DELAWARE GEOLOGICAL SURVEY
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Geologic Map of Offshore Delaware

by

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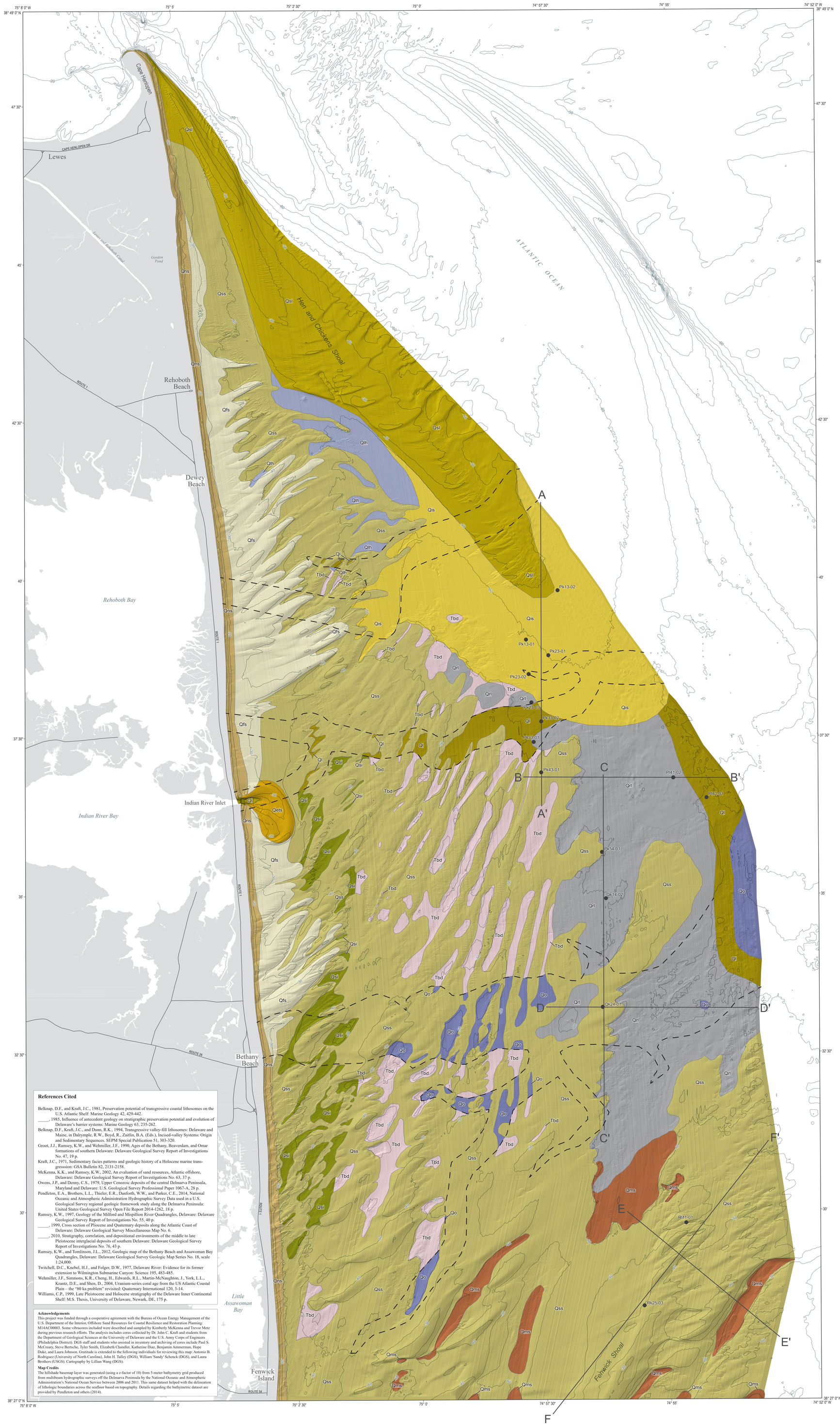

EXPLANATION

NEARSHORE DEPOSITS — Qns

Pale-yellow to light-gray, cross-bedded, silty fine to coarse sand with laminae to thin beds of very coarse sand, granules, and pebbles. Whole shells and granule-size shell fragments are a common constituent. Shells in the sands range from fragmented, granule-size pieces to whole shells. The unit is up to 5 ft thick. Late Holocene.

FINGER SHOAL DEPOSITS — Qfs

Gray, silty very fine to coarse sand that grades seaward to very fine sandy silt. Fragments and whole *Mercenaria* shells are common in medium sand. Clay-filled and clayey silt-lined burrows are common throughout. The sands are finely laminated with opaque heavy minerals and textural laminae of very fine silty sand and coarser sand. The unit is up to 10 ft thick. Late Holocene.

SHOAL DEPOSITS — Qsl

Pale-yellow to gray, fine to medium sand that grades to very fine to fine sand with increasing water depth and distance from the shoreline. Thin laminae to beds of coarse to very coarse sand are common. The deposits become siltier with increasing depth below the seafloor and grade to gray, silty fine to medium sand with pebbles. The deposits are moderately silty to silty where they interfinger laterally with finer inter-shoal deposits. Burrows are common. Shells ranging from sand-size fragments to whole shells are rare to common. Shoal deposits are commonly greater than 10 ft thick and range from 3 to 20 ft in thickness. Late Holocene.

SHEET SAND DEPOSITS — Qss

Pale-yellow, well-sorted, fine to very coarse sand with abundant granules, pebbles, and shell fragments. Cross-bedding is common, consisting of laminae of sand, granules, and pebbles. *Spisula* shells are common; *Ensis* and *Anomia* shells are less common. Sand dollars, echinoid spines, and solitary corals (*Astrangia*?) have been observed. Sheet sand deposits range from a few inches to over 15 ft in thickness. Late Holocene.

INTER-SHOAL DEPOSITS — Qis

Light-gray to very dark-gray, very fine silty sand to silt. Burrows are common to abundant. Whole shells to fragments of *Ensis* shell are common to abundant. Thin laminae of silt and very fine silty sand are common. These deposits generally occur at water depths >45 ft. Deposits range from 1 to 10 ft in thickness. Late Holocene.

EBB-TIDAL DELTA SAND DEPOSITS — Qets

Pale-yellow to light-gray, cross-bedded, fine to coarse sand with laminae of heavy minerals and granules to pebbles. Shells and shell fragments are rare. Thicknesses can exceed 20 ft. Late Holocene.

LAGOONAL DEPOSITS — Ql

Largely homogenous unit consisting of clay to silty, sandy clay that varies in color from dark-gray to olive-gray to bluish-gray. Scattered silt to fine sand-filled burrows and/or fine sand laminae may occur in the clay-rich unit, which can give it a mottled appearance. Clay-filled burrows are also common, but are less distinct than sand-filled ones. Organic material is rare and, if present, generally occurs closer to the stratigraphic base, which, in some cases, marks a transition to peat. An enrichment in organic content is marked by an increase in scattered fibrous plant remains and a color change to dark brownish-gray. Thickness can reach 60 ft. Holocene.

RAVINEMENT LAG DEPOSITS — Qrl

Interbedded fine- to very coarse-grained, light brownish-gray sands with abundant well-rounded quartz and chert pebbles. Fine sands tend to be silty or silt-laminated and are dark-gray in color. Heavy mineral and clay laminae occur as well. Cobbles are rare. While similar in texture, the unit is distinct from the Beaverdam Formation in that it is more poorly sorted and lacks the latter's distinctly white silt matrix. Thickness can reach 15 ft. Pleistocene to Holocene.

SINEPUXENT FORMATION — Qsl

Gray, laminated, silty, very fine to fine, micaceous sand to sandy silt. The base of the unit is typically a 3- to 5-ft thick bed of bluish-gray to dark-gray clayey silt to silty clay that is interbedded with and grades upward into the sandy silt. In places, silty clay and the lower portion of the sandy silt are interbedded with a fine to medium sand. In the vicinity of Bethany Beach, the lower sand contains abundant *Mulinia* shells. Thickness can exceed 20 ft. Late Pleistocene.

MARINE SHELF DEPOSITS — Qms

Dark-gray to dark olive-gray, interbedded fine to coarse-grained silty sands. Some light-gray beds are also described. Sand beds range from <1 ft thick to several feet thick and may exhibit normal grading, generally separated by sharp contacts with a color change. Bioturbation is common, as are heavy mineral, silt, and organic laminae. Scattered granules and pebbles also occur and some beds are micaceous. Scattered clay-filled burrows can occur within fine sand beds while sand-filled burrows are more common in coarser sands. Burrow fills vary in appearance and texture, but are commonly dark bluish-gray in color. Thickness is up to 15 ft within map area. Late Pleistocene.

LYNCH HEIGHTS FORMATION — Qlh

Clean, white to pale-yellow, well-sorted fine to coarse sand with scattered very coarse to pebble laminae and silty clay laminae overlying light-gray to greenish-gray, compact silty clay with rare laminae of *Mulinia* shells and shell fragments. The silty clay beds grade laterally to well-sorted sands with clay laminae. Thickness can exceed 20 ft. Middle Pleistocene.

OMAR FORMATION — Qo

Light-gray to gray, silty clay to silty, very fine sand with scattered shell beds. The Omar Formation consists of up to 5 ft of light- to dark-gray, basal, pebbly sand (coarse to very coarse) that grades upward into 1 to 3 ft of gray to very dark-gray, fine to coarse silty sand with scattered laminae to thin beds of peat composed of sand- to gravel-size plant fragments. The sands are overlain by 3 to 5 ft of very dark-gray to black organic-rich sandy silt to silty clay. Above this organic-rich zone, in the areas where the Omar is thickest, 10 to 40 ft of greenish-gray, compact, silty clay to clayey silt is common. The clayey silt grades upward into a gray, to light greenish-gray, silty clay to silty fine sand with scattered laminae to thin beds of *Crassostrea* (oyster) shell. In places, there is a 2- to 10-ft thick bed of medium to coarse relatively clean sand separating the compact, clayey silt from the overlying shelly, silty clay. Thickness can exceed 75 ft. Middle Pleistocene.

BEAVERDAM FORMATION — Tbd

Heterogeneous unit ranging from very coarse sand with pebbles to silty clay. The predominant lithologies at the seafloor are white to mottled light-gray and reddish-brown, silty to clayey, fine to coarse sand. Laminae and beds of very coarse sand with pebbles to gravel are common. Laminae and beds of bluish-gray to light-gray silty clay are also common. The sands of the Beaverdam Formation have a white silt matrix that creates a milky appearance when wet. This white silt matrix is the most distinguishing characteristic of the unit and readily differentiates the Beaverdam Formation from the adjacent cleaner sands of the Sinepuxent Formation and overlying sheet sand deposits. It ranges from 50 to 100 ft thick in the map area and underlies it entirely, cropping out between the Holocene sands of the inner shelf platform. Late Pliocene to earliest Pleistocene.

Discussion

Delineation of map units is based on sediment-core descriptions (e.g., texture, color, and composition) from 469 locations and seafloor morphology, which was assessed from a seamless NOAA/USGS topo-bathymetric model (Pendleton et al., 2014). The latter was integrated with high-resolution 'chirper' seismic reflection data, collected in 2013 by the Delaware Division of Natural Resources and Environmental Conservation (DNREC) and in 2015 as part of the 2015-2017 Bureau of Ocean Energy Management (BOEM) Atlantic Sand Assessment Project (ASAP), using sweep frequency pulses of 2-12 kHz and 0.7-12 kHz, respectively. Stratigraphic mapping based on these data allowed seafloor composition to be inferred across areas of limited core coverage (e.g., Federal waters, beyond 3 miles from shore) and facilitated the delineation of unit boundaries based on subsurface trends and seafloor geomorphology. A minimum surface-unit thickness of 1 ft served as the cut-off for geologic mapping of the seafloor, given the vertical resolution constraints of geophysical data. If surficial sediments were <1 ft thick, the underlying unit was mapped. Unit names and descriptions conform to those established in prior subsurface work along the Delaware barrier shoreline by Ramsey (1999), a synthesis of the Delaware coastal plain geology (Ramsey, 2010), and a previous map which included portions of the offshore surface geology (Ramsey and Tomlinson, 2012).

The geological history of the surficial units of the inner Delaware continental shelf are the result of cyclic sea-level oscillations during the mid-to-late Pleistocene. Low sea-level periods left the shelf exposed and Atlantic-bound fluvial systems were entrenched within valleys. High relief strongly influenced coastal evolution during periods of sea-level rise, as depositional dynamics and the resulting sedimentary architectures were influenced by the irregular distribution of sediment accommodation space (Belknap and Krafft, 1985). Estuarine deposits dating to several Pleistocene sea-level highstand periods are preserved within former erosional topographies while valleys incised during the most recent (late Pleistocene) glacio-eustatic cycle contain a fill record documenting Holocene sea-level rise (Krafft, 1971; Belknap and Krafft, 1981, 1985; Belknap et al., 1994). Valleys are incised into late Tertiary to early Pleistocene fluvio-deltaic sediments, which underlie the entire inner shelf region and crop out along paleovalley interfluves in absence of younger sediment cover. Recent shelf sand deposits that are, in large part, winnowed from the late Tertiary outcrops, occur as distinct shoal bodies, sheet sands, and other geomorphic configurations. While dominating the surface cover by aerial extent (~70%), they are thin to absent across portions of the shelf, and locally interfinger with muddier deposits in low-energy regions, particularly in the lee of the Hen and Chickens Shoal.

The Beaverdam Formation (Tbd) is the oldest map unit. Also mapped extensively across the southern coastal plain of Delaware, the deposits represent a fluvial or estuarine environment (Ramsey, 2010). Burrows observed in the Beaverdam Formation suggest at least a marginal estuarine setting (DGS unpublished data; Owens and Denny, 1979). It is exposed across the central portion of the map, near the -50 ft contour, which coincides with the transition from outer platform to inner shelf, based on a regional geomorphologic framework by McKenna and Ramsey (2002). The age of the Beaverdam Formation is uncertain given lack of age-definite fossils, but stratigraphic relationships suggest it is no older than Pliocene and no younger than early Pleistocene (Groot et al., 1990; Ramsey, 2010). A ravinement lag (Qrl) overlies the Beaverdam Formation across much of the central Delaware shelf, particularly in water depths exceeding 60 ft (cross sections A-A', B-B', and C-C'). Where the unit crops out and is only locally blanketed by shelf sands, it is differentiated based on color and texture.

Mid-Pleistocene estuarine and lagoonal deposits comprise several distinct lithosomes, which lie unconformably over the Beaverdam Formation and crop out along the seafloor between shoal bodies in some areas. The Omar Formation (Qo) fills an east-west oriented paleovalley that extends beneath the town of Bethany Beach. It is comprised of swamp, marsh, and lagoonal sediments deposited during a sea-level highstand at around 400,000 yrs B.P. and possibly reworked during the subsequent highstand at 320,000 yrs B.P. (Ramsey, 2010). Seismic reflection data across and along the axis of the paleovalley strongly suggest a compound fill (over multiple glacio-eustatic cycles), with thicknesses of >70 ft (cross sections C-C' and D-D', respectively). A tributary to the main trunk valley is mapped to the southwest, where a few cores encountered the Omar Formation at the sediment-water interface or beneath sheet sand. The Omar paleovalley is truncated perpendicularly by the shore-parallel Sinepuxent Formation (Qsi), the offshore extent of a late Pleistocene (approximately 80,000 yrs B.P.) backbarrier lagoon. Heterogeneous deposits of the Omar age-equivalent, middle Pleistocene (400,000 to 320,000 yrs B.P.) Lynch Heights Formation (Qlh), occur in the northern map area around 2 miles seaward of Rehoboth Bay, south of the Hen and Chickens Shoal. These deposits lie unconformably over the Beaverdam Formation and represent estuarine to nearshore deposition along the margins of an ancestral Delaware Bay (Ramsey, 1997; 2010). Sediments here were deposited in a lagoon (silty clay with shell) with tidal flats (sand with clay laminae) that was prograded by spit deposits (well-sorted fine to coarse sand). The lagoonal and tidal flat deposits are considered to have been emplaced during a sea-level highstand at approximately 400,000 yrs B.P. (Ramsey, 2010). These deposits are mostly covered by recent sand bodies, but crop out in some areas (e.g., inter-shoal areas).

A seaward thickening wedge of muddy marine sands (Qms) is found beneath the Fenwick Shoal and surrounding area (i.e., the southeastern map extent), lying unconformably over the Beaverdam Formation (cross sections E-E' and F-F'). The unit pinches out around where the Beaverdam Formation forms a paleo-high along the central portion of the map area, near the transition from inner to outer platform (-50 ft contour interval). The unit is noted for its heavy mineral content, organic laminae, bioturbation, and lack of shell material. Radiocarbon ages of organic sediments and wood fragments range from 29,550 yrs B.P. to >50,000 yrs B.P. (radiocarbon-dead). Amino-acid racemization data from shells indicate that it is late Pleistocene (Williams, 1999; unpublished DGS data; J.F. Wehmiller personal communication). It may, in part, be contemporaneous with the Sinepuxent Formation.

The late Pleistocene Sinepuxent Formation (Owens and Denny, 1979), distinguished from all other map units by an abundance of mica, is interpreted to represent backbarrier lagoon deposits. Shell beds dominated by *Mulinia* occur near the base of the formation near Bethany Beach. The overlying sediments are highly bioturbated, reflecting an active sub-bottom biota at time of deposition. The upper, sandier portion of the unit reflects the transgression of the coastal barrier shoreline. Amino-acid racemization data from *Mulinia* shells derived from the Sinepuxent Formation place the unit in zone IIa, which likely corresponds to MIS 5a (80,000 yrs B.P.; Ramsey, 2010; Wehmiller et al., 2004). It is correspondingly mapped along the lower half of the map area (south of the Indian River Inlet) from 1.5 miles offshore to the approximate location of the 10 ft elevation contour of the lower coastal plain (Ramsey and Tomlinson, 2012). Reworked at the surface in areas of absent sheet sand or shoal sand cover, it represents a local source of fine sand.

Two mud-dominated Holocene lagoonal lithosomes are mapped (Ql), in the northern portion of the map area, seaward of the modern Rehoboth Bay and Indian River systems. They trend to the east-northeast, are each around 0.5 miles wide, and are up to 60 ft thick (cross section A-A'). The remnants of several small tributary branches are resolved as well, which merge with the sinusoidal trunk valleys. A topographic high in the Beaverdam Formation separates the two paleovalleys. The paleovalleys are late Pleistocene in age, based on a strictly Holocene fill succession, with radiocarbon dates from organic sediments, wood fragments, and basal peat deposits <10,000 yrs B.P. (unpublished DGS data). Muddy Holocene lagoonal valley fill sediments are also mapped from seismic reflection data along the distal-most offshore extent of the map area (cross section B-B') and are interpreted to reflect the transition to MIS 2 Delaware paleovalley flank (based on Twitchell et al., 1977). Outcroppings of Holocene lagoonal deposits are sparse overall and are primarily found in this most shore-distal map region.

Holocene to modern shelf sands are encountered as distinct geomorphic and lithologic seafloor units. While similar in texture, units are distinguished based on subtle differences in grain size, shell content, color, and geomorphic association. The distribution of late Holocene litho-units across the inner continental shelf of Delaware is a function of both the influence of the underlying stratigraphic framework, particularly paleovalley topographies and their impacts on the creation of accommodation space throughout late Holocene coastal inundation (Krafft, 1971; Belknap and Krafft, 1981, 1985; Belknap et al., 1994), and modern shelf hydrodynamics. Textural analyses and stratigraphic mapping imply the absence of significant influxes of materials into this coastal system, which has evolved from the reworking of earlier deposits.

Nearshore deposits (Qns) are mapped from the shoreline to where the seafloor drops from the gradual slope from the beach with water depths of less than 10 ft to water depths of greater than 20 ft. They fine offshore from coarse sand to gravel in the surf zone to very fine silty sand and are thin, usually less than 2 ft in thickness. Texture of nearshore sediments is related to texture of underlying deposits from which they are reworked. Deposits are fine silty sand off the Pleistocene headland at Rehoboth Beach and are fine to coarse sand off the barrier south of Dewey Beach. Nearshore deposits consist of fine silty sand north of Bethany Beach and grade into fine to coarse sand with shells reworked from the underlying Sinepuxent Formation off Bethany Beach. South of Bethany Beach, nearshore deposits range from medium to coarse sand. Pre-Holocene units (e.g. Holocene and Pleistocene estuarine/lagoonal deposits and the Beaverdam Formation) and gravel-lag deposits affiliated with Holocene transgression and early shelf inundation are draped by sheet sand deposits (Qss), the most continuous surface unit. While the unit is commonly less than a few feet thick, it also comprises the up to 35 ft-thick Fenwick Shoal, located in the southeasternmost portion of the map area. The source of the sediment in the sheet sand is the underlying Beaverdam Formation. Obliquely shore-attached shoal bodies, termed finger shoals (Qfs), are another thicker accumulation of modern shelf sands. They extend from nearshore waters to around 50 ft in depth off of Rehoboth Bay and to depths on the order of 35 ft off of Bethany Beach. Finger shoals have a characteristic bathymetric signature of shore-oblique highs that extend like fingers from the nearshore. Thickness ranges from less than 1 ft off of Rehoboth Beach to greater than 10 ft where best developed off of the Rehoboth Bay barrier. The Hen and Chickens Shoal (Qsl), a southeast-trending sand ridge of >20 ft relief, is the ebb-tidal shoal on the south side of the mouth of Delaware Bay, attached to Cape Henlopen. Radiocarbon ages of *Ensis* shells from deposits at depth infer a late Holocene age (<1,500 yrs B.P.), while shell dates (incl. *Mercenaria*) of finger shoal deposits are slightly older (3,000 to 4,500 yrs B.P.; unpublished DGS data). The silt and fine sand cover flanking the distal end of the Hen and Chickens Shoal (Qis), associated with *Ensis*-derived radiocarbon ages around 1,000 yrs B.P., is interpreted as a low-energy deposit sequestering on the protected leeward side of the shoal in relatively deep (>60 ft) water. These inter-shoal deposits are confined to areas below the depth of closure and occur mainly in water depths >60 ft. Deposits are late Holocene in age, based on radiocarbon dates <1,200 yrs B.P.

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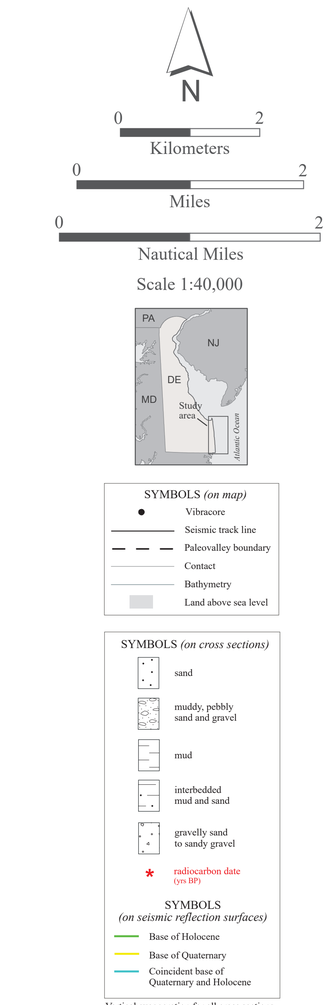
Map Credits
The hillshade basemap layer was generated (using a z-factor of 10) from 5-meter bathymetry grid produced from multibeam hydrographic surveys off the Delmarva Peninsula by the National Oceanic and Atmospheric Administration's National Ocean Service between 2006 and 2011. This same dataset helped with the delineation of lithologic boundaries across the seafloor based on topography. Details regarding the bathymetric dataset are provided by Pendleton and others (2014).



SYMBOLS *(on map)*
- Vibracore
- Seismic track line
- Paleovalley boundary
- Contact
- Bathymetry
- Land above sea level

SYMBOLS *(on cross sections)*
- sand
- muddy, pebbly sand and gravel
- mud
- interbedded mud and sand
- gravelly sand to sandy gravel
- radiocarbon date (yrs BP)

SYMBOLS *(on seismic reflection surfaces)*
- Base of Holocene
- Base of Quaternary
- Coincident base of Quaternary and Holocene

Vertical exaggeration for all cross sections is x 105.