is not a potential resource. A future product of this work will be a derivative map that shows the geologic unit at a depth likely to be encountered during a dredge project (3-5 ft below the sea floor). Showing the presence of thin surficial units is important for understanding the geologic history and present geologic processes (e.g., sediment transport and deposition, bottom currents, wave climate, and storm wave base) which factor into both mapping and identification of sand resources.

DISCUSSION

Geochronologic Interpretations

The geochronologic data compiled and generated by this project provide an updated age framework for the stratigraphic units mapped offshore (Figures 9, 10). Given the complexity of cross-cutting paleochannel networks that were incised during Quaternary sea-level lowstands (Figure 3; Belknap and Kraft, 1985; Kraft et al., 1987; Williams, 1999), geochronologic data are essential for determining the age of the sediment infill and for dating of Holocene seafloor sediments that overlie the paleochannels. The following sections highlight some of the significant geochronologic results anticipated from this project.

<u>AAR</u>

1. AAR D/L ratios from Holocene-age shells can be clearly differentiated from late Pleistocene shells (Figure 9), even those attributed to MIS-3 (25 ka BP to 60 ka BP).
2. AAR calibration for five mollusk genera, *Mercenaria*, *Mulinia*, *Ensis*, *Spisula*, and *Astarte* indicate that *Spisula*, *Astarte*, and *Ensis* all have very similar D/L values for samples of the same age. *Mulinia* samples of the same age would have slightly lower D/L values and *Mercenaria* samples of the same age would have somewhat higher D/L values.

3. MIS-3 marine deposits are found offshore Delmarva Peninsula at depths > 60 ft at similar depths to MIS-3 deposits found off New Jersey (Wright et al., 2009).
4. As many as five aminozones in the mid-Atlantic region can be separated into early, middle, two late Pleistocene, and Holocene. Early Pleistocene deposits are found in Virginia and New Jersey, but not in between. At the Delaware coastline and offshore, middle and late Pleistocene deposits are found in stratigraphic position in single vibracores.
5. Onshore and offshore shell-bearing paleovalley-fill deposits can be correlated using AAR data. The paleovalleys correlated with AAR data are consistent with those mapped by core data and seismic line interpretations (e.g. shells from a paleovalley mapped onshore and offshore have the same AAR values) (Figures 3 and 4; Plate 1).

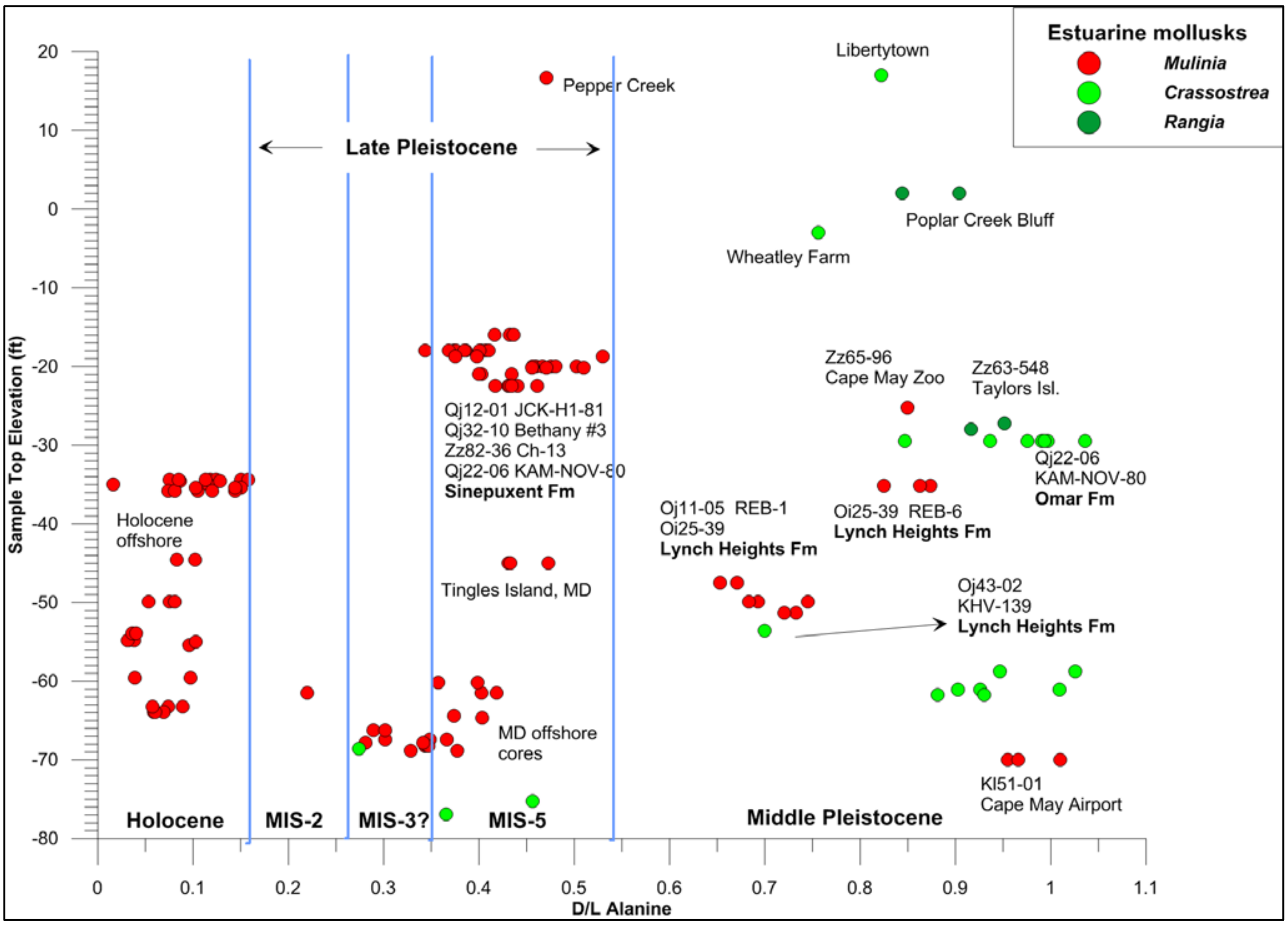

Figure 9. Alanine D/L ratios vs sample elevation for estuarine mollusks with age interpretations. Sample site and stratigraphic units are noted for clusters of data. Age interpretations are preliminary based on stratigraphic unit and previous interpretations (Groot et al., 1990, 1995; Ramsey, 2010; Wehmiller et al., 1988; Toscano et al., 1989) and interpretations of new data generated by this project.

Radiocarbon

1. The Holocene rise of sea level began to affect the region at about 11 ka when sea level was at approximately -90 ft MSL (Figure 10).
2. No organic material has been found along the coast that dates between about 12 ka and 22 ka (Figure 10). This is the time of maximum glaciation; the area was exposed land.
3. There are an abundance of dates on plant material between 22 ka and 38 ka (early MIS-2 and MIS-3) (Figure 10). These dates have been cited as evidence of MIS-3 sea level higher in the region than predicted by global sea-level estimations (Finkelstein and Kearney, 1988; Scott et al., 2010). Pollen data from samples associated with radiocarbon dates (Finklestein, 1986; Weigle, 1974; McLaughlin, 2016, unpublished DGS pollen data), however, indicate that these are actually non-marine periglacial deposits (Figure 10). These deposits are similar in pollen flora and lithology to the Cypress Swamp Formation found on the uplands of the Delmarva Peninsula of Delaware and Maryland (Andres and Howard, 2000; Ramsey and Tomlinson, 2014; unpublished DGS data). This is the first indication that late Pleistocene periglacial non-marine sediment deposits occur offshore.
4. Radiocarbon dates on shell (red dots in Figure 10) indicate marine deposits that are Holocene in age.

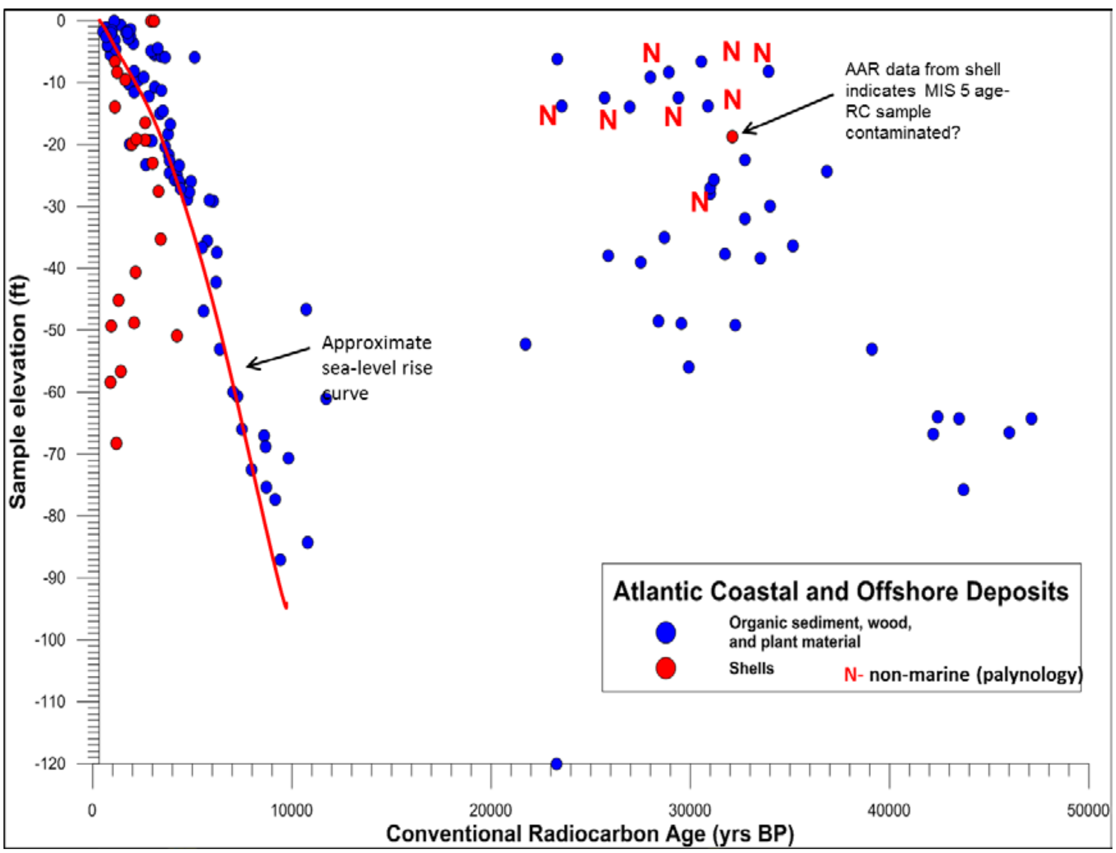

Figure 10. Radiocarbon dates from the coastal and offshore region of the Delmarva Peninsula plotted relative to sample elevation. Note non-marine samples (N) identified by palynology.

Offshore Geology

A preliminary surficial geologic map offshore Delaware was constructed (Plate 1). This map is considered preliminary because the core and geophysical data from the ASAP project have not yet been obtained and need to be integrated into the results. Additional cores from the DGS-BOEM ASAP cooperative agreement are likely forthcoming. Geochronologic data generated by this project and the ASAP project have just been received or are still being processed and have not been completely examined and integrated into the map interpretations. Likewise, detailed cross-sections have not been constructed because the geophysical data may greatly influence interpretations of the subsurface expression of geologic units. For the ease of readingt, a smaller version of Plate 1 without the detailed unit descriptions can be found in Figure 11. For details regarding the stratigraphic units and geologic history refer to the cited maps, Plate 1, and Ramsey (2010). The following is a brief synopsis of the geology offshore Delaware leading into a discussion offshore sand resources.

<u>Major geologic units and geologic history</u>

1. The oldest unit encountered in the offshore cores, the Beaverdam Fm. of probable late Pliocene age, is mapped onshore throughout the central Delmarva Peninsula (Ramsey, 2010; Owens and Denny, 1979). The Beaverdam Fm. (Tbd in Figure 11) has a very distinctive lithology with a characteristic white color and white silt matrix. All younger units found onshore and offshore have an erosional contact with the underlying Beaverdam Fm. The Quaternary history of the area can be summarized as erosion into and reworking of the Beaverdam Fm. (Ramsey 2010).
2. Quaternary deposits consist of sand reworked from the Beaverdam Fm. with an addition of new sediment, primarily mud deposited in estuarine environments within paleovalleys incised into the Beaverdam during sea-level lowstands during the middle and late Pleistocene (Ramsey, 2010).
3. The middle Pleistocene muddy units, the Lynch Heights Fm. and Omar Fm. (Qlh and Qo in Figure 11) are also mapped at the sea floor and fill coast-perpendicular paleovalleys that are also mapped onshore (Ramsey, 2011; Ramsey and Tomlinson, 2012).
4. The late Pleistocene Sinepuxent Fm. fills a coast-parallel paleovalley that crosses the present shoreline in the vicinity of Bethany Beach (Ramsey and Tomlinson, 2012) and extends offshore. The Sinepuxent is distinctive in that it is very fine to fine silty sand that is noticeably micaceous and in places has very abundant *Mulinia* shells.
5. The offshore Holocene deposits are primarily sand with the exception of muddy lagoonal deposits (Ql in Figure 11) off Indian River and Rehoboth Bays. These lagoonal deposits occupy paleovalleys filled with muds during the early Holocene, transgressed by the shoreline during continued sea-level rise and now exposed at the sea floor (Figure 4).
6. The most prominent Holocene deposit is an ebb shoal (Hen and Chickens shoal) that extends seaward from Cape Henlopen. The sands in the shoal (Qsl in Figure 11) fine seaward from medium to coarse sands near the Cape to fine to very fine sands at the distal end of the shoal. The shoal sands are greater than 20 ft thick over much of their extent and thin landward and towards their distal end.
7. The shoal sands interfinger with and are overlain by finer-grained quiet water deposits (Qqw in Figure 11) on the leeward side of the shoal. These quiet water deposits consist of very fine silty sand to silt with *Ensis* shells as a common to abundant component.

These deposits represent deposition in an area sheltered by the shoal from wave and storm climate and at depths greater than 45 ft.

8. Finger shoals (Qfs in Figure 11) are silty fining-seaward coarse to very fine sands that have a characteristic shore-oblique bathymetric signature. They are located just to the south of Indian River Inlet and off Rehoboth Bay. The sand in the shoals likely is a mix of sand moved from the shoreline during storms and sand reworked from the Sinepuxent and Beaverdam Fms.
9. Sheet sands (Qss in Figure 11) are found offshore of most of the coastline. The sheet sands are clean, fine to coarse sands with shells of *Spisula* being a common component. These deposits range in thickness from a few inches to over 20 ft. The thickest deposits are found in ridges off the Delaware-Maryland border (Fenwick Shoal and smaller unnamed ridges). In terms of texture, the sheet sands that have no bathymetric expression and the ridge deposits are the same and have been mapped together.
10. Other minor units such as ebb tidal shoal deposits and nearshore are also mapped (Plate 1) but are not potential sand resources.

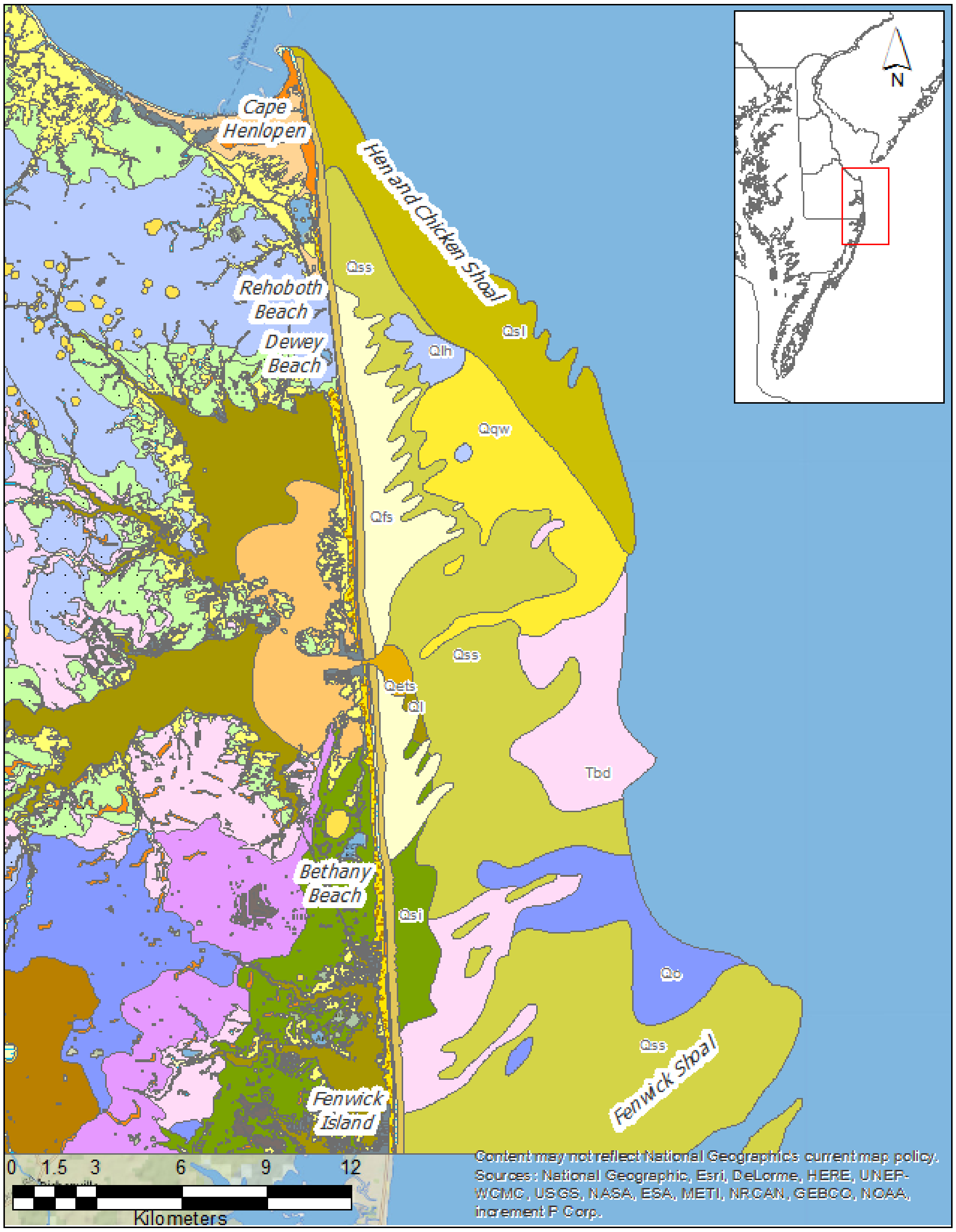

Figure 11. Geologic map showing the interpreted extent of Holocene, Pleistocene, and Pliocene units, both onshore and offshore Delaware. Map unit names are abbreviated: Qns-near shore deposits, Qsl-shoal deposits, Qss-sheet sand deposits, Ql-lagoon, Qfs-finger shoal deposits, Qqw-quiet water deposits, Qets-ebb tidal shoal deposits, Qlh-Lynch Heights Fm., Qsi-Sinepuxent Fm, Qo-Omar Fm., Tbd-Beaverdam Formation. Plate 1 shows the offshore units in more detail, including unit descriptions.

Offshore Geology and Sand Resources

Figure 12 includes interpreted geologic units offshore with annotations regarding potential for sand resources for beach replenishment. The geologic map units and their potential for sand resources are given in Table 3. The most promising units for sand resources in Federal waters are Holocene shoal deposits, Holocene sheet sand deposits, and the Pliocene Beaverdam Fm. (Figures 11, 12). The southern Delaware Beach communities of Bethany, South Bethany, and Fenwick Island are closest in proximity to the sheet sand deposits that have already been used for beach replenishment. Resources closest to Dewey Beach and Rehoboth Beach are most likely Holocene shoal deposits and the Beaverdam Fm. The geologic composition (i.e. pebble layers) within the Beaverdam Fm and the biologic importance (i.e. essential fish habitat) of the shoal deposits are additional factors when considering these units as beach nourishment resources.

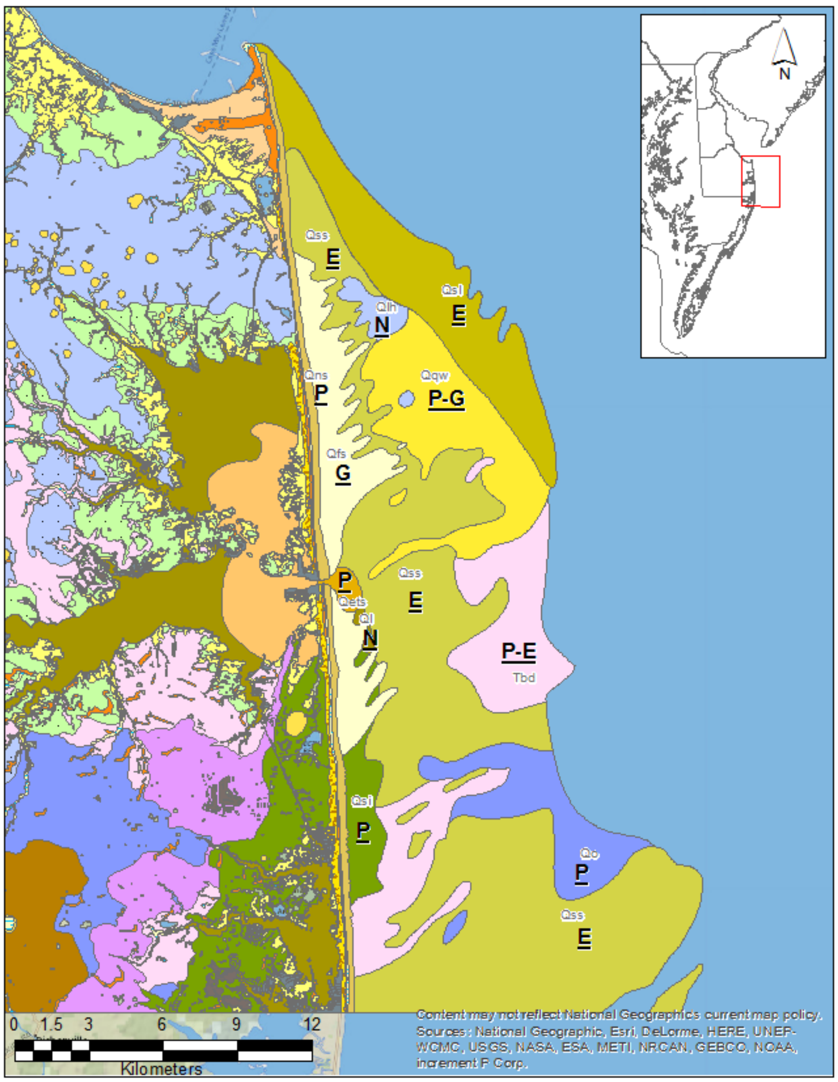

Figure 12. Geologic map showing the interpreted extent of Holocene, Pleistocene, and Pliocene units adjacent to the Delaware Atlantic coast. Units are annotated with a Resource Potential symbology found in Table 2, E-excellent, G-good, P-poor, N-none.

Map unit abbreviation	Map Unit	Description	Resource Potential	Comments
Ql	Holocene lagoon	Muddy lagoonal paleovalley fill sediments	None (N)	
Qsl	Holocene shoal deposits	Fining seaward coarse to fine-grained sands associated with Hen and Chickens Shoal	Excellent (E)	Societal factors may preclude this unit from being used
Qqw	Holocene quiet water deposits	Fine to very fine silty sands landward of Hen and Chickens Shoal	Poor-good (P-G)	May find some decent sand bodies adjacent to Qsl
Qfs	Holocene finger shoal deposits	Fining seaward medium to very fine sands on shore-attached ridges.	Good (G)	Probably too close to the shoreline to be used
Qss	Holocene sheet sand deposits	Clean fine to coarse sands and shell	Excellent (E)	Highly variable in thickness, will need detailed site-specific evaluation for borrow areas. May contain too much gravel in places
Qsi	Sinepuxent Fm.	Fine to very fine micaceous sand	Poor (P)	Too fine and micaceous. Too close to shore to use
Qlh	Lynch Heights Fm.	Muddy lagoonal paleovalley fill sediments	None (N)	
Qo	Omar Fm.	Muddy lagoonal paleovalley fill sediments	Poor (P)	There are sand beds in the Omar Fm. onshore but they have not been seen offshore
Tbd	Beaverdam Fm.	Coarse to fine sand with varying amounts of gravel	Excellent (E)-poor (P)	Consistently sand but highly variable in the percentage of gravel. Will need detailed site-specific evaluation for borrow areas

Table 2. Summary of sand resource potential for geologic map units. Resource potential is indicated for each geologic unit in Figure 12. Ebb tidal shoal and nearshore deposits not included.

RESULTS AND CONCLUSIONS

1. A new geologic map for offshore Delaware (Plate 1) provides a geologic framework for detailed sand resource exploration. Core and geophysical data from the ASAP project will allow for refinement of this map and identification of targets for sand resource investigations in Federal waters.
2. Geologic map units were determined to be useful in identifying areas of potential sand resources and in ruling out areas where resources do not exist.
3. Databases for managing offshore core data and AAR data were constructed. Existing databases for RC data and stratigraphic picks were upgraded to include additional queries useful for mapping offshore.
4. Geochronologic data were generated and interpreted to provide age context for the geologic history of the offshore and identification of stratigraphic units.

FUTURE WORK

This project has identified the following areas that need to be addressed in future DGS-BOEM Cooperative Studies.

1. Reassessment of sand resource potential mapping using sediment texture (stack-unit mapping). QA/QC and compilation of sediment texture data will be necessary in order to accomplish this task. A database to manage the texture data will need to be constructed.
2. Once the ASAP seismic records have been analyzed and interpreted, analog seismic data will need to be assessed in order to determine which data need to be converted to a digital format and then interpreted.
3. Once all seismic data are analyzed and interpreted, additional areas for seismic data collection can be identified.
4. Site specific areas for potential resources need to be identified so that detailed seismic studies and cores can be used to delineate potential borrow areas.
5. The RC data need to be analyzed in detail to determine rates of Holocene sea-level rise that can be used in predictions of future rates of sea-level rise and the geologic effects of sea-level rise.
6. AAR data need additional analysis and calibration. Calibration of racemization rates will aid in age determination of the Quaternary units. Understanding the age of the units and their present elevation ranges is important for studies of glacial neotectonics (forebulge dynamics) that are used in interpretations of present rates of sea-level rise.

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Appendix I Database Metadata

Ramsey, K.W., 2016, The Delaware Geological Survey Delmarva Peninsula Radiocarbon Database, version 2016.1, Delaware Geological Survey data, not Web accessible, Microsoft Access 2010 relational database.

Metadata. The Delaware Geological Survey Delmarva Peninsula Radiocarbon Database, version 2016.1. Delaware Geological Survey. Microsoft Access 2010 relational database. A compilation of radiocarbon dates from geologic samples from the Delmarva Peninsula Region including the Delmarva Peninsula, offshore Delmarva Peninsula, Chesapeake Bay, offshore Virginia from Cape Henry to the North Carolina Border, and Cape May, New Jersey both onshore and offshore. Data are compiled from 65 published and unpublished sources included in the database. All sample sites are given DGS Watsys database identifiers associated with UTM northings and eastings and land surface elevations. Sample type (e.g., peat, wood, shell), top of sample elevation, elevation datum (e.g., MSL, NAVD88, NGVD29), sample interval thickness (in tenths of feet) sample identifiers (for DGS-generated samples) date collected (where known) project that generated the sample, and other data relevant to the sample are recorded. Radiocarbon date data from the radiocarbon laboratories in the database include laboratory identifier, conventional and measured radiocarbon ages, calibrated dates and dating curve intercepts, calibration method, 13C/12C ratios, analytical method, pretreatment method, and date of report and any comments from the lab regarding the sample. All original lab reports or copies of lab reports are archived in paper format and digital versions (for more recent dates). This database is an updated version of Ramsey, K.W., and Baxter, S.J., 1996, Radiocarbon dates from Delaware: a compilation: Delaware Geological Survey Report of Investigations, 54, 18 p.

Ramsey, K.W., and Wehmiller, J.F., 2016, The Delaware Geological Survey Delmarva Peninsula Amino Acid Racemization (AAR) Database, version 2016.1, Delaware Geological Survey data, not Web accessible, Microsoft Access 2010 relational database.

Metadata. The Delaware Geological Survey Delmarva Peninsula Amino Acid Racemization (AAR) Database, version 2016.1. Delaware Geological Survey. Microsoft Access 2010 relational database. . A compilation of amino acid racemization data from geologic mollusk shell samples from the Delmarva Peninsula Region including the Delmarva Peninsula, offshore Delmarva Peninsula, Chesapeake Bay, offshore Virginia from Cape Henry to the North Carolina Border, and Cape May, New Jersey both onshore and offshore. Data are compiled from published and unpublished sources, primarily a subset of Wehmiller, J.F., and Pellerito, V., 2015, Database of Quaternary Coastal Geochronologic Information for the Atlantic and Pacific Coasts of North America (additional information for sites in Peru and Chile): Delaware Geological Survey Open File Report No. 50, 7 p and at NOAA-World Data Center http://www.ncdc.noaa.gov/paleo/aar.html.

All sample sites are given DGS Watsys database identifiers (DGSID) associated with UTM northings and eastings and land surface elevations. Data associated with the site included as a table are DGS AARDB site number, DGSID, localid, UDAMS (Wehmiller site identifier), geographic setting (e.g., onshore, offshore, upland for each state in the database), UTM northing and easting, land surface elevation in feet, and expanded notes regarding collection sources, dates, samples and other information about the sample site. The shell samples from which most of the data were generated are now housed in the DGS Core and Sample Repository as the Quaternary Shell (QuatShl) Collection. All shell samples in the collection are in the database as a table with data including DGSID, UDAMS whether the sample has associated AAR data, local identifiers (e.g., boring number, outcrop local name), DGS sample number, stratigraphic unit, Wehmiller sample number, date collected, dominant and other mollusk genera in the sample, and associated notes regarding the sample. The AAR data are in a table that contains the DGSID and localid, DGS sample number, elevation from which the sample was taken, lab, lab procedure and analysis used, AA ratio type, and the lab results of the amino acid ratios for all0-isoleucine, alanine, aspartic acid, glutamic acid, leucine, phenylalanine, proline, valine, VLPG, alanine/aspartic acid, and valine/leucine. A table under construction contains the interpretations of the data regarding mollusk genera, age ranges, marine isotope stage (MIS) associations, aminozone, and any published data interpretations.

For more information regarding the Wehmiller AAR database:

Article title: AN EVOLVING DATABASE FOR QUATERNARY AMINOSTRATIGRAPHY
Reference: GRJ30
Journal title: GeoResJ
Corresponding author: Dr. John F. Wehmiller
First author: Dr. John F. Wehmiller
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DOI information: 10.1016/j.grj.2015.02.009

http://authors.elsevier.com/sd/article/S2214242815000170

Metz, T.L., 2016, The Delaware Geological Survey Offshore Vibracore Database, version 2016.1, Delaware Geological Survey data, not web accessible, Microsoft Access 2010 relational database.

Metadata. The Delaware Geological Survey Offshore Vibracore Database, version 2016.1, Delaware Geological Survey (DGS), not web accessible, Microsoft Access 2010 relational database. A compilation of vibracore sampling records, data, and analysis offshore Delaware and Maryland in both state and federal waters from Cape Henlopen spit in Delaware to Ocean City Inlet in Maryland along with correlating amino acid racemization (AAR) and radiocarbon (RC) data sets. All vibracore locations are given unique DGS Watsys database identifiers associated with UTM northings and eastings and land surface (seafloor) elevations. DGS identifier, sub-sample numbers, project specific records, elevation (MSL, NAVD88, NGVD29), and core length (in tenths of feet) are incorporated from the DGS Watsys database. Sample identifiers, sample types, and associated age analysis results from the DGS AAR and DGS RC databases are incorporated for reference. Completeness of offshore sampling records, including photographs, lithologic logs, consultant well logs, texture analysis data, and pollen samples, are inventoried as a summary. Lithologic descriptions, including depth interval (in feet), predominant sediment size, sediment color (Munsell color standard), and interpretation have been produced by DGS staff. Further, DGS staff interpretations of stratigraphic units include depth intervals, interpreted age, depositional environment, and subsequent stratigraphic unit. All data records are associated with a unique DGS Watsys database identifier and are searchable on this criterion. All original reports or copies of reports are archived in paper and/or digital format at the DGS where available.

Tomlinson, J.L., and Ramsey, K.W. ., 2016, The Delaware Geological Survey Mapping Stratigraphic Pick Database, version 2016.1, Delaware Geological Survey data, not web accessible, Microsoft Access 2010 relational database.

Metadata. The Delaware Geological Survey Mapping Stratigraphic Pick Database, version 2016.1, Delaware Geological Survey (DGS), not web accessible, Microsoft Access 2010 relational database. The database is a compilation of all stratigraphic picks generated by a DGS geologic mapping project. A stratigraphic picks is defined as an interpretation of a stratigraphic contact, the depth and elevation of the contact, and the stratigraphic units above and below the contact. All stratigraphic pick locations are assigned unique DGS Watsys database identifiers associated with UTM northings and eastings and land surface (seafloor) elevations (in ft). All stratigraphic units are those recognized by the DGS and published on DGS Geologic Maps or other publications by DGS authors. All data records are associated with a unique DGS Watsys database identifier and are searchable on this criterion. All original reports or copies of reports that contain the primary geologic data are archived in paper and/or digital format at the DGS.