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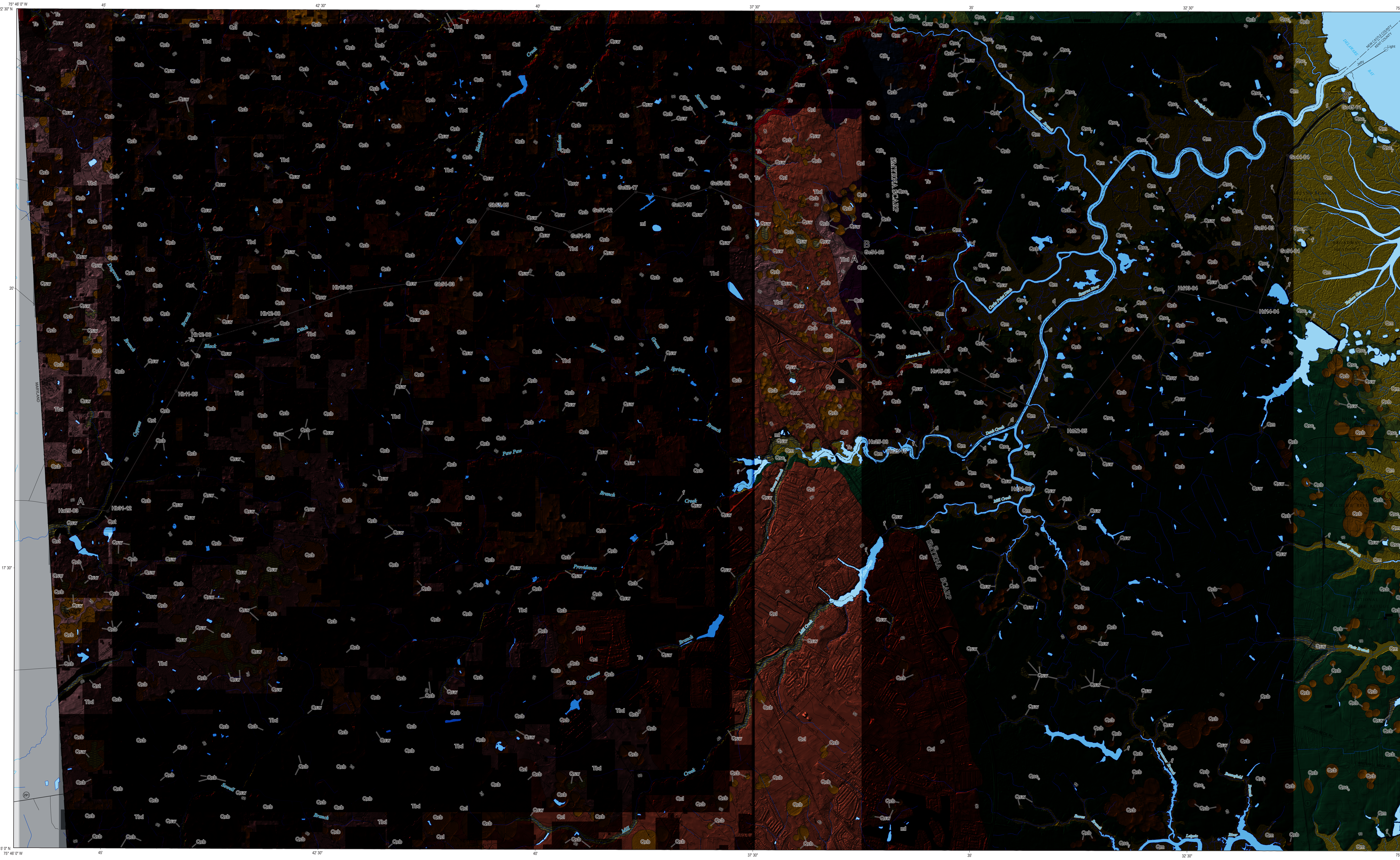


GEOLOGIC MAP OF THE MILLINGTON, CLAYTON AND SMYRNA QUADRANGLES, DELAWARE

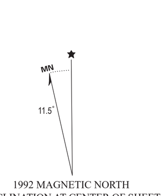
by

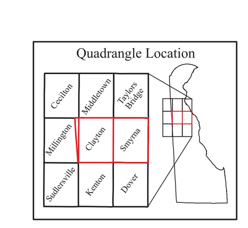
Kelvin W. Ramsey and Jaime L. Tomlinson

2018

SCALE 1:24,000

10-foot Index with a 6-foot Intermediate Contour Interval
NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)





SYMBOLS (*on map*)

- Gc54-08 Well or borehole
- Sandpit
- State Forest and Wildlife Areas
- State Boundary
- County Boundary
- Power Transmission Line
- Contact

MAP CREDITS

Base Map

Delaware state plane coordinate system
Transverse mercator projection
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, 2014
USGS National Hydrography Dataset, 2009
USGS Delaware LiDAR Contours, 2005
USGS Delaware LiDAR DEM, 2014
USGS Delaware Miscellaneous Features, 1993
Delaware Department of Agriculture State Forest Areas, 2013
Delaware Division of Natural Resources and Environmental Control Wildlife Areas, 2009

Other

Cartography by Lillian T. Wang, Delaware Geological Survey

Acknowledgements

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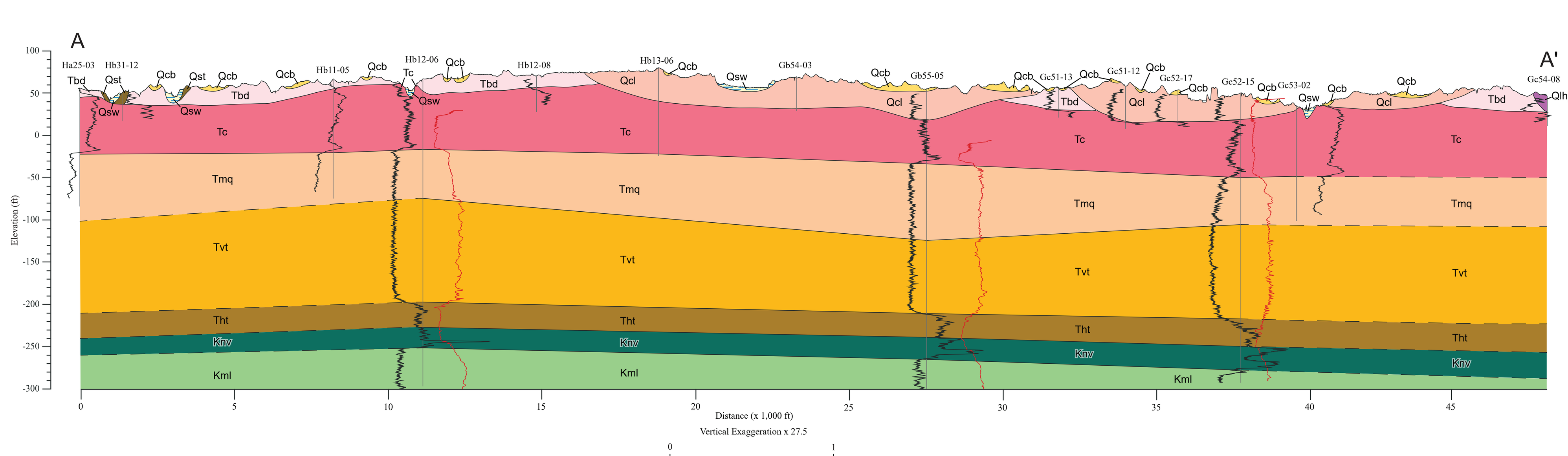


SYMBOLS (*on cross section*)

- gamma log
- resistivity log
- Radiocarbon date (calibrated yrs B.P.)
- Contact (unconformity)
- Inferred Contact

Colors for geologic formations on the cross sections appear lighter than shown on the map explanation and stratigraphic chart because they do not include the shading effect of the DEM used on the map.

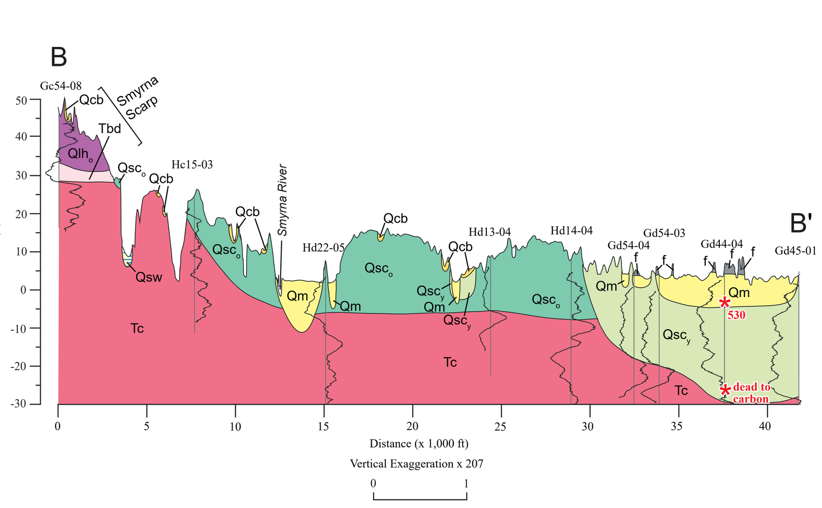
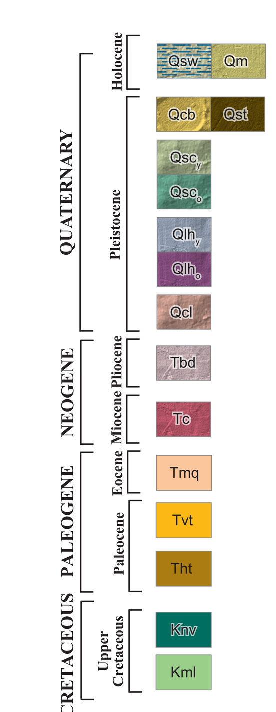


Table 1. STATEMAP-funded radiocarbon dates from the Smyrna Quadrangle. Locations of boreholes shown on map.

Radiocarbon Lab ID	DGS ID	Land Surface Elevation (ft)	Sample Elevation (ft)	Conventional Radiocarbon Date (yrs B.P.)	Conventional Radiocarbon Error Range (yrs)	Calibrated Date (2 Sigma Median) (yrs B.P.)	Strat Unit
Beta-424738	Gd44-04	6	-4.35	510	30	530	Qm
Beta-424740	Gd44-04	6	-27.5	>43500			Qsc_y
WIS-2034	Hc25-08	1	-5.56	11480	150	13321	Qcb
	Hc25-10	1	-4.64	1370	110	1282	Qm
	Hc25-10	1	-4.91	5750	60	6562	Qm
	Hc25-10	1	-5.69	5620	70	6383	Qm
WIS-2035	Hd21-06	1	-5.6	1730	60	1636	Qm



EXPLANATION

FILL (f)

Man-made and natural materials (mud, sand, gravel) emplaced in stream valleys or marshes to bring the topography above grade, usually in road beds, dams, or construction near a shoreline. Recent.

DREDGE DISPOSAL DEPOSITS (d)

Material dredged from the Smyrna River and emplaced on the riverbanks and uplands. Recent.

MODIFIED LAND (ml)

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

SWAMP DEPOSITS (Qsw)

Gray to brown, silty and clayey, gravelly sand overlain by organic-rich, fine to coarse sand and silt. Swamp deposits occur in the upper reaches of the modern stream valleys and in the interiors of some Carolina Bays. In the stream valleys, swamp deposits consist of 1 to 3 ft of gray to brown, silty and clayey gravelly sand at the base overlain by up to 5 ft of organic-rich, fine to coarse sand. The organic-rich material consists of sand- to silt-size organic fragments as well as deciduous leaves and twigs. Where mapped in Carolina Bays, swamp deposits consist of 1 to 3 ft of light-gray to gray silty, gravelly sand at the base overlain by up to 5 ft of light yellowish-brown to light-gray clayey silt with organics and wood fragments. Holocene.

MARSH DEPOSITS (Qm)

Gray to brown, clayey silt to silty clay with beds of peat, and muddy, fine to coarse sand with pebbles at its base. Scattered fragments of wood, *Spartina* blades, and *Spartina* rootlets are common. The unit ranges in thickness from less than 10 ft along the Smyrna River and its tributaries to greater than 30 ft near Delaware Bay. Holocene.

CAROLINA BAY DEPOSITS (Qcb)

White to pale-yellow, well-sorted, medium to fine sand in raised rims (dunes) with silty fine to medium sand in the interior of the circular morphologic features. The deposits are less than 5 ft thick in their interiors and up to 10 ft thick where the sand rims are best developed. Carolina Bay deposits consist of 1 to 3 ft of light-gray to brown gravelly sand overlain by grayish-brown organic sediment consisting of silt to fine sand-size organic fragments in their interiors. Some of the features contain seasonal standing water and modern swamp deposits (Tomlinson et al., 2013). Late Pleistocene.

STREAM TERRACE DEPOSITS (Qst)

Grayish-brown, organic-rich, clayey silt to silty clay with clean, medium to coarse sand that grades down into very coarse sand and gravel at the base. The clayey silt to silty clay is overlain by brownish-yellow to yellow, slightly silty, moderately well- to well-sorted fine to medium sand. Stream terrace deposits are less than 20 ft thick and are found adjacent to streams in the western portion of the map area. Distal from the streams, the deposits become thinner and are composed of fine to coarse sand and gravel with no organic deposits. Late Pleistocene.

SCOTTS CORNERS FORMATION (YOUNGER) (Qsc_y)

Pale-yellow to light-gray, medium to very coarse sand fining upward to fine to medium sand. Pebbles are common at the base of the unit. Along the Smyrna River, a 1- to 2 ft-thick bed of light-gray to reddish-brown silty clay to sandy silt occurs above the basal gravel. Beneath the Holocene marsh deposits east of Route 9, beds of organic-rich silty sand occur at the top of the unit. The younger Scotts Corners Formation occupies small terraces adjacent to the Smyrna River and outcrops as islands in the marshes east of Route 9 at elevations between 4 and 8 ft. The unit is less than 10 ft thick along the Smyrna River and its tributaries and up to 30 ft thick between Route 9 and Route 1. Late Pleistocene.

SCOTTS CORNERS FORMATION (OLDER) (Qsc_o)

Pale-yellow to light-gray, fine to coarse sand with scattered laminae to beds of coarse sand to granules with pebbles and opaque heavy mineral laminae. Scattered beds of gravel are common, especially near the base of the unit. North of the Smyrna River, the sand is overlain by light-gray, pale-yellow, and reddish-brown clayey silt. Between the Smyrna River and the Leispic River, the silt cap is commonly absent. The older Scotts Corners Formation occupies a terrace at elevations between 12 and 28 ft and is bordered on its western margin by a prominent scarp separating the unit from older units to the west. Over much of its extent, the unit is between 10 and 25 ft thick. It is less than 5 ft thick where it overlies the clay of the Calvert Formation near its western margin and is up to 35 ft thick where it overlies the Cheswold sand of the Calvert Formation east of Smyrna. Late Pleistocene.

LYNCH HEIGHTS FORMATION (YOUNGER) (Qlh_y)

Light-gray to grayish-brown fine to coarse sand to sandy gravel overlain by slightly to moderately clayey silt. The younger Lynch Heights Formation occupies a terrace near the northern boundary in the center of the map area at elevations of 32 to 40 ft. The unit is 8 to 12 ft thick. Middle Pleistocene.

LYNCH HEIGHTS FORMATION (OLDER) (Qlh_o)

Light-gray to reddish-brown fine to very fine sand interbedded with medium to coarse sand overlain by slightly clayey to clayey, slightly to moderately sandy silt. Gravel beds are common at the base of the unit. In the town of Smyrna and to the south, where the upper silt is absent, the unit is comprised entirely of sand and cannot be differentiated from the Columbia Formation unless basal gravel is present. The older Lynch Heights Formation is mapped in the north-central portion of the map area between elevations of 42 to 52 ft. It is less than 15 ft thick. Middle Pleistocene.

COLUMBIA FORMATION (Qcl)

Yellowish- to reddish-brown, fine to coarse, slightly silty, feldspathic quartz sand with gravel and some to abundant mica. The Columbia Formation is typically crossbedded with cross-sets up to 3 ft thick (Ramsey, 2005). Beds of gravel (pebbles to cobbles) ranging from a few inches to several ft thick are found throughout the unit and are common at the base of the unit. Dark-brown spot-like concentrations of manganese are common and help to distinguish the Columbia Formation from the sands of other formations. Where the Columbia Formation forms channels in the western portion of the map area, it is up to 75 ft thick. Outside the channel fills, it is typically less than 15 ft thick. Early Pleistocene.

BEAVERDAM FORMATION (Tbd)

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 reddish-brown, silty to clayey, fine to coarse sand with rare mica. Laminae and beds of very coarse sand with pebbles 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 to yellowish silt matrix that gives samples a distinct milky appearance when wet (Ramsey and Tomlinson, 2011). It is less than 40 ft thick. Late Pliocene.

CALVERT FORMATION (Tc)

Compact, gray to olive-gray to grayish-brown, clayey silt to silty clay overlain by beds of gray to light-gray to brownish-yellow, silty fine to coarse quartz sand with laminations of clayey silt and fine to coarse sand. Shell and shell fragments are rare. The clay and silt become denser and more compact with depth. The sandy facies of the formation is found in the southcentral portion of the map area (Cheswold sand). It is a brownish-yellow to light-gray, clean to slightly silty, medium to coarse sand that fines upward to very fine to fine sand. Laminae of mica and clayey silt are common. The Calvert Formation is typically less than 100 ft thick but in some locations it is up to 180 ft thick. Early Miocene.

MANASQUAN FORMATION *subsurface only* (Tmq)

Greenish-gray, fine to medium glauconite sand (60-70%) and very fine to very coarse quartz sand (30-40%) with a carbonate matrix (McLaughlin and Velez, 2006). The carbonate matrix is composed of sand- and silt-size shell fragments and forams that form weakly- to well-cemented beds. Quartz granules are common. Whole and fragments of thin-walled scallop shells are also common. In the map area the Manasquan Formation ranges from 50 to 75 ft thick. Early Eocene.

VINCENTOWN FORMATION *subsurface only* (Tvt)

Light greenish-gray, very fine carbonate sand (70-80% forams) with 10-15% very fine glauconite and 10-15% very fine quartz (Ramsey, 2005). The unit is finely laminated with scattered burrows and bioturbated zones and is weakly cemented. Some well-cemented carbonate beds occur in the lower part of the unit. Glauconite percentages increase to over 50% near the base of the formation. Late Paleocene.

HORNERSTOWN FORMATION *subsurface only* (Tht)

Greenish-gray, very fine to fine glauconite (>90%) sand. Carbonate grains (forams) comprise less than 5% of the sediment and quartz grains comprise less than 1% (Ramsey, 2005). Burrows are common. Whole shells and shell fragments of the brachiopod *Oleneothyris harlani* are common near the base of the unit. Early Paleocene.

NAVESINK FORMATION *subsurface only* (Knv)

Dark-gray to dark olive-gray, fine to coarse quartz (50-70%) with very fine to fine glauconite (30-50%) sand (Ramsey, 2005). Mollusk shell fragments are common. Late Cretaceous.

MOUNT LAUREL FORMATION *subsurface only* (Kml)

Olive-gray to olive-brown, silty to moderately silty (carbonate), slightly clayey, medium to very coarse quartz sand (Ramsey, 2005). Belemnite and mollusk shell fragments are rare to common. Quartz granules are common to abundant. Bioturbation is widespread and primary sedimentary structures are rare. Late Cretaceous.

Discussion

Mapping was conducted using field maps at a scale of 1:12,000 with 2-ft contours. Stratigraphic boundaries drawn at topographic breaks reflect detailed mapping using contours not shown on this map. Stratigraphic units mapped in stream valleys are projected from subsurface data. Except for a few erosional bluffs, these units are covered by colluvium. This map supersedes Geologic Map of New Castle County, Delaware (Ramsey, 2005) and Geology of the Geologic Map of Kent County, Delaware (Ramsey, 2007).

The geological history of the surficial units of the Clayton, Smyrna, and the Delaware portion of the Millington Quadrangles are the result of deposition of the Beaverdam Formation and its modification by erosion and deposition of the Columbia Formation during the early Pleistocene. These units were then modified by the Lynch Heights and Scotts Corners Formations as a result of sea-level fluctuations during the middle to late Pleistocene. The geology is further complicated by periglacial activity that produced Carolina Bay deposits in the map area, which modified the land surface.

Cross-section A-A' shows a succession of glauconite- and carbonate-rich Late Cretaceous- to Eocene-age units (McLaughlin and Velez, 2006) beneath the surficial deposits in the map area. The Mount Laurel Formation occurs at depths below 300 ft. It is a quartzose, shallow-marine deposit. The Mount Laurel Formation is overlain by the latest Cretaceous glauconite and quartz marine sand of the Navesink Formation. An unconformity occurs at the Cretaceous-Paleocene boundary. Above the boundary, the Paleocene Hornerstown Formation is a shallow marine glauconite sand with trace amounts of clastic sediment (quartz). The sediments of the Hornerstown Formation grade upward into the shallow-marine Vincentown Formation as glauconite percentages decrease and the percentages of carbonate increase. The carbonate beds in the lower Vincentown are commonly well-cemented and difficult to drill. The contact with the overlying Manasquan Formation (cross-section A-A') records a shift from primarily carbonate sediments to a mix of quartzose glauconitic sand with a carbonate matrix that is also cemented in places.

The Calvert Formation occurs in the subsurface throughout the entire map area. It crops out along stream valleys in the north-central portion of the map, to the east along Alabam Road, and in a small area just southwest of the town of Clayton. The lowermost Calvert consists of muddy estuarine deposits overlain by sandy shallow marine to estuarine deposits that comprise a portion of the Cheswold aquifer downdip (McLaughlin and Velez, 2006). The sandy shallow marine to estuarine deposits of the Calvert Formation are present in the southern half of the map and function as an important recharge area for the Cheswold aquifer. After deposition in the Miocene, the Calvert Formation was truncated during deposition of the fluvial Beaverdam Formation in the Pliocene, cut into by the Columbia Formation, and dissected by streams during the middle Pleistocene to early Holocene (Ramsey, 2010a).

The Beaverdam Formation consists of stacked, 1- to 5-ft thick beds of very coarse sand and gravel that commonly fine upwards to fine to medium sand and rarely to very fine silty sand. 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 is exposed at the surface in the western portion of the map area. 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 (Groot et al., 1990; Ramsey, 2010a, b).

The Columbia Formation occurs in a north-south trending channel roughly parallel to and west of Route 1 and Route 13. A second, smaller channel cuts across the northwestern portion of the map area from north of Blackbird Station Road to near Massey Branch where it joins the main channel. At its thickest in the Town of Smyrna, the Columbia Formation is over 100 ft thick. It is a sandy unit similar in appearance to the Beaverdam Formation. The Columbia Formation is differentiated from the Beaverdam Formation in that the sand fraction is coarser, it contains coarser clasts (large pebbles, and in places, cobbles and small boulders), and it typically contains spot-like concentrations of manganese in the sand beds. The Columbia Formation is interpreted to be the result of early Pleistocene glacial dam burst flooding from a source in the Delaware River in Pennsylvania that scoured channels into the Beaverdam Formation and older sediments. The channels were filled with sediment as the flood waters receded (Spoljaric, 1967; Jengo et al., 2013).

Middle to late Pleistocene and Holocene deposits occur in the eastern half of the map area as a succession of estuarine terraces (cross-section B-B') underlain by quartzose sandy and muddy deposits associated with sea-level highstands. The heterogeneous deposits of the Lynch Heights Formation are the result of estuarine and near-shore deposition along the margins of an ancestral Delaware Bay during the middle Pleistocene (400,000 to 320,000 yrs B.P.) (Ramsey, 1997; 2010a). The Lynch Heights Formation lies unconformably over the Beaverdam and Columbia Formations. Where these formations are absent, the Lynch Heights Formation overlies the Calvert Formation. It occupies two distinct terraces referred to as the older and younger Lynch Heights Formation (Ramsey, 2010a). The older Lynch Heights Formation occurs at elevations between 42 and 52 ft and is associated with marine isotope stage (MIS) 11 (Ramsey, 2010a). The younger unit, which is present as a small terrace remnant in the northern part of the map area, occurs at elevations between 32 and 40 ft and is associated with MIS 9 (Ramsey, 2010a). This remnant indicates that the major north-south scarp (herein named the "Smyrna Scarp") was formed as a sea-level highstand estuarine shoreline prior to the deposition of the younger Lynch Heights Formation.

Similar to the Lynch Heights Formation, the Scotts Corners Formation is also a composite unit of older and younger sediments (Ramsey, 2010a). Geomorphic correlation with dated deposits along the Atlantic Coast indicates the Scotts Corners Formation is late Pleistocene. The older Scotts Corners occupies a terrace with land surface elevations between 12 and 28 ft. The sea-level highstand that deposited the older Scotts Corners Formation during MIS 5e reoccupied the middle Pleistocene-aged shoreline and eroded the majority of the younger Lynch Heights Formation. The younger Scotts Corners Formation occupies small terraces along the Smyrna River with land surface elevations between between 4 and 8 ft. In the eastern portion of the map area it occurs as islands actively being covered by marsh with Holocene sea-level rise. A wood sample from the younger Scotts Corners Formation was dated using radiocarbon and yielded an age of >43,500 yrs B.P. (cross-section B-B').

Stream terrace deposits occur parallel to streams along the west-central margin of the map area. A calibrated radiocarbon date from a recent soil boring indicates these sediments were deposited by streams and swamps before 25,000 yrs B.P. (DGS unpublished data). Their surfaces are overprinted with Carolina Bays, which indicates that their deposition predates the formation of the bays.

The Carolina Bays are cold climate-related features located where winds moved sand across a landscape barren of forests (Ramsey, 1997; Markewich et al., 2009). In the map area, the features occur as a periglacial overprint on the surficial deposits and are densely spaced. Typically they are less than 10 ft from base to rim top and less than 1,500 ft in diameter. Carolina Bay features were visually identified using a hillshade DEM generated from 2014 LiDAR and were mapped by digitizing their outline, including their rim. In areas where Carolina Bays occur in clusters and individual bays could not be differentiated, the outline of the entire cluster was mapped. The exact process by which the distinctive circular shape of the Carolina Bays was formed is unknown. It is possible that the features began as interdunal lows or dune blowouts (Stolt and Rabenhorst, 1987) or as periglacial patterned ground later modified by wind into circular features aided by ponding in the lows. Where the water table is high, Carolina Bays commonly contain up to 5 ft of modern swamp deposits. Not all of the features mapped as Qcb contain Carolina Bay sediments as described above. Given the large number of features in the map area, the majority were mapped based on morphology alone and were not field verified.

In addition to Holocene swamp deposits that are in some Carolina Bays, Holocene swamp and marsh deposits related to sea-level rise are located along the margins of Delaware Bay. Radiocarbon dates from marsh deposits along Smyrna River and Mill Creek (Table 1) indicate that tidal deposition began around 6,500 yrs B.P. and has continued until the present. An inversion of dates from Hc25-10 (Table 1) indicates mixing or reworking of the woody material in the sediments. A major change in the marsh drainage occurred in 1878 when hurricane storm surge changed the marsh drainage and created a digitate tidal creek in what is now known as Broadway Meadows (Ramsey and Reilly, 2002).

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