

## GEOLOGIC MAP OF THE BETHANY BEACH AND ASSAWOMAN BAY QUADRANGLES, DELAWARE

NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

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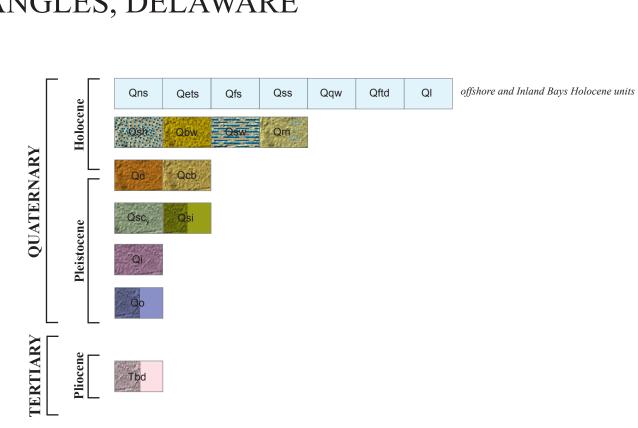
North American Datum of 1983 (NAD83) HARN The Delaware Department of Transportation Centerline for Delaware, 2009 The Delaware Office of State Planning Coordination Delaware Municipal Boundaries, 2009 USGS National Hydrography Dataset, 2009 USGS Delaware LiDAR Contours, 2005 USGS Delaware Miscellaneous Features, 1993 http://datamil.delaware.gov Delaware Department of Agriculture State Forest Areas, 2009

Delaware Division of Natural Resources and Environmental Control Park Areas. 2009 NOAA National Geophysical Data Center, U.S. Coastal Relief Model Bathymetry, volume 02, version 1.0, 1999

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1991 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Kelvin W. Ramsey and Jaime L. Tomlinson 2012 SCALE 1:24,000 10-foot Index with a 6-foot Intermediate Contour Interval 10-foot Bathymetric Contour Interval Soundings in feet 2-foot contour data are available for this map from the Delaware DataMIL at http://datamil.delaware.gov



**EXPLANATION** 

FILL Man-made and natural materials (sand, gravel) emplaced in stream valleys or marshes to bring the topography above grade, usually in road beds, dams, or construction near a shoreline. Fill deposits include sediment dredged from the marshes and offshore in Indian River Bay and emplaced on the uplands.

MODIFIED LAND

Areas of land where the surficial deposits have been modified due to human activity to the point that surficial deposits can no longer be reliably determined. The unit is mapped in areas large enough to be shown on the map and does not include local disturbances on the scale of an individual housing lot or shallow disturbances such as large parking lots or retail areas. An example of modified land is a golf course where numerous ponds and embankments have been constructed.

NEARSHORE DEPOSITS offshore

Pale-yellow to light-gray, cross-bedded, very fine, silty sand to fine to coarse sand with laminae to thin beds of very coarse sand, granules, and pebbles. Shells are a common constituent of the sands and range from fragmented, granule-size pieces to whole shells. Nearshore deposits are mapped from the shoreline to the break in slope where water depths increase from less than 10 ft to greater than 20 ft. Texture of nearshore sediments is related to texture of underlying deposits from which they are reworked. Nearshore deposits consist of fine, silty sand north of Bethany Beach to fine to coarse sand with shells reworked from the underlying Sinepuxent Formation off Bethany Beach. To the south of Bethany Beach, nearshore deposits range from medium to coarse sand. Nearshore deposits are thin, usually less than 2 ft in thickness. Holocene.

EBB TIDAL SAND DEPOSITS offshore

Pale-yellow to light-gray, cross-bedded coarse to fine sand with laminae of heavy minerals and granules to pebbles. Shells and shell fragments are a rare constituent of the sands. Ebb tidal delta deposits are found offshore of Indian River Inlet. The sediments are partly disturbed by dredging and influenced by the location of the jetties offshore of the inlet. Ebb tidal delta deposits range from 5 to over 25 ft in thickness. Holocene.

FINGER SHOAL DEPOSITS offshore

Gray, silty, coarse to fine, and fine to very fine sand that fines seaward to very fine sandy silt. In the medium sands, shell fragments and whole shells are common. Clay 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 deposits interfinger with the quiet-water deposits. Finger shoal deposits extend from the bathymetric break between 20 and 30 ft offshore that marks the limit of the nearshore deposits to water depths of about 35 ft. They 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 Bethany Beach to greater than 10 ft to the south. Holocene.

SHEET SAND DEPOSITS offshore

Pale-yellow, well-sorted, fine to medium, to coarse to very coarse sand with abundant granules, pebbles, and shell fragments. Cross-bedding is common, consisting of laminae of sand, granules, and pebbles. Shells most common within sheet sand deposits ar Spisula, Ensis and Anomia (few to common in abundance) and lesser amounts of sand dollars, echinoid spines, and solitary corals (Astrangia?) have been observed. Sheet sand deposits range from a few inches to over 5 ft in thickness. Where thin (<2 ft), the deposits tend to be patchy, overlying shoal, finger shoal, or quiet-water deposits. Where thicker, the deposits form an extensive layer or sheet of sand on the seafloor; most commonly where the Beaverdam Fm. underlies the sheet sand deposits. Holocene.

QUIET-WATER DEPOSITS offshore

Light-gray to very-dark-gray, very fine, silty sand to silt. Burrows are common to abundant. Whole and fragments of Ensis shell are common to abundant. Thin laminae of silt and very fine silty sand are common. These deposits are commonly found at water depths greater than 45 ft, which is below storm wave base. Deposits range from 1 to 10 ft in thickness. Holocene.

FLOOD TIDAL DELTA DEPOSITS Indian River Bay

Light-gray to gray, clean to silty, very fine to coarse sand. Sedimentary structures range from well-developed cross-bedding to structureless where the deposit is completely bioturbated. Flood tidal delta deposits are found adjacent to Indian River Inlet in Indian River Bay and have been greatly modified by dredging. The deposits are up to 25 to 30 ft thick adjacent to the barrier and thin to the west in Indian River Bay (Chrastowski, 1986). Flood tidal delta deposits grade laterally into barrier washover deposits along the coast and into lagoon deposits in Indian River Bay. Holocene.

LAGOON DEPOSITS Indian River and Little Assawoman Bays Medium-gray to dark-gray clayey silt. Sedimentary structures are rare, consisting of relict burrows or thin laminae of marsh grass fragments or very fine sand. Shells and shell fragments are rare to common. Lagoon deposits grade laterally into marsh deposits and barrier washover deposits. They underlie a portion of the water body of Indian River Bay and Little Assawoman Bay and the tidal portions of their tributaries, and extend offshore. Lagoon deposits are up to 30 ft thick near the center of Indian River Bay (Chrzastowski, 1986). Holocene.

SHORELINE DEPOSITS

White to light-gray, well-sorted, very coarse to fine sand with scattered pebbles. Along the shoreline of Indian River Bay, they are thin, ephemeral bodies of sand less than 3 ft thick. Along the Atlantic shoreline, the sands on the beach are up to 10 ft thick and grade laterally into dune deposits and washover deposits. Holocene.

BARRIER WASHOVER DEPOSITS

White to gray, cross-bedded beds of very coarse to fine sand with scattered laminae of pebbles and heavy minerals. Laminae of organic fragments and thin peat layers are also common. These deposits are the result of storm events transporting shoreline and dune deposits into the margin of Indian River Bay. Peat and organic debris layers represent establishment of marshes that were buried by subsequent washover events. Washover deposits are up to 25 ft thick (Chrzastowski, 1986). Holocene.

SWAMP DEPOSITS

Gray to brown silty and clayey gravelly sand overlain by organic-rich fine to coarse sand. In some of the larger stream valleys, the unit has several feet of organic silt at its top. Swamp deposits are up to 15 ft thick in the larger stream valleys and less than 5 ft thick in the smaller tributaries. Deposits are found in the upper reaches of modern stream valleys and interfinger with and grade into marsh deposits. Holocene.

MARSH DEPOSITS

Light-gray to brown, organic-rich, clayey silt. Peat beds consisting of finely comminuted organic fragments (primarily of marsh grass) are common near the base of the unit and scattered throughout. Marsh deposits are generally less than 10 ft thick along the northern shore of Indian River Bay and up to 25 ft along buried stream channels in Indian River Bay (Chrzastowski, 1986). Holocene.

CAROLINA BAY DEPOSITS

Circular features located primarily in the Assawoman Wildlife Area. They consist of raised rims (dunes) of well-sorted, medium to fine sand with silty sand in the interior of the circular features. A few of the features contain either seasonal or year-round bodies of water where the water table is high. The deposits are less than 5 ft thick in their interiors and up to 10 ft thick where the sand rims are best developed. Circular features that are actively being filled and covered by marsh deposits are inferred to be Carolina Bays and are shown with a dashed line. Features are likely related to cold-climate processes during the Pleistocene (Ramsey, 1997). Latest Pleistocene to Holocene.

**DUNE DEPOSITS** 

White to pale-yellow, well-sorted, medium to fine sand. In dune deposits found along the shoreline, some coarse to very coarse sand laminae with scattered pebbles are found, and are relicts of storm-related washover deposits. The sands in shoreline dunes are typically cross-bedded. The unit includes man-made dunes along the Atlantic shoreline, which are similar in morphology and texture to natural dunes. Dune deposits along the Atlantic Coast are up to 10 ft thick and grade laterally with barrier washover and shoreline deposits. They are Holocene in age. Inland, dune deposits have a similar lithology. Laminae of coarse sand are common. Thin, brown soil lamellae are commonly found at depths of 1 to 3 ft within the inland dunes. Inland dune deposits, which are up to 6 ft thick, are eolian features related to cold-climate processes when arboreal vegetation was scarce and winds blew sand dunes across the landscape. Some of the inland dunes that have well-developed and deep (>3 ft) soil profiles may be older than latest Pleistocene and are middle to late Pleistocene in age. Middle Pleistocene to Holocene.

SCOTTS CORNERS FORMATION (YOUNGER)

Pale-yellow to light-gray, gravelly sand grading up to medium to coarse sand, to fine sand, commonly capped by 1 to 3 ft of very fine, sandy, clayey silt. Scattered beds of 1to 3-ft thick gray silty clay with organic-rich laminae are also common. These deposits are found beneath low terrace flats less than 5 ft in elevation along the margins of Indian River Bay and are up to 6 ft in thickness. They are considered to be lagoon-margin deposits; the result of a sea-level highstand along the margins of an ancestral Indian River Bay at approximately 80,000 yrs B.P. (Ramsey, 2010a). Late Pleistocene.

SINEPUXENT FORMATION

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 zone of bluish-gray to dark-gray clayey silt to silty clay that is interbedded with and grades upward into the sandy silt. In places, the 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 clam shells. The upper portion of the Sinepuxent Formation, especially near its contact with the Ironshire Formation, consists of 2 to 10 ft of clean, fine to medium sand with some coarse sand to pebbles that coarsens to the north toward Cedar Neck. Total thickness of the unit ranges from less than 5 ft at its western margin to over 50 ft thick just west of the town of Fenwick Island. The Sinepuxent Formation is interpreted to have been deposited in a lagoonal environment during the late Pleistocene (approximately 80,000 yrs B.P.) (Ramsey, 2010a). The coarser sediments near the land surface represent nearshore deposits laid down after the lagoon was filled when the Atlantic Ocean shoreline was west of its present position (Ramsey, 2010a). Late Pleistocene.

IRONSHIRE FORMATION

Pale-yellow to light-gray, fine to very coarse sand. Granules to pebbles are a common constituent of the unit, especially near its base. Thin, light-gray, silty clay beds occur but are not present at all localities. The Ironshire Formation is found between the more widespread Sinepuxent Formation to the east and the Omar Formation to the west. It is up to 25 ft thick. It is distinguished from the adjacent Sinepuxent and underlying Omar Formations by the cleaner and coarser textures of the sands. Where the sands are finer, such as the area between Miller and Dirickson Creeks, the Ironshire Formation may not be easily differentiated from the sandy, upper part of the adjacent Omar Formation. In these areas, the contact between the Ironshire and Omar Formations is drawn at the toe of a topographic break at approximately 18 ft in elevation. The Ironshire Formation is interpreted to be a shoreline and nearshore deposit related to a sea-level highstand at approximately 120,000 yrs B.P. (Ramsey, 2010a). Late Pleistocene.

## OMAR FORMATION

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, coarse to very coarse sand 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, gray 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. The overall thickness of the Omar Formation in the map area ranges from 2 ft thick along the surficial contact with the Ironshire Formation to about 75 ft thick just south of Ocean View. The Omar Formation fills an east-west oriented paleovalley and is comprised of swamp, marsh, and lagoonal sediments deposited during a sea-level highstand at approximately 400,000 yrs B.P. and possibly reworked during the subsequent highstand at 320,000 yrs B.P. (Ramsey, 2010a). Middle Pleistocene.

BEAVERDAM FORMATION

Heterogeneous unit ranging from very coarse sand with pebbles to silty clay. The predominant lithologies at the land surface are white to mottled light-gray and reddishbrown, 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. In a few places near the land surface, but more commonly in the subsurface, beds ranging from 2 to 20 ft thick of finely laminated, very fine sand and silty clay are present. The sands of the Beaverdam Formation have a white silt matrix that gives samples 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, Ironshire and Scotts Corners Formations. The Beaverdam Formation is interpreted to be a late Pliocene fluvial to estuarine deposit (Ramsey, 2010a, b). It ranges from 50 to 100 ft thick in the map area. Late

## Discussion

The geologic history of the surficial units of the Bethany Beach and Assawoman Bay Quadrangles is that of deposition of the Beaverdam Formation and its subsequent modification by erosion and deposition related to sea-level fluctuations during the Pleistocene. The geology reflects this complex history onshore, in Indian River Bay and Assawoman Bay, and offshore in the Atlantic Ocean. Erosion during the late Pleistocene sea-level lowstand and ongoing deposition offshore and in Indian River Bay during the Holocene rise in sea level represents the latest of several cycles of erosion and deposition.

The Beaverdam Formation consists of stacked, 1- to 5-feet thick beds of very coarse sand and gravel that commonly fine upwards to fine to medium sand and rarely to very fine silty sand to silty clay. These types of deposits are typical of either fluvial or estuarine environments (Ramsey, 2010a, b). Rare burrows have been observed in the Beaverdam Formation elsewhere in Delaware that indicate at least a marginal estuarine setting (DGS unpublished data; Owens and Denny, 1979). The Beaverdam Formation in the Bethany Beach and Assawoman Bay Quadrangles is exposed along the south side of Indian River Bay and on Miller Neck and Dirickson Neck. The Beaverdam underlies all the younger deposits of the area and extends offshore (cross sections A-A' and B-B'). The age of the Beaverdam Formation is uncertain due to the lack of age-definitive fossils within the unit. Stratigraphic relationships in Delaware indicate that it is no older than late Miocene and no younger than early Pleistocene, and is most likely late Pliocene (Ramsey, 2010a, b).

The Omar Formation is found primarily in the subsurface in the map area, but crops out in the west-central portion of the quadrangles. Thick deposits are found in a paleovalley on the west side of the map that is filled with fine-grained sediments (cross sections A-A', B-B'). It is a composite unit consisting of deposits related to one or possibly two sea-level highstands (Ramsey, 2010a). The Omar Formation consists of a lower brown to gray, organic-rich, sandy clay overlain by a compact, greenish-gray clayey silt to silty clay. Overlying the silty clay is a bed of fine to coarse sand that ranges from 5 to 15 feet thick, which is in turn overlain by a greenish-gray clayey silt to silty clay that commonly contains shell beds dominated by Crassostrea virginica (oyster). These beds grade upward into greenish-gray to yellowish-brown very fine sand. Aminoacid racemization of shells from the Dirickson Creek ditch just west of the map area indicates that the deposits occur in aminozone IIc with an approximate age of 320,000 yrs B.P. (Ramsey, 2010a; Groot, Ramsey and Wehmiller, 1990). The Omar Formation ranges from 2 feet thick along the margins of the paleovalley to 75 feet thick beneath the Ironshire Formation near Ocean View (cross section A-A'). The unit extends offshore to the east (cross section B-B').

The Ironshire Formation (Owens and Denny, 1979) consists of fine to very coarse sand that is commonly interlaminated or interbedded with coarse to very coarse gravelly sand. The unit is found in a northeast-southwest band across the map area south of Indian River Bay and to the west of a topographic break between the surface of the Sinepuxent Formation, at elevations of less than eight feet. It unconformably overlies the Beaverdam Formation to the north of Route 26 where it forms the core of Cedar Neck, and to the south of Miller Creek. Where the Ironshire overlies the Beaverdam, it is usually less than 10 feet and commonly less than 5 feet thick. The sands of the Ironshire are readily distinguishable from those of the Beaverdam in that they are better sorted and lack the characteristic white silt matrix. Where the Ironshire overlies the Omar Formation west of Bethany Beach, it is up to 25 feet thick near its eastern extent and thins westward. The sediments of the Ironshire are coarsest at the eastern bounding scarp (gravelly sand) and fine westward to a fine to medium sand. Fine and very fine sands of the Ironshire Formation are difficult to distinguish from the fine sands of the uppermost Omar Formation. A granule lamina is commonly found at the contact between the two units but is not present everywhere. The sands of the Ironshire also tend to have little to no silt whereas the upper Omar sands are slightly silty to silty. The Ironshire Formation in the map area is interpreted to be a nearshore deposit where the shoreline was eroding a headland of the Beaverdam Formation, which provided the coarse sediments found in the Ironshire. The Ironshire Formation is considered to be the equivalent of the older Scotts Corners Formation (Ramsey 2010a, 2011). No fossils have been found in the Ironshire Formation in Delaware. Based on its stratigraphic and geomorphic position, it is estimated to be about 120,000 yrs B.P. in age (Ramsey, 2010a).

The Scotts Corners Formation consists of sand that ranges from fine to very coarse sand with scattered beds and laminae of silty clay found on flat areas adjacent to Indian River Bay and its tributaries. Based on geomorphologic and lithologic differences, these deposits can be separated into two units designated as the older and younger Scotts Corners Formations. Only the younger Scotts Corners Formation (Ramsey, 2010a, 2011) is found in the map area and is thought to be the age equivalent of the Sinepuxent Formation deposited along the shores of an ancestral Indian River Bay. The Scotts Corners Formation is interpreted to be the result of two separate sea-level highstands associated with the last interglacial, the older Scotts Corners being about 120,000 yrs B.P. and the younger Scotts Corners about 80,000 yrs B.P. (Ramsey, 2010a).

The Sinepuxent Formation (Owens and Denny, 1979) consists of a lower, silty clay to clayey silt that grades upward into a micaceous, very fine, sandy silt to silty sand The upper few feet of the Sinepuxent consist of a fine to medium sand that grades to gravelly sand to the west toward the bounding scarp with the Ironshire Formation. The micaceous sediments of the Sinepuxent distinguish it from all other units in the map area. The sediments of the Sinepuxent Formation are interpreted to be back-barrier lagoonal deposits with the lagoon being relatively open water, more like that of Chincoteague Bay in Maryland and Virginia than Rehoboth Bay in Delaware. Shell beds dominated by Mulinia are found near the base of the Sinepuxent Formation in the vicinity of Bethany Beach. Other than the presence of Mulinia, the unit is lacking shells or other fossils, but the sediments are highly bioturbated, indicative of an active subbottom biota during deposition. The sandy upper portion of the Sinepuxent represents the transgression of the coastal barrier across the map area to where the shoreline of the Ironshire Formation was reoccupied and coarse sediments from the Ironshire were reworked into the Sinepuxent. Amino-acid racemization data from *Mulinia* shells from the Sinepuxent Formation place the unit in aminozone IIa (Ramsey, 2010a), which is late Pleistocene in age, most likely OIS 5a (~ 80,000 yrs B.P.) (Ramsey, 2010a; Wehmiller et al., 2004).

Dune deposits on the uplands are fine to medium, well-sorted sands that are found west of Cedar Neck and on Miller Neck. The dunes have a pronounced surficial expression as linear features that rise above the surrounding landscape. Some of these dunes are probably latest Pleistocene to early Holocene in age (Andres and Howard, 2000), but some could possibly be contemporaneous with deposition of the Lynch Heights or Scotts Corners Formations. Dune features are also associated with the rims of Carolina Bays. Some of the features inferred to be Carolina Bays on Dirickson Neck in the Assawoman Wildlife Area are presently being inundated by sea-level rise and are occupied by marshes. Because the features are generally circular in shape and are consistent in size with Carolina Bays mapped elsewhere (Ramsey, 2001, 2003, 2010b; Ramsey and Tomlinson, 2011), they are interpreted to be Carolina Bays. Both the dunes and the Carolina Bays are cold-climate related features located where winds moved sand across a landscape barren of forests (Ramsey, 1997). The exact process by which the distinctive circular shape of the Carolina Bays was formed is unknown. A calibrated radiocarbon date of 18,424 yrs B.P. from peat in an area mapped as modified land west of Bethany Beach indicates that deposition contemporaneous with the Cypress Swamp Formation (Andres and Howard, 2000) occurred on the uplands in the map area during the cold climate of the latest Pleistocene.

Modern deposition is occurring in Indian River Bay and its tributaries, Little Assawoman Bay and its tributaries, on the barrier coastline, and offshore. The succession of deposits related to Indian River Bay and Little Assawoman Bay grades from freshwater swamp deposits in the upper reaches of the tributaries, into the tidal streams, marshes, and lagoonal deposits (Chrzastowski, 1986). The area of Indian River Bay adjacent to the inlet is dominated by the sands of the flood tidal delta. Offshore, the area is dominated by the sands of the ebb tidal delta. The barrier that separates Indian River Bay and Little Assawoman Bay from the Atlantic Ocean is composed of nearshore and shoreline (beach) deposits on the Atlantic side. The barrier itself is composed of dune deposits that overlie, and interfinger with, barrier washover deposits on the bay side of the barrier. Man-made dunes and widened shorelines constructed by beach replenishment projects along the Atlantic shoreline are not differentiated from natural dunes or natural shorelines. The barrier washover deposits are the result of storms that transport beach, nearshore, and dune sand across the barrier. On the bay side, the washover deposits are overlain by, and interfinger with, marsh and lagoon deposits that accumulate between washover (storm) events.

To lithologically map offshore deposits, 129 vibracores were used. Most of the cores are 20 feet below the sea floor (McKenna and Ramsey, 2002; Williams, 1999; unpublished DGS data). Rather than creating a new stratigraphic nomenclature, the offshore lithologies were assigned names related to their depositional environments. This is in keeping with nomenclature onshore for modern deposits such as marsh, swamp, or shoreline. The offshore deposits are the result of the rise of sea level during the latest Pleistocene to Holocene and consist of deposits associated with the migration of the shoreline as sea level rose (lagoon and barrier washover and nearshore) and deposits associated with the modern marine setting (shoal, finger shoal, quiet water, ebb tidal sand, flood tidal sand, and sheet sand). Shoal deposits reflect the migration of sediment from onshore to offshore from the barrier shoreline (finger shoal). Sheet sand deposits are found where bottom sediments are reworked by storms and a source of sand, commonly the Beaverdam Formation, is present. Radiocarbon dates from offshore samples indicate sea-level rise deposits began prior to 11,000 yrs B.P. (Ramsey and Baxter, 1996; McKenna and Ramsey, 2002; unpublished DGS data).

Stratigraphic units found onshore are also recognized offshore. In some areas, modern deposition is thin to absent; the seafloor being a surface of erosion rather than deposition. The Sinepuxent Formation is mapped to the east of the barrier at Bethany Beach and is at the seafloor or beneath nearshore or finger shoal deposits (cross section B-B'). The extension of the margins of the paleovalleys filled with the Omar Formation and Holocene lagoon deposits are shown offshore with red dashed lines. These lagoonal deposits are found beneath the surficial Holocene lithologic units. Interfluve areas within and between paleovalleys are topographic highs of Beaverdam Formation (cross section B-B') and are indicated as interfluves on the map. The Beaverdam Formation comprises a portion of the seafloor to the northeast of Fenwick Island.

## **References Cited**

Andres, A.S., and Howard, C.S., 2000, The Cypress Swamp Formation, Delaware: Delaware Geological Survey Report of Investigations No. 62, 13 p. Andres, A.S., and Klingbeil, A.D., 2006, Thickness and transmissivity of the unconfined aquifer of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations No. 70, 19 p. Chrzastowski, M.J., 1986, Stratigraphy and geologic history of a Holocene lagoon:

Rehoboth Bay and Indian River Bays, Delaware: Ph.D. dissertation, University of Delaware, Newark, DE, 337 p. Groot, J.J., Ramsey, K.W., and Wehmiller, J.F., 1990, Ages of the Bethany, Beaverdam, and Omar formations of Southern Delaware: Delaware Geological Survey

Report of Investigations No. 47, 19 p. McKenna, K.K., and Ramsey, K.W., 2002, An evaluation of sand resources, Atlanta offshore, Delaware: Delaware Geological Survey Report of Investigations No. Owens, J.P., and Denny, C.S., 1979, Upper Cenozoic deposits of the central Delmarva

Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-A, 28 p. Ramsey, K.W., 1997, Geology of the Milford and Mispillion River Quadrangles, Delaware: Delaware Geological Survey Report of Investigations No. 55, 40 p. \_\_\_\_\_, 2001, Geologic map of the Ellendale and Milton Quadrangles, Delaware: Delaware Geological Survey Geologic Map Series No. 11, scale 1:24,000.

\_\_\_\_\_, 2003, Geologic map of the Lewes and Cape Henlopen Quadrangles, Delaware: Delaware Geological Survey Geologic Map Series No. 12, scale 1:24,000. \_\_\_\_\_, 2010a, Stratigraphy of the middle to late Pleistocene deposits of Delaware: Delaware Geological Survey Report of Investigations No. 76, 43 p.

\_\_\_\_\_, 2010b, Geologic map of the Georgetown Quadrangle, Delaware: Delaware Geological Survey Geologic Map Series No. 15, scale 1:24,000. \_\_\_\_\_, 2011, Geologic map of the Fairmount and Rehoboth Beach Quadrangles, Delaware: Delaware Geological Survey Geologic Map Series No. 16, scale

Ramsey, K.W., and Baxter, S.J., 1996, Radiocarbon dates from Delaware: a compilation: Delaware Geological Survey Report of Investigations No. 54, 18 p. Ramsey, K.W., and Tomlinson, J.L., 2011, Geologic map of the Harbeson Quadrangle, Delaware: Delaware Geological Survey Geologic Map Series No. 17, scale

Wehmiller, J.F., Simmons, K.R., Cheng, H., Edwards, R.L., Martin-McNaughton, J., York, L.L., Krantz, D.E., and Shen, C., 2004, Uranium-series coral age from the US Atlantic Coastal Plain-the "80 ka problem" revisited: Quaternary

International, v. 120, p. 3-14.

Williams, C.P., 1999, Late Pleistocene and Holocene stratigraphy of the Delaware Inner Continental Shelf: M.S. Thesis, University of Delaware, Newark, DE, 175 p.

Distance (x 1,000 ft)

