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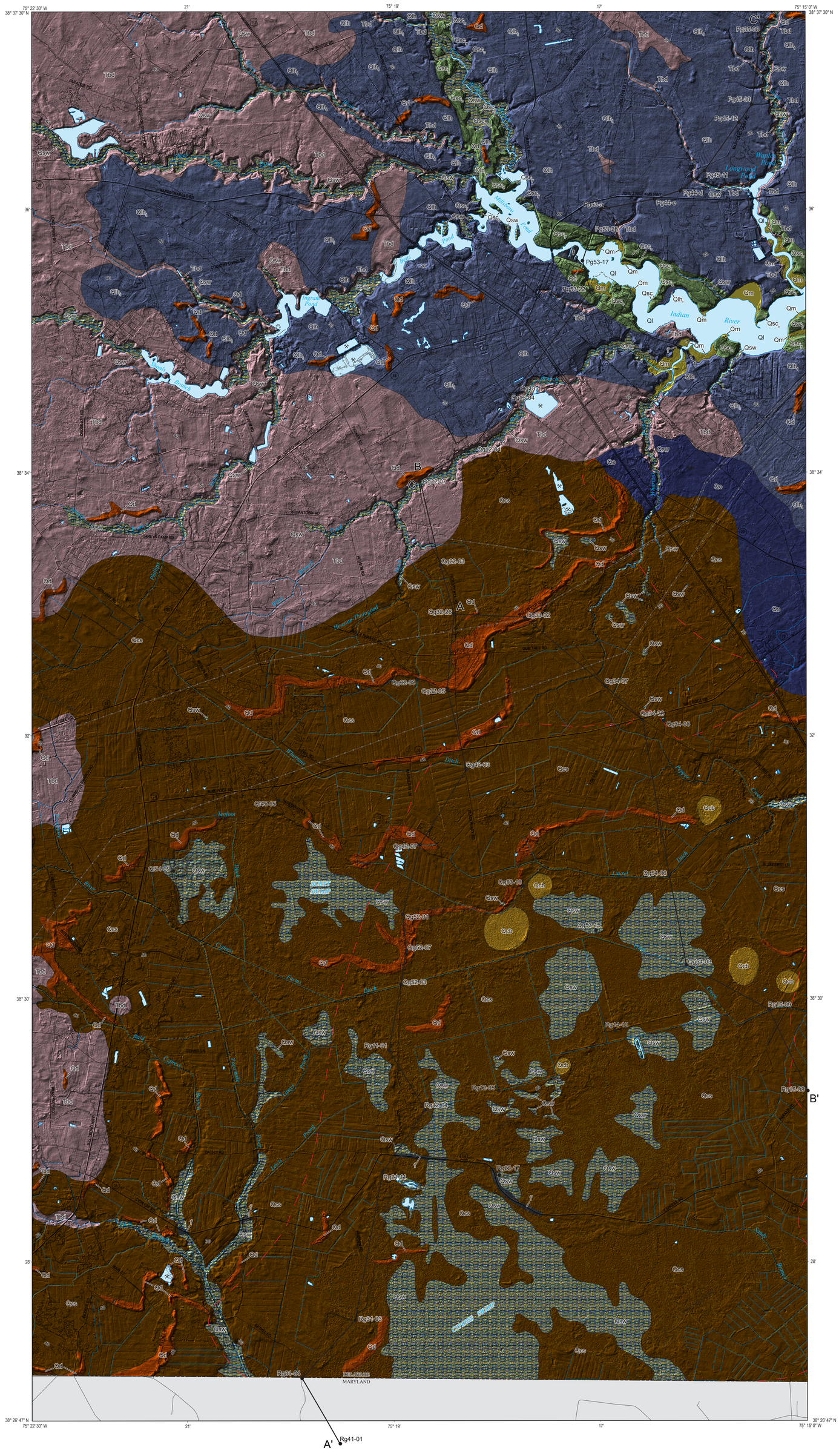

GEOLOGIC MAP OF THE MILLSBORO AND WHALEYSVILLE QUADRANGLES, DELAWARE

by

Kelvin W. Ramsey and Jaime L. Tomlinson

2014

SCALE 1:24,000

Acknowledgements
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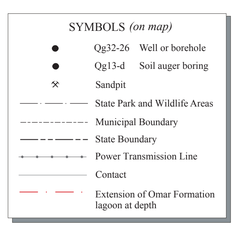
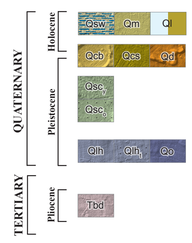
MAP CREDITS
Base Map
Delaware state plane coordinate system
Transverse mercator projection
North American Datum of 1983 (NAD83) HARN
The Delaware Department of Transportation Centerline for Delaware, 2009
The Delaware Office of State Planning Coordination Delaware Municipal Boundaries, 2009
USGS National Hydrography Dataset, 2009
USGS Delaware LiDAR Contours, 2005
USGS Delaware Miscellaneous Features, 1993
Delaware Department of Agriculture State Forest Areas, 2009
Delaware Division of Natural Resources and Environmental Control Park Areas, 2009
Other
Cartography by Lillian T. Wang, Delaware Geological Survey
Edited by Stefanie J. Baxter, Delaware Geological Survey

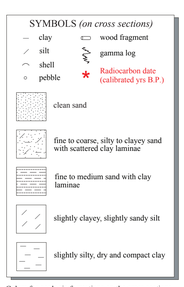
10-foot Index with a 6-foot Intermediate Contour Interval
NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

Table 1. Radiocarbon dates. 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.)
Beta-291467	Qf45-05	40	17.1	33850	290	38817
Beta-118806	Qf54-09	42	30.5	21400	220	25562
Beta-93655	Qg32-08	41	30.0	19330	100	23128
Beta-78724	Qg34-08	37	32.0	19470	110	23246
Beta-291466	Qg42-07	40	28.6	27740	170	31773
Beta-122862	Qg53-15	38	35.3	2840	60	2937
Beta-122863	Qg53-15	38	31.7	3840	60	4226
Beta-128232	Qg53-15	38	31.3	14210	50	17293
Beta-122864	Qg53-15	38	27.1	18440	100	22033
Beta-312982	Qg53-16	34	32.6	0	0	recent organics
Beta-312983	Qg53-16	34	29.1	18830	80	22397
Beta-312984	Qg53-16	34	24.6	21170	90	25255
Beta-312985	Qg53-16	34	20.4	40910	380	44648
Beta-312980	Rg11-01	38	21.7	42390	500	45603
Beta-312981	Rg12-05	36	20.9	21380	90	25583
Beta-122860	Rg14-12	38	35.3	3460	50	3709
Beta-122861	Rg14-12	38	27.6	20280	130	24190
Beta-312986	Rg21-11	38	23.8	23280	100	28118
Beta-128233	Rg22-17	37	33.3	10230	40	3164
Beta-312987	Rg31-03	35	11.8	21770	90	26074







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.

EXPLANATION

FILL

Man-made and natural materials (sand, gravel) placed 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 and placed on the uplands.

LAGOON DEPOSITS *Indian River*

Medium-gray to dark-gray clayey silt that grades westward to clayey silt with fine to coarse sand and organic laminae. Sedimentary structures consist of relict burrows and thin laminae of marsh grass, sand, or organic fragments (twigs and leaves). Lagoon deposits grade laterally into marsh deposits. Lagoon deposits are up to 15 ft thick near the center of Indian River and thin to less than 5 ft thick to the west (Chrzastowski, 1986). Holocene.

SWAMP DEPOSITS

Gray to brown, silty and clayey gravelly sand overlain by organic-rich fine to coarse sand. Swamp deposits are found in the upper reaches of the modern stream valleys and also are associated with the modern Cypress Swamp. In the stream valleys, deposits consist of 1 to 3 ft of gray to brown, silty and clayey gravelly sand at the base overlain by organic-rich, fine to coarse sand. In some of the larger stream valleys, deposits (up to 15 ft thick) are capped by several feet of organic silt. Swamp deposits associated with Cypress Swamp consist primarily of clean, pale-yellow, fine to coarse sand with scattered laminae of light-brown to brown, organic-rich silt and fine to very fine sand with abundant plant fragments. The deposit is overlain in places by an organic muck consisting primarily of silt-size organic fragments with varying amounts of silt to very fine sand. 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. Holocene.

CAROLINA BAY DEPOSITS

Well-sorted, medium to fine sand in raised rims (dunes) with silty sand in the interior of the circular features. These deposits are found in the northern portion of the Whaleysville Quadrangle and the southern portion of the Millsboro Quadrangle. A few of the features contain seasonal standing water where the water table is high and commonly contain swamp deposits. The deposits are less than 5 ft thick in their interiors. Latest Pleistocene to Holocene.

CYPRESS SWAMP FORMATION

Dark grayish-brown, organic-rich, very fine silty sand to sandy silt with organic silt and peat beds overlain by a pale-yellow, fine to very fine, clean to slightly silty sand with scattered light-gray silt and grayish-brown organic silt laminae. The basal organic sand ranges from 5 to 15 ft thick, with scattered 1- to 5-ft thick beds of peat (with plant fragments) to organic silt. In places, the lower sand overlies a 1- to 3-ft thick bed of light-gray to grayish-brown sand that ranges from very fine slightly silty sand to clean coarse sand with granules and pebbles. The fine to very fine clean sand that overlies the unit is 5 to 10 ft thick. In the map area, the Cypress Swamp Formation is up to 30 ft thick. Late Pleistocene to early Holocene.

DUNE DEPOSITS

White to pale-yellow, well-sorted, medium to fine sand. Laminae of coarse sand are common. Thin, brown soil lamellae are commonly found at depths of 1 to 3 ft. Dune deposits are up to 7 ft thick. 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 fine sand, commonly capped by 1 to 3 ft of very fine, sandy, clayey silt. Scattered beds of 1 to 3 ft of gray silty clay with organic-rich laminae are also common. The deposits are found beneath low terrace flats less than 10 ft in elevation along the margins of Indian River and are up to 15 ft thick. Late Pleistocene.

SCOTTS CORNERS FORMATION (OLDER)

White to pale-yellow, well-sorted, coarse to fine sand with scattered thin clay laminae and rare beds of gray silty clay. Beds of pebbly, coarse to granule sand are common at the base of the unit. These deposits, which are up to 23 ft thick, are found beneath terrace flats between 10 and 24 ft in elevation along the margins of Indian River, Swan Creek, Millsboro Pond, and Cow Bridge Branch. Late Pleistocene.

LYNCH HEIGHTS FORMATION

Loose, clean to slightly silty, white to pale-yellow, well-sorted, fine to coarse sand with scattered very coarse sand to pebble laminae. These deposits are found along the margins of the Indian River, Swan Creek, Cow Bridge Branch, Millsboro Pond, and Betts Pond in the Millsboro Quadrangle. The sands are over 15 ft thick in Millsboro adjacent to the Indian River. Middle Pleistocene.

Where mapped as Qlh_l in the northern third of the Millsboro Quadrangle, the Lynch Heights Formation consists of a thin (<5 ft thick) layer of heterogeneous sediments ranging from reddish-brown, pale-yellow, and light-gray silty, clayey, very coarse to fine sand, to pale-yellow to light-gray gravelly sand to sandy gravel. These deposits are interpreted to be the result of local reworking of the underlying Beaverdam Formation sediments in shallow nearshore tidal environments. The Lynch Heights Formation is differentiated from the Beaverdam Formation by the lack of the characteristic white silt matrix. A layer of coarse sand to gravel is commonly found at the base of the unit overlying the typical Beaverdam sands. Middle Pleistocene.

OMAR FORMATION

Light-gray to dark greenish-gray, clayey silt to silt and very fine sand with scattered shell beds and a coarse basal sand. 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 majority of the Omar Formation in the map area consists of up to 30 ft of interbedded and interlaminated clayey silt to silt and very fine sand. Scattered laminae to thin beds of *Crassostrea* (oyster) shell are rare to common. The overall thickness of the Omar Formation in the map area ranges from 2 ft along the surficial contact with the Beaverdam Formation to about 35 ft underneath the central portion of Cypress Swamp. The Omar Formation fills a northeast-west southwest oriented paleovalley across the map area. Middle Pleistocene.

BEAVERDAM FORMATION

Heterogeneous sediments 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. 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 Scotts Corners and Lynch Heights Formations and the upper sands of the Cypress Swamp and Omar Formations, where present. The Beaverdam Formation ranges from 50 to 100 ft thick in the map area. Late Pliocene.

Discussion

The geological history of the surficial units of the Millsboro Quadrangle and Delaware portion of the Whaleysville Quadrangle was the result of deposition of the Beaverdam Formation during the late Pliocene and its subsequent modification by erosion and deposition related to sea-level fluctuations during the Pleistocene and late Pleistocene upland swamp and bog deposition. The geology at the land surface was then further modified by periglacial activity that produced dune deposits and Carolina Bays in the map area. Surficial geologic mapping was conducted using field maps at a scale of 1:12,000 with 2 foot contours. Stratigraphic boundaries drawn at topographic breaks reflect detailed mapping using contours not shown on this map.

The Beaverdam Formation is exposed in the north-central and western portion of the Millsboro Quadrangle and on the northwest corner of the Whaleysville Quadrangle and underlies all the younger deposits in the map area. The Beaverdam Formation consists of stacked, 1- to 5-ft thick beds of very coarse sand and gravel that commonly fine upward 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 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 Lynch Heights Formation is found in the northern portion of the Millsboro Quadrangle in areas adjacent to the Indian River and its tributaries. It is a composite unit consisting of deposits from two sea-level highstands that occurred approximately 400,000 yrs B.P. and 320,000 yrs B.P. (Groot et al., 1990; Ramsey, 2010a; Ramsey and Tomlinson, 2011), which cannot be differentiated in this map area. In the majority of its exposure area, the Lynch Heights Formation (Qlh_l) is a thin unit (<5 ft thick) consisting of fine to medium sand that coarsens downward to a coarse sand. In places, a pebbly sand to pebble gravel containing abundant opaque heavy minerals is found at the base of the overlying the Beaverdam Formation. This portion of the Lynch Heights Formation is interpreted to be a shallow water deposit consisting of sand eroded from the Beaverdam Formation as the shoreline transgressed during one or both of the sea-level highstands. In the northern portion of the Millsboro Quadrangle, fluvial deposits flank the modern drainage and are related to the initial stages of drainage formation during the middle Pleistocene (Ramsey and Tomlinson, 2012). Lynch Heights Formation (Qlh) sediments nearest to the modern drainage are thicker deposits (6 to >15 ft) of clean, loose, well-sorted sand with few to abundant heavy minerals. Away from the drainage, deposits become less well-sorted and siltier.

The Omar Formation is exposed at the surface southeast of Millsboro. It is found in the subsurface beneath the Cypress Swamp Formation in the central portion of the map area, where it occupies a northeast-southwest oriented paleovalley carved into the Beaverdam Formation (cross sections A-A', B-B'). The Omar Formation is a composite unit consisting of deposits related to one or possibly two sea-level highstands (Ramsey, 2010a). It is comprised of a lower, brown to gray, coarse sand to gravel overlain by an organic-rich, sandy clay, clayey silt or silty sand with woody organic fragments and thin peat beds. The lower Omar is overlain by greenish-gray clayey silt to silty, very fine sand. Within the clayey silts and sands, rare to common laminae to thin beds of shell dominated by *Crassostrea virginica* (oyster) are found. The sands commonly contain horizontal and vertical burrows up to 0.5 inches in diameter. Amino-acid racemization of shells from the Pepper Creek ditch just east of the map area indicates that the unit was deposited during aminozone IIc (approximate age of 320,000 yrs B.P.). These results suggest that deposition of the Omar Formation was contemporaneous with a depositional phase of the Lynch Heights Formation that is younger than that found to the east at Dirickson Creek (Ramsey and Tomlinson, 2012; Ramsey, 2010a; Groot et al., 1990). The Omar Formation ranges from 2 ft thick along the margins of the paleovalley to approximately 35 ft underneath the central portion of Cypress Swamp. Where the Omar Formation is the surficial unit, it is differentiated from the Lynch Heights in that it is composed of relatively clean fine sand overlying estuarine mud, while the Lynch Heights Formation consists of poorly sorted sand with pebbles. The surficial Omar Formation is differentiated from the adjacent Cypress Swamp Formation in that it does not contain organic-rich silt beds that are common in the clean sands of the Cypress Swamp Formation.

Following deposition of the Lynch Heights and Omar Formations, the Indian River drainage developed in its current location. Subsequent erosion carved into these deposits and inset terraces of stream, nearshore, and beach deposits were formed in the late Pleistocene (120,000 yrs B.P. and 80,000 yrs B.P.; Ramsey, 2010a) during sea-level highstands. These deposits comprise the Scotts Corners Formation mapped along the north and south shores of Indian River Bay (cross section C-C'). Two phases of deposition and erosion (120,000 yrs B.P. (older) and 80,000 yrs B.P. (younger)) are represented in the Scotts Corners Formation. The units are very similar lithologically and are therefore mapped based on their geomorphology (land surface elevations).

The Cypress Swamp Formation (Andres and Howard, 2000) is interpreted to have originated as fluvial and swamp deposits in a stream valley and as sphagnum bog deposits on poorly drained uplands during the last interglacial (MIS 3). Radiocarbon dates (Table 1) indicate two periods of deposition of the organic-rich sands, one from 42,000 to 33,000 yrs B.P. and another, the main phase of deposition, from 25,000 to 17,000 yrs B.P. After a hiatus in deposition during the transition between the interglacial and the last glacial period, deposition of the lower organic silts resumed in sphagnum bogs, which filled the stream valley with sediment. After the organic silts were deposited, sand dunes migrated across the area leaving behind the sheets of sand in the upper portion of the Cypress Swamp Formation. Organic laminae in the upper sandy portion were deposited in ephemeral bogs between the dunes. Radiocarbon dates from organic deposits of the Cypress Swamp Formation generally increase in age with increasing depth; however, organic deposits in incised streams that drained the map area during deposition of the Cypress Swamp Formation yield dates that are younger than deposits on the uplands that flank the streams (e.g., Rg31-03, cross section A-A'). Older upland deposits were buried by the rapidly migrating dunes before erosion of these upland deposits could occur. During and after burial of the upland deposits, incision and deposition of organic material continued in the stream valleys. As a result, older aged sediments can be found higher elevations. Upland swamp deposition in Cypress Swamp appears to have begun around 5,000 yrs B.P. in topographically low areas and where fine-grained organic deposits in the Cypress Swamp Formation created local perched ground water at or near the land surface.

Dune deposits consist of fine to medium, well-sorted sands that have a pronounced surficial expression as curvilinear features that rise above the surrounding landscape. The majority of these features in the map area are found in the southern portion of the Millsboro Quadrangle. Most of these dunes are latest Pleistocene to early Holocene in age (Andres and Howard, 2000). A few of the dunes have well-developed and deep (>3 ft) soil profiles and could possibly be as old as late Pleistocene. Dune features are also associated with the rims of Carolina Bays. The exact process by which the distinctive circular shape of the Carolina Bays was formed is unknown. Both the dunes and the Carolina Bays are cold-climate related features located where winds moved sand across a landscape barren of forests (Denny and Owens, 1979; Ramsey, 1997) and are, in part, contemporaneous with deposition of the sands within the Cypress Swamp Formation.

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