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GEOLOGY OF THE CANTON AND TAYLORS BRIDGE QUADRANGLES
SALEM AND CUMBERLAND COUNTIES, NEW JERSEY
OPEN FILE MAP SERIES OFM 92

INTRODUCTION

The Canton and Taylors Bridge quadrangles are located along Delaware Bay in the Coastal Plain in southwestern New Jersey. Geologic materials in the map area include unconsolidated Coastal Plain formations overlain by surficial deposits. Coastal Plain formations include sand, clay, silt, and glauconite clay laid down in coastal, nearshore-marine, and continental-shelf settings 120 to 10 million years ago (Ma). Surficial deposits include sand, gravel, silt, clay, and peat laid down in estuaries, salt marshes, and flood plains, as sea level rose and fell within the past 450,000 years.

A discussion of sea-level change as recorded by the surficial deposits, and evidence for recent sea-level rise in the map area, is provided in the following two sections. The lithology and age of the formations are discussed in the *Description of Map Units*. Age relations are summarized in the *Correlation of Map Units*. Cross sections AA' and BB' show the subsurface geometry of the formations along the line of section. Lithologic logs for three test borings drilled for this study are provided in table 1.

The cross sections show materials to a depth of 400 to 500 feet. This depth extends to the base of the Mount Laurel Formation, which is the principal aquifer in the map area and is the target stratum for most water wells. Several wells on Artificial Island penetrate below 500 feet, into the Magothy and Potomac Formations (wells 33-30, 33-363, 33-385, 33-401, 34-1031, and 34-4055). The deepest well (33-401) was drilled to nearly the base of the Potomac Formation at a total depth of 1800 feet. Correlation of aquifer sands and confining units in the Potomac in this well are shown by Sugarman and Monteverde (2008).

CAPE MAY FORMATION AND PLEISTOCENE SEA LEVELS

Coastal landforms and surficial deposits in the map area were shaped by alternating periods of high sea level during warm interglacial climate, and longer periods of low sea level during cold glacial climate. Deposition of sediment in estuaries and salt marshes occurs during interglacials; fluvial incision and erosion of these deposits by the Delaware River and its tributaries occurs during glacials (fig. 1). The Cape May Formation consists primarily of estuarine sediments laid down during three or more interglacial sea-level highstands within the past 450,000 years. The Cape May deposits rest on a composite erosional surface formed by fluvial incision during at least two periods of low sea level between the highstands. The earliest highstand is marked by the Cape May Formation, unit 1 (Qcm1), which forms an eroded terrace with a surface elevation as much as 65 feet above sea level. Amino-acid racemization measurements on shells from this deposit, sampled in boreholes on the Cape May peninsula and in sand-pit excavations near the Maurice River, indicate that it was laid down sometime between 450,000 and 200,000 years ago (Lacovara, 1997; O'Neal and others, 2000; Sugarman and others, 2007). Estimates of global sea level during this period show highstands at about 330,000 years ago (oxygen-isotope stage 9) and 420,000 years ago (oxygen-isotope stage 11). Global sea level 420,000 years ago reached approximately 70 feet above present sea level, about the level of the Cape May 1 terrace. The highstand at 330,000 years ago reached no higher than about 25 feet above present sea level (O'Neal and McGeary, 2002). Thus, if local sea level in the Delaware Bay region is similar to global sea level, it is likely that most of the Cape May 1 was deposited during oxygen-isotope stage 11.

Lower-than-present sea level between 330,000 and 125,000 years ago (a period known as the Illinoian glacial stage in North America) allowed fluvial incision and erosion of the Cape May 1. This incision reached a maximum depth about 150,000 years ago (red lines on fig. 1), when the Illinoian glacier was at its greatest extent. At this time, the glacier advanced into the Delaware River valley, to a maximum position near Easton, Pennsylvania. The main Delaware channel at this time in the map area was to the east of the present Delaware River. It was at a depth of more than 200 feet below sea level beneath the present Cape May peninsula (Gill, 1962; Newell and others, 1995), and 75 to 100 feet below sea level in the Pennsville paleovalley in and north of the map area (Stanford, 2006, 2009). In the map area this channel is along the east edge of Artificial Island.

Sea level rose as Illinoian ice melted. The sea reached an interglacial highstand 20 to 30 feet above modern sea level about 125,000 years ago. Estuarine deposits of the Cape May Formation, unit 2 (Qcm2 and Qcm2f) were laid down during this highstand, known as the Sangamonian interglacial, filling the Illinoian channel and forming a terrace with a maximum surface altitude of about 35 feet. Bay mud (Qcm2f) filled the deeper channels. Sandier tidal-flat and shoreline deposits (Qcm2) aggraded in shallower water around the bay margins. Amino-acid racemization measurements on shells from borehole and outcrop samples of the Cape May 2 on the Cape May peninsula (Lacovara, 1997) confirm a Sangamonian age. Three radiocarbon dates on organic material from the Cape May 2 in the map area, including dates of >40,000 radiocarbon years (W-2296) and >42,000 radiocarbon years (W-2266) from depths of 37 and 43 feet, respectively, in the deep foundation excavation for the Salem power plant on Artificial Island (Owens and Minard, 1979), and a date of >43,500 radiocarbon years (Beta 292101 AMS) on organic silt from a depth of 7 feet in a hand-auger hole near Gum Tree Corner (latitude 39°25'34", longitude 75°23'25", location on map), are consistent with a Sangamonian age.

After the peak highstand 125,000 years ago, sea level began to lower as glaciers again grew. Global records show two periods of stable or minor rises of sea level between about 120,000 and 80,000 years ago. Beginning about 80,000 years ago, significant glacial growth caused rapid sea-level decline. The Cape May Formation, unit 3, is estuarine and fluvial sediment laid down during these late Sangamonian sea-level events 120,000 to 80,000 years ago. It is a generally thin, sandy veneer inset into the Cape May 2 and forms a low terrace bayward from the Cape May 2 terrace, with a maximum surface elevation of about 15 feet. Luminesence dates of two samples of the Cape May 3 from east of the Cohansey River yielded ages of >37,000 and >101,000 years (O'Neal and Dunn, 2003). A radiocarbon date of >40,000 radiocarbon years (lab number not reported) was obtained on organic material from a depth of 7 feet in auger hole CAN-3 (latitude 39°28'38", longitude 75°26'23"), with pollen indicating a temperate oak-hickory forest (Newell and others, 1995). These dates indicate a pre-middle Wisconsinan age and are consistent with a late Sangamonian age.

As glaciers grew during the Wisconsinan glacial stage (80,000 to 10,000 years ago), sea level lowered. At its maximum in the late Wisconsinan, 25,000 to 20,000 years ago, the glacier again entered the Delaware River valley, advancing southward to the Belvidere, New Jersey area. The Delaware River incised into the Cape May 2 and 3 deposits, cutting a channel to a depth of about 175 feet at the mouth of Delaware Bay, and between 100 and 150 feet deep in the map area (purple lines on fig. 1). As the Wisconsinan glaciers melted and sea level rose between 20,000 and 5,000 years ago, these channels were filled with Holocene estuarine and salt-marsh deposits (unit Qm), and beach deposits (unit Qbs). Most of this sedimentation occurred between 10,000 years ago, when the sea began flooding areas outside the Delaware channel, and about 4,000 years ago, when sea-level rise slowed (Fletcher and others, 1990). Sedimentation continued at a slowed rate in the past 4,000 years, and will again accelerate as the rate of sea-level rise increases in the future (see next section).

RECENT SEA-LEVEL RISE

Tide gauges at several sites in and near Delaware Bay (table 2) record an average rate of sea-level rise since 1930 of between 3 and 4 mm/yr. This rate gives a rise of between 9 and 12 inches (230-300 mm) in sea level between 1930 and 2007 in the Delaware Bay region. The pre-industrial late Holocene (4,000 years ago to 1900) geologic background rate in this region, based on radiocarbon-dated salt-marsh peat, is between 1 and 2 mm/yr (Miller and others, 2008; Englehart and others, 2009), leaving between 2 and 3 mm/yr as the post-industrial anthropogenic component of the observed rise. The geologic background rate in this region is the highest along the U. S. Atlantic East Coast, in part because crustal subsidence due to postglacial isostatic adjustment is at a maximum here (Englehart and others, 2009).

Table 2. Recent sea-level rise observed at tide gauges in the Delaware Bay region. From National Oceanic and Atmospheric Administration data available at http://tidesandcurrents.noaa.gov/sltrends/index.shtml.

Station	Observed Sea-Level Rise ± Standard Deviation	Period of Record
Atlantic City	3.99±0.18 mm/yr	1911-2006
Cape May	4.06±0.74 mm/yr	1965-2006
Philadelphia	2.79±0.21 mm/yr	1900-2006
Lewes, DE	3.20±0.28 mm/yr	1919-2006
Reedy Point, DE (near Artificial Island)	3.46±0.66 mm/yr	1956-2006

Aerial photographs and field observations document sea-level rise in the map area since 1930 (fig. 2). The approximately 1-foot rise since 1930 has caused the salt marsh to advance inland, and the shoreline of the bay to retreat inland. Aerial photographs taken in 1930 and 2007 were registered to the 1:24,000 topographic base using fixed points such as roads, stable tidal channels, and fence lines. Marsh limits are defined by the vegetation change from marsh grasses to upland forest, shrub, or field. The 1930 photos are black and white images with less resolution and clarity than the 2007 photos, which are high-resolution color infrared images. Thus, the 1930 marsh limit is less certain than the 2007 limit. The marsh grasses are typically high-marsh reeds (mostly *Phragmites*) which grow as much as a foot or two above daily mean high tide but are flooded during storm or high astronomical tides (Tiner, 1985). The bayshore is mostly the eroded edge of the salt marsh, which is cohesive due to a dense root mat (chiefly from *Phragmites* rhizomes) in the upper six to eight inches of the marsh surface, and due to the underlying fibrous plant matter mixed with clay-silt matrix sediment. In a few places, small deposits of beach sand are banked against the marsh edge along the shoreline. The cohesive marsh material forms a well-defined erosional scarp between two and four feet high at low tide.

Figures 3 and 4 are paired 1930-2007 aerial photos documenting marsh advance at two sites on the edge of low Cape May 3 terraces. Marsh advance is indicated by fringes of dead and dying trees along the edge of the upland, by the spread of reeds into agricultural fields and forested upland, and by the submergence of freshwater thermokarst ponds and man-made features. For example, much of the southern half of the road in the 1930 photo in figure 4 is now covered by reeds growing in several inches of organic mud atop the original gravel road bed.

The salt marsh advanced as much as 700 feet inland between 1930 and 2007 around the low Cape May 3 terraces west of Silver Lake Meadow, and on the low Cape May 3 islands west of Stow Creek and Mad Horse Creek. Shrubby freshwater wetlands along Raccoon Ditch in 1930 had become salt marsh by 2007, accounting for the large areas of marsh advance there. Elsewhere, marsh advance is less extensive because uplands are higher and slopes at the marsh edge steeper. Dikes across the outlets of Silver Lake Meadow and Canton Drain may have restricted tidal flow in those valleys, possibly affecting the growth of marsh vegetation and thus the inferred marsh advance in those areas, but there is no artificial alteration elsewhere.

The bayshore has retreated generally between 300 and 500 feet, and as much as 800 feet, between 1930 and 2007, distances that are comparable to the marsh advance onto low upland. There has been no anthropogenic modification of the bayshore since 1930, except at Artificial Island (west of the area shown on figure 2) and small areas at the end of the two roads at Bay Side, so the shoreline retreat reflects natural erosion.

The rate of sea-level rise is expected to accelerate during coming decades in response to melting of polar ice sheets. A rise in global sea level of 0.6 to 2 feet (0.2 to 0.6 m) between 2000 and 2100 is projected, based on thermal expansion of the ocean and observed melting of the Greenland and Antarctic ice sheets between 1993 and 2003 (IPCC, 2007). Since 2003, the melt rate of the polar ice sheets has more than doubled from the 1993-2003 value (Velicogna, 2009). This rate of melting, if sustained, increases the projected global sea-level rise by 2100 to a range of 1 to 4 feet (0.4 to 1.2 m). In the Delaware Bay area, this rise will add to the geologic background rise of 1 to 2 mm/yr, or 0.3 to 0.6 feet (90 to 180 mm) between 2010 and 2100, giving a projected total rise of between 1.3 and 4.6 feet (0.5 and 1.4 m) by 2100. Based on shoreline and marsh response to the approximately 1-foot rise between 1930 and 2007, a 4-foot rise would cause the bayshore to retreat, and the marsh to advance, over roughly four times the amounts shown in figure 2.

DESCRIPTION OF MAP UNITS

▨ ARTIFICIAL FILL--Sand, silt, gravel, clay; gray to brown; minor amounts of demolition debris (concrete, brick, wood, metal, etc.), cinders, ash, slag, glass, trash. Unstratified to weakly stratified. As much as 30 feet thick on Artificial Island, generally less than 15 feet thick elsewhere. In road embankments, dikes, and filled wetlands and flood plains.

afd DREDGE SPOILS--Fine sand, silt, clay, minor medium-to-coarse sand and gravel; gray to brown. Contains varied amounts of organic matter and mica, and minor amounts of man-made materials. Massive to weakly stratified. As much as 40 feet thick. A radiocarbon date of 6330 radiocarbon years (W-2324, error not reported) on wood from a depth of 15 feet (elevation -4 feet) sampled in the foundation excavation for the Salem power plant on Artificial Island is likely from dredged Holocene estuarine deposits (Owens and Minard, 1979).

Qal ALLUVIUM--Sand, silt, peat, minor clay; brown, yellowish-brown, gray; and pebble gravel. Contains varied amounts of organic matter. Peat and organic silt and clay typically overlie sand and pebble gravel. Sand and silt is unstratified to weakly stratified. Gravel occurs in massive to weakly stratified beds generally less than 2 feet thick. Sand consists chiefly of quartz with minor (<5%) mica. Gravel consists chiefly of white, gray, and yellow quartz and quartzite, and a trace (<0.1%) of gray chert. As much as 15 feet thick. Deposited in modern flood plains and stream channels. Also underlies unit Qm in the lower reaches of stream valleys drowned by Holocene sea-level rise.

Qm SALT-MARSH AND ESTUARINE DEPOSITS—Peat, clay, silt, fine sand; brown, dark-brown, gray, black; and minor medium sand and pebble gravel. Contain abundant organic matter and some mica and shells. As much as 100 feet thick beneath and adjacent to the Delaware River. Deposited in tidal wetlands, salt marshes, tidal flats, and tidal channels during Holocene sea-level rise, chiefly within the past 10,000 years.

Qbs BEACH SAND—Fine-to-medium quartz sand, very pale brown to yellowish-brown. Contains few (1-5%) quartz pebbles and shells. As much as 5 feet thick. Overlies salt-marsh deposits.

Qtl LOWER TERRACE DEPOSITS--Fine-to-medium sand, minor silt and clay; very pale brown, yellowish-brown; pebble gravel. Sand is weakly stratified to well-stratified. Gravel occurs in thin beds (generally less than 6 inches thick) within and at the base of the deposit. Sand consists chiefly of quartz. Gravel consists chiefly of white, gray, and yellow quartz and quartzite, and a trace of gray chert. As much as 10 feet thick (estimated). Form stream terraces with surfaces 2 to 5 feet above modern estuaries and flood plains. Also occurs in places beneath unit Qm in valleys cut into unit Qcm3 (section AA').

Qtu UPPER TERRACE DEPOSITS—Fine-to-medium sand, minor silt; very pale brown, yellowish-brown, light gray; pebble gravel. Sand is weakly stratified. Sand consists chiefly of quartz. Gravel consists chiefly of white, gray, and yellow quartz and quartzite, and a trace of gray chert. As much as 10 feet thick. Form stream terraces with surfaces 10 to 15 feet above modern flood plains. The terraces grade downstream to, or are onlapped by, the Cape May Formation, unit 2, indicating that the Upper Terrace Deposits are older than, or contemporaneous with, the Cape May 2.

CAPE MAY FORMATION (Salisbury and Knapp, 1917)--Estuarine and fluvial-estuarine deposits of middle and late Pleistocene age. Divided into three units (Qcm1, Qcm2, Qcm3) based on surface elevation and age (Newell and others, 1995).

Qcm3 CAPE MAY FORMATION, UNIT 3—Silty very-fine-to-fine sand, fine-sandy silt, fine-to-medium sand, minor coarse sand, silty clay, and peat; yellow, brownish-yellow, pale brown, very pale brown, light gray; and minor pebble gravel, rare fine cobbles. Weakly stratified to laminated, sand is cross-bedded in places. Sand consists chiefly of quartz with a trace of glauconite, mica, feldspar, and chert. Feldspar and chert grains may be partially or completely weathered. Pebbles are chiefly white, gray, and yellow quartz and quartzite, with minor gray chert. Cobbles are white to gray subangular quartzite and quartz-pebble conglomerate, derived from silcrete-cemented zones in the Cohansey and Bridgeton formations on the upland east of the Cape May terraces. As much as 40 feet thick. Forms a terrace with a maximum surface elevation of about 15 feet.

Qcm2 **Qcm2f** CAPE MAY FORMATION, UNIT 2—Silty fine sand, fine-sandy silt, fine-to-medium sand, minor coarse sand, silty clay, and peat; yellow, brownish-yellow, very pale brown, light gray; and minor pebble gravel, rare cobbles. Weakly stratified to laminated, sand is cross-bedded in places (fig. 5). Sand and gravel composition as in unit 3. As much as 35 feet thick. Forms a terrace with a maximum surface elevation of about 35 feet. In the subsurface in the paleovalley at and east of Artificial Island, wells and borings, and the foundation excavation for the Salem power plant (Owens and Minard, 1979), penetrated gray to dark gray silt, clayey silt, and sandy silt, with some peat and wood, as much as 30 feet thick, beneath sandier deposits of unit 3. These fine-grained sediments are mapped separately as unit Qmc2f on section AA', and also fill the Illinoian paleovalley to the north and south of the section line, beneath Holocene marsh deposits and unit 3 sands.

Qcm1 CAPE MAY FORMATION, UNIT 1—Fine-to-medium sand, some silty fine sand, minor clayey silt; very pale brown, yellow, locally reddish-yellow and reddish-brown; and minor pebble gravel. Weakly stratified. Sand consists chiefly of quartz with a trace of glauconite and mica. Gravel consists chiefly of white and yellow quartz with minor gray chert. Locally, sand and gravel beds are hardened or cemented by iron, particularly near the base of the deposit. In places atop terrace remnants, fragments of reddish, silty-clayey paleosol material occur in the upper several feet of the deposit, reflecting the longer exposure to weathering of unit 1 compared to units 2 and 3. As much as 30 feet thick. In eroded remnants of a terrace with a maximum surface elevation of 65 feet.

Tch COHANSEY FORMATION—Fine-to-medium sand, minor coarse-to-very-coarse sand and very fine-to-fine pebbles. White, very pale brown, yellow, brownish-yellow, reddish-yellow, light gray. Unstratified to cross-bedded. Sand consists of quartz with a trace of weathered chert. Gravel consists of subangular to subrounded quartz with minor weathered chert. As much as 70 feet thick. Latest middle Miocene to late Miocene in age based on pollen (Greller and Rachele, 1983; Owens and others, 1988) and dinocysts (deVerteuil, 1997; Miller and others, 2001). Unconformably overlies the Kirkwood Formation.

Tkw KIRKWOOD FORMATION—Silty clay, clay, minor sandy clay and silty very fine sand. Gray, grayish-brown, olive-gray where unweathered; light gray, yellow, white, reddish-yellow where weathered. Locally contains shells, lignite, and subangular to subrounded fine quartz pebbles. Sand consists chiefly of quartz with minor lignite, mica, pyrite and, near the base of the formation, glauconite. Clay minerals are chiefly illite and kaolinite (Isphording and Lodding, 1969). As much as 110 feet thick. The Kirkwood sediments in the map area are within the Kirkwood 1 sequence of Sugarman and others (1993), informally termed the "lower member" of the Kirkwood Formation by Owens and others (1998), and also known as the Alloway Clay in outcrop in this area (Isphording and Lodding, 1969). The lower member is of early Miocene age (19.5-22 Ma) based on strontium stable-isotope ratios (Sugarman and others, 1993). Strontium-isotope ratios ($^{87}Sr/^{86}Sr$) of 0.708512 and 0.708456 on shells from a depth of 70-80 and 60-70 feet in auger hole Canton 2 yield ages of 19.5 and 20.3 Ma, respectively (J. Browning, written communication), confirming placement in the lower Kirkwood member. Unconformably overlies the Shark River, Manasquan, and Vincentown formations.

Tsr SHARK RIVER FORMATION—Glauconitic silty clay to silty clayey sand, olive-gray to olive-brown. As much as 100 feet thick (estimated) in map area. Early and middle Eocene in age, based on foraminifera and calcareous nannofossils (Sugarman and others, 2005). In subsurface only, covered by the Kirkwood Formation and surficial deposits. Unconformably overlies the Manasquan Formation. The unconformity is marked by a positive gamma-ray response on geophysical well logs.

Tmq MANASQUAN FORMATION—Glauconitic clay to sandy clay. Olive, green, olive-brown. As much as 50 feet thick. In subsurface only, covered by surficial deposits and younger Coastal Plain formations. Described by drillers as olive, green, or black clay. Early Eocene in age, based on foraminifera and calcareous nannofossils (Owens and others, 1998; Sugarman and others, 2005). Unconformably overlies the Vincentown Formation. The unconformity is marked by a positive gamma-ray response on geophysical well logs.

Tvt VINCENTOWN FORMATION—Glauconitic clayey quartz sand, medium-grained, and, in the upper 20 to 30 feet of the formation, silty clay. Olive, light gray, brown, dark gray. Locally calcareous and fossiliferous, with coral, echinoid, and bryozoan remains. Glauconite occurs primarily in soft grains of medium sand size. The upper, clayey part of the Vincentown in this region is informally termed the "Ancora Member" by Sugarman and others (2005). As much as 90 feet thick. In subsurface only, covered by surficial deposits and younger Coastal Plain formations. Described by drillers as coral sand, limestone, lime rock, and marl sand. Late Paleocene in age, based on foraminifera (Olsson and Wise, 1987). Unconformably overlies the Hornerstown Formation. The unconformity is marked by a sharp positive gamma-ray response on geophysical well logs.

Tht HORNERSTOWN FORMATION—Glauconite clay. Olive, green, black. Glauconite occurs primarily in soft grains of fine-to-medium sand size. Quartz, mica, feldspar, and phosphatic material also occur as minor constituents. Between 20 and 25 feet thick. In subsurface only. Described by drillers as black or green marl. Early Paleocene in age based on foraminifera (Olsson and Wise, 1987). Unconformably overlies the Navesink Formation. The unconformity is marked by a positive gamma-ray response on geophysical well logs.

Kns NAVESINK FORMATION—Glauconite clay to sandy clay. Locally fossiliferous, with calcareous shell beds. Olive, green, black. Between 20 and 25 feet thick. In subsurface only. Described by drillers as gray or green marl, rock with shells, or crystal clay. Glauconite occurs primarily in soft grains of medium-to-coarse sand size. Quartz sand, medium-grained, is the principal accessory. Late Cretaceous (Maastrichtian) in age, based on foraminifera (Olsson, 1964). Strontium stable-isotope age estimates for the Navesink range between 69 and 67 Ma (Sugarman and others, 1995). Unconformably overlies the Mount Laurel Formation. The unconformity is marked by sharply decreased gamma-ray response in the Mount Laurel on geophysical well logs.

Kml MOUNT LAUREL FORMATION—Quartz sand, slightly glauconitic (5-10% by volume), medium-grained. Olive, gray, black. Between 90 and 100 feet thick. In subsurface only. Described by drillers as salt-and-pepper sand, pepper sand, and crystal sand. Late Cretaceous (late Campanian) in age based on nannoplankton (Sugarman and others, 1995). Grades downward into the Wenonah Formation. The contact is marked by a sharp positive gamma-ray response on geophysical well logs. The Mount Laurel is the principal aquifer for domestic water supplies in the map area.

Kw WENONAH FORMATION—Quartz sand, micaceous, slightly glauconitic, fine- to very fine-grained. Gray to pale-olive. Between 50 and 60 feet thick. Late Cretaceous (late Campanian) in age based on pollen (Wolfe, 1976) and ammonite fossils (Kennedy and Cobban, 1994). Grades downward into the Marshalltown Formation.

Kmt MARSHALLTOWN FORMATION—Glauconitic clayey quartz sand, fine- to medium-grained. Olive to dark gray. Between 20 and 25 feet thick. Late Cretaceous (middle Campanian) in age, based on nannoplankton (Sugarman and others, 1995). Unconformably overlies the Englishtown Formation.

Ket ENGLISHTOWN FORMATION—Quartz sand, fine- to medium-grained, with thin beds of clay and silt. Sand is white, light gray, and gray. Silt and clay are light gray, dark gray, and black. Between 20 and 30 feet thick. Sand contains some lignite and mica and minor amounts of glauconite; silt and clay contain some mica and lignite. Late Cretaceous (early Campanian) in age, based on pollen (Wolfe, 1976). Grades downward into the Woodbury Formation. Transition to Woodbury is marked by increased gamma-ray response on geophysical well logs.

Kwb WOODBURY FORMATION—Clay with minor thin beds of very fine quartz sand. Dark gray and black. Between 20 and 30 feet thick. Clay is micaceous, with some pyrite and lignite and traces of glauconite. Late Cretaceous (early Campanian) in age based on pollen (Wolfe, 1976). Grades downward into the Merchantville Formation. Transition to Merchantville is marked by increased gamma-ray response on geophysical well logs.

Kmv MERCHANTVILLE FORMATION—Glauconitic fine-sandy silty clay to clayey silt. Olive, dark gray, black. Between 20 and 30 feet thick. Glauconite occurs primarily as soft grains of fine-to-medium sand size. Late Cretaceous (early Campanian) in age based on nannoplankton (Sugarman and others, 2005). Unconformably overlies the Magothy Formation. The unconformity is marked by sharply decreased gamma-ray response in the Magothy on geophysical well logs. The lowermost 5 to 10 feet of the Merchantville may include the Cheesequake Formation, which is identified in core holes at Fort Mott and Millville (Sugarman and others, 2004, 2005) but, as a thin silty unit, cannot be distinguished from the Merchantville based on well data in the map area.

Kmg MAGOTHY FORMATION—Quartz sand, fine- to very coarse-grained, and clay and silt, thin-bedded. Sand is white, light gray, gray. Clay and silt are white, yellow, brown, rarely reddish-yellow where weathered, gray to black where unweathered. Gray colors are dominant. Sand includes some lignite, pyrite, and minor feldspar and mica. Silt and clay beds include abundant mica and lignite. Between 30 and 50 feet thick. Late Cretaceous (Turonian-Coniacian) in age based on pollen (Christopher, 1979, 1982). In the Fort Mott corehole (about 10 miles northwest of Canton), pollen from the Magothy Formation at a depth of 137 feet indicates a late Turonian age (Sugarman and others, 2004), as does pollen from the Magothy at a depth of 1249-1292 feet in the Millville core hole (about 20 miles east of Canton) (Sugarman and others, 2005). Unconformably overlies the Potomac Formation.

MAP SYMBOLS

Contact of surficial deposits—Solid where well-defined by landforms; dashed where approximately located; short-dashed where feather-edged or gradational; dotted where covered by water.

Contact of Coastal Plain bedrock formations—Approximately located.

Tkw/Tmq **Covered contact**—Contact of Cohansey, Kirkwood, Shark River, Manasquan, and Vincentown formations beneath surficial deposits. Approximately located.

Tmq/Tsr **Subcrop contact**—Contact of Shark River, Manasquan, and Vincentown formations beneath Kirkwood Formation. Approximately located.

Qm7/Qal ● **Material observed in exposure, excavation, or penetrated in 5-foot hand-auger hole**—Number, if present, indicates thickness of surficial material, in feet. No number indicates map unit is thicker than 5 feet. Where more than one unit was penetrated, the thickness (in feet) of the upper unit is indicated next to its symbol and the lower unit is indicated following the slash.

figure 5 ● **Photograph location**

Qe4 ● **Windblown or wetland deposits overlying map unit**—Windblown very fine sand and silt (indicated by symbol "Qe") or peat and organic clay (Qs) observed in hand-auger hole or exposure. Number following symbol is thickness of deposit, in feet. Windblown deposits are discontinuous and lack distinctive morphology and so are not mapped separately from underlying surficial deposit. Wetland deposits fill some shallow basins.

Excavation perimeter—Marks edges of sand pits. Topography within these areas may differ from that on the base map.

Dikes and ditch-spoil banks—Visible on 1979 stereo aerial photographs.

✕ **Sand and gravel pit**—Inactive in 2011.

Shallow topographic basin—Line at rim, pattern in basin. Marks shallow surface depressions generally less than 5 feet deep, as seen on stereo aerial photographs taken in 1979 and color infrared planimetric aerial photographs taken in 2007. They are most abundant on flat surfaces where the water table is at shallow depth. They do not occur on lower terraces or modern flood plains and tidal marshes. A few basins are visible beneath thin salt marsh deposits; these are mapped within unit Qm although they are developed on the underlying Cape May 3. Basins that are perennially wet contain peat and organic silt and clay as much as 6 feet thick. Basins were likely formed by melting of permafrost between 18,000 and 15,000 years ago; some may have been formed by wind erosion or groundwater processes.

Seepage scarp—Line at foot of scarp, at position of groundwater emergence. Most of these features are inactive or rarely active today. Active seepage is common along the upland margins of flood plains and marshes.

-50 **Elevation of base of surficial deposits**—Contour interval 25 feet. Approximately located, based on well and boring data. Shown only where thickness of surficial deposits exceeds 20 feet. Shows topography of composite Quaternary erosional surface at top of Coastal Plain bedrock formations.

● 34-3784 28 Qcm1 35 Tkw **Well or boring, location accurate to within 200 feet**—Number followed by map-unit symbol is depth, in feet below land surface, of base of unit as inferred from driller's log. Final number is total depth of well rather than base of unit. Depths may deviate from those on map and sections owing to variations in drillers' descriptions. Units joined with a "+" cannot be separately identified in the driller's description. Map units are not listed for wells shown on sections. Identifiers of the form 33-xxx are U. S. Geological Survey Ground Water Site Inventory numbers. Identifiers of the form 34-xxxx are N. J. Department of Environmental Protection well permit numbers. Identifiers of the form CANx are auger borings drilled by D. S. Powars and J. P. Owens of the U. S. Geological Survey. Logs for borings B36 and CAN3 are from Newell and others (1995). Auger borings Canton 1, Canton 2, and Canton 3 were drilled for this study. Logs for these borings are provided in table 1.

⊙ 34-1103 11 Qcm1 85 Tkw 138 Tkw+Tsr **Well or boring, location accurate to within 500 feet**—Identifiers and symbols as above.

Geophysical well log—On sections. Gamma-ray log shown by red line, intensity increases to right. Resistivity log shown by blue line, resistance increases to right. For well 33-33, blue lines show resistivity on right-hand curve and spontaneous potential on left-hand curve, with voltage increasing to the right.

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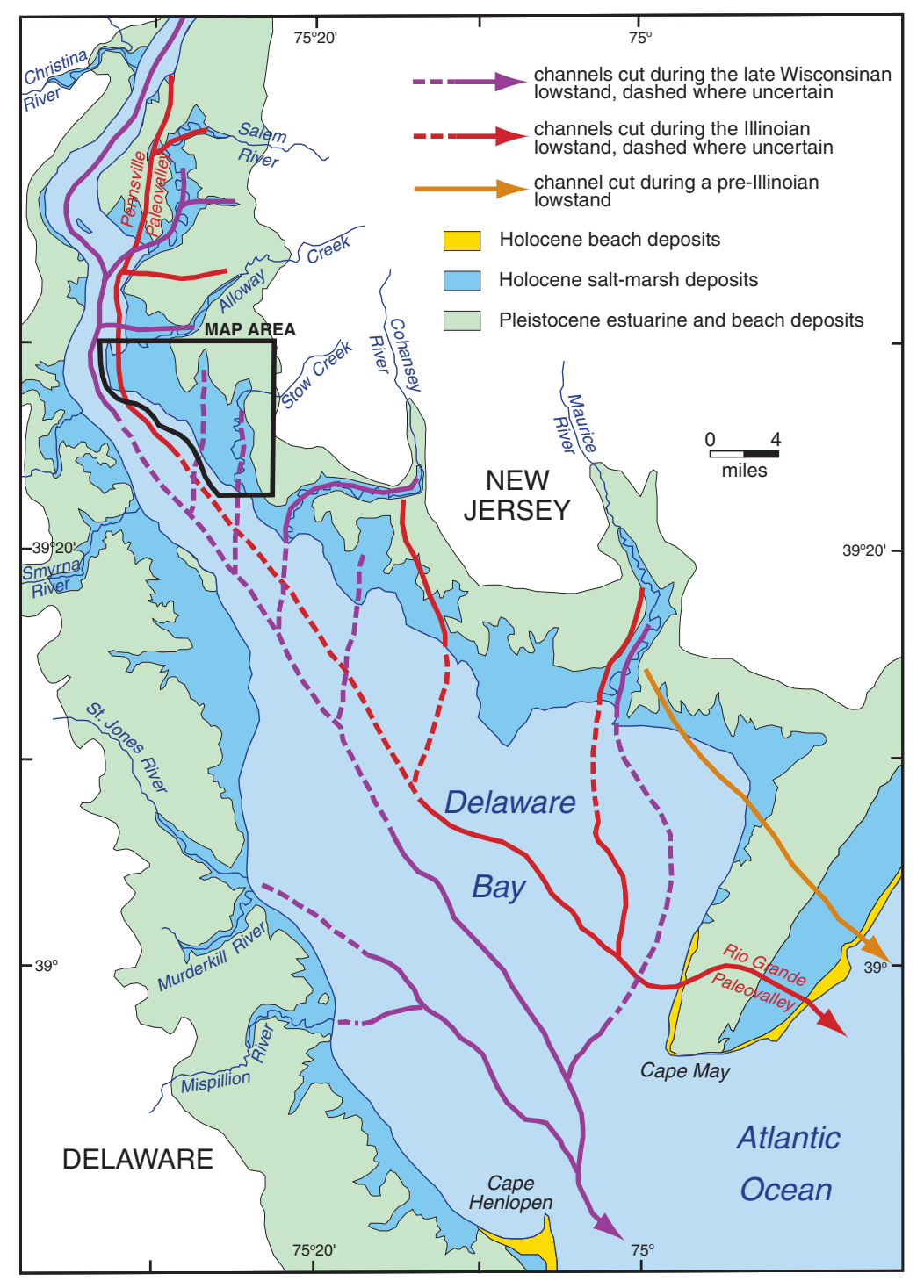
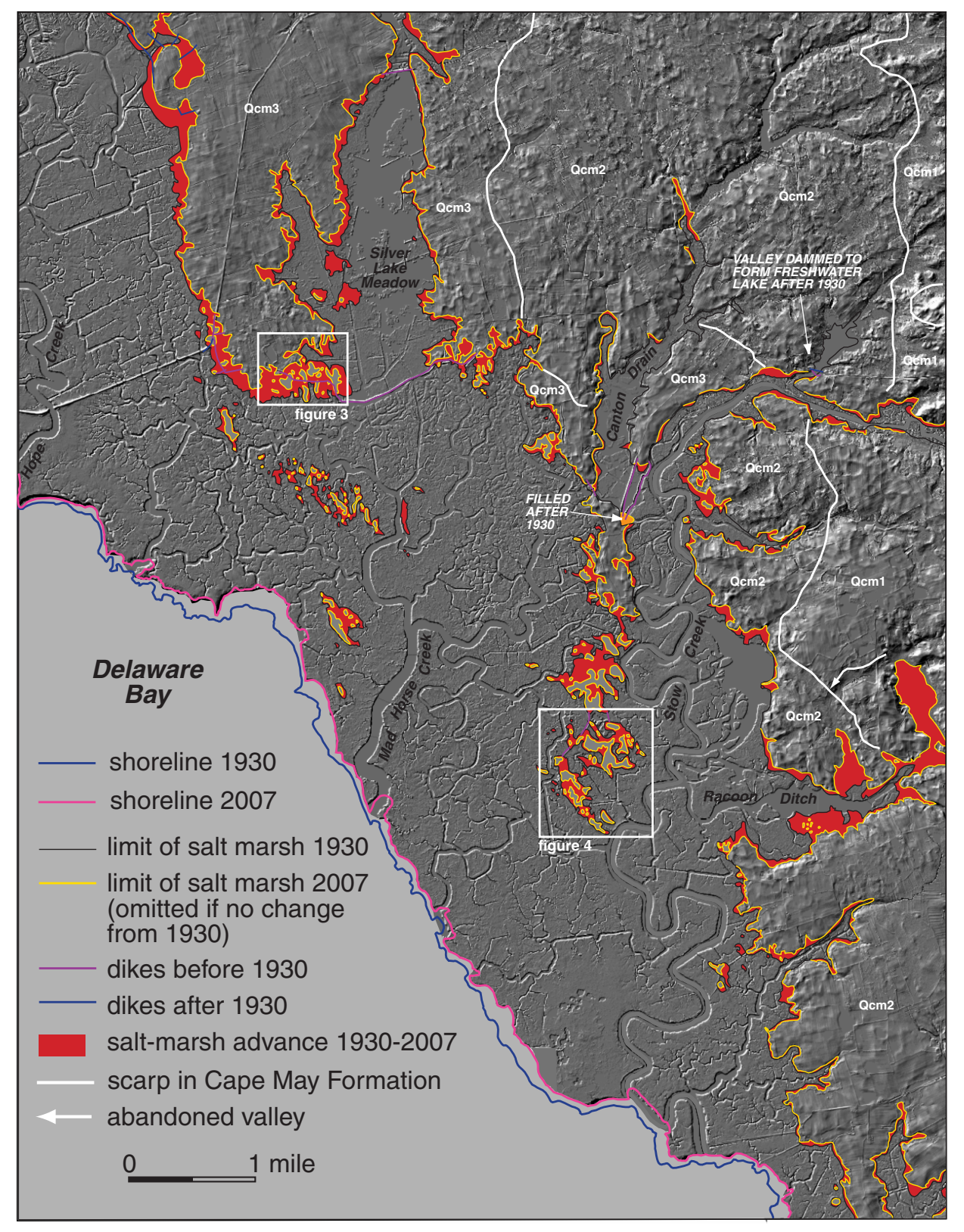


Figure 1. Fluvial channels and extent of Pleistocene and Holocene estuarine deposits in the Delaware Bay area. Pleistocene deposits include the Cape May Formation in New Jersey (Newell and others, 2000) and the Delaware Bay Group in Delaware (Groot and Jordan, 1999). Illinoian channels (red) are filled with Sangamonian estuarine deposits (Cape May Formation, unit 2). Late Wisconsinan channels (purple) are filled with Holocene estuarine deposits. Pre-Illinoian channel of the Maurice River (orange) is filled with pre-Sangamonian and Sangamonian estuarine deposits (Cape May Formation, units 1 and 2). Channel locations from Gill (1962), Knebel and Circe (1988), Newell and others (1995), Stanford (2006, 2009).

Table 1.—Lithologic logs of test borings. Gamma-ray logs shown on sections AA' and BB'.

New Jersey Department of Environmental Protection Permit Number and Identifier	Lithologic Log	
	Depth (feet below land surface)	Description (map unit assignment in parentheses)
E201012369 Canton 1	0-25	pale brown to very pale brown fine-to-medium quartz sand (Qcm3)
	25-35	light brownish-gray to grayish-brown fine-to-medium quartz sand, a few very fine quartz pebbles from 30-35 feet (Qcm3)
	35-57	dark grayish-brown to dark olive-gray silty clay (Tkw)
	57-75	dark grayish-brown to dark olive-gray silty clay with some to many coarse quartz sand grains and some subangular to subrounded very fine-to-fine quartz pebbles (Tkw)
	75-103	olive-gray to dark green, clayey, glauconitic fine-to-medium quartz sand (Tsr over Tmq)
E201012377 Canton 2	0-34	very pale brown, brownish-yellow, yellowish-brown, medium-to-coarse quartz sand, minor fine quartz sand, some subangular to subrounded very fine-to-fine quartz pebbles (Qcm3)
	34-103	dark grayish-brown to dark olive-gray silty clay with a few embedded subangular to subrounded very fine-to-fine quartz pebbles and fine shell fragments, trace of very fine mica, becoming sandy below 85 feet (Tkw)
E201012379 Canton 3	0-20	yellow to brownish-yellow fine-to-coarse quartz sand, trace feldspar, some subrounded quartz pebbles; bed of medium-to-coarse sand with many quartz pebbles from 10-15 (Qcm1)
	20-80	gray clay with a few subangular fine pebbles of gray clay (rip-ups) and a trace of subangular to subrounded fine quartz pebbles (Tkw)
	80-104	olive-gray to dark olive-gray clay to silty clay with some fine-to-very fine mica and a trace to few subangular fine pebbles of gray clay (rip-ups) and a trace of subangular to subrounded fine quartz pebbles (Tkw)



Topographic image from U. S. Geological Survey LiDAR digital data with 2m horizontal resolution.

Figure 2. Shoreline and salt-marsh change, 1930-2007, based on airphoto analysis, and extent of Cape May Formation marine terraces in the Canton quadrangle. Labels on Cape May teraces are: Qcm1=Cape May Formation, unit 1, Qcm2=Cape May Formation, unit 2, Qcm3=Cape May Formation, unit 3. The abandoned valley just north of Racoon Ditch was cut during and before deposition of the Cape May Formation, unit 2. It was abandoned due to stream capture during Wisconsinan incision.

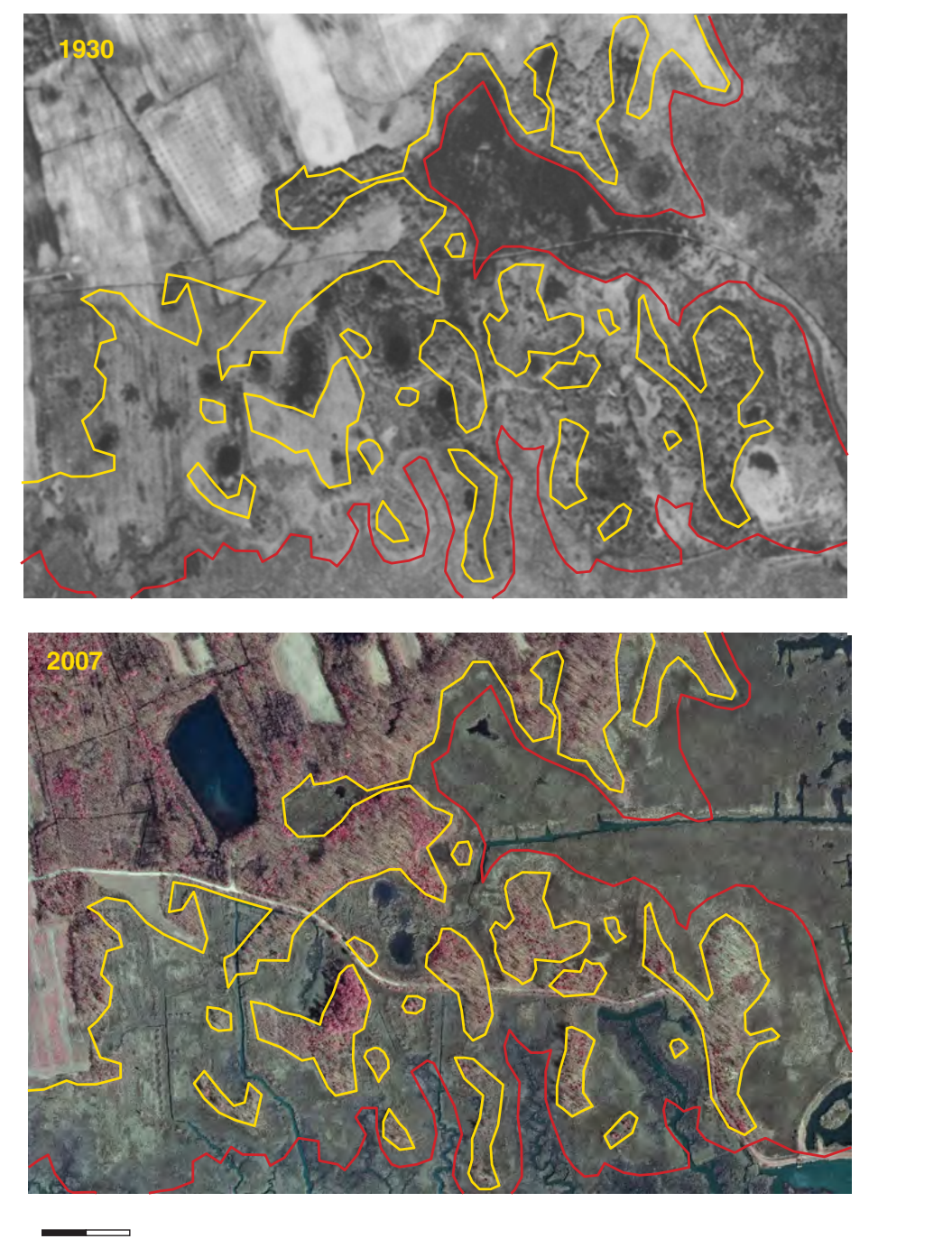


Figure 3. Limit of salt marsh in 1930 (red lines, top photo) and in 2007 (yellow lines, bottom photo). Area of photos shown in figure 2. Imagery from N. J. Department of Environmental Protection, Office of Information Resources Management, Bureau of Geographic Information Systems (1930 imagery) and N. J. Office of Information Technology, Office of Geographic Information Systems (2007 imagery).

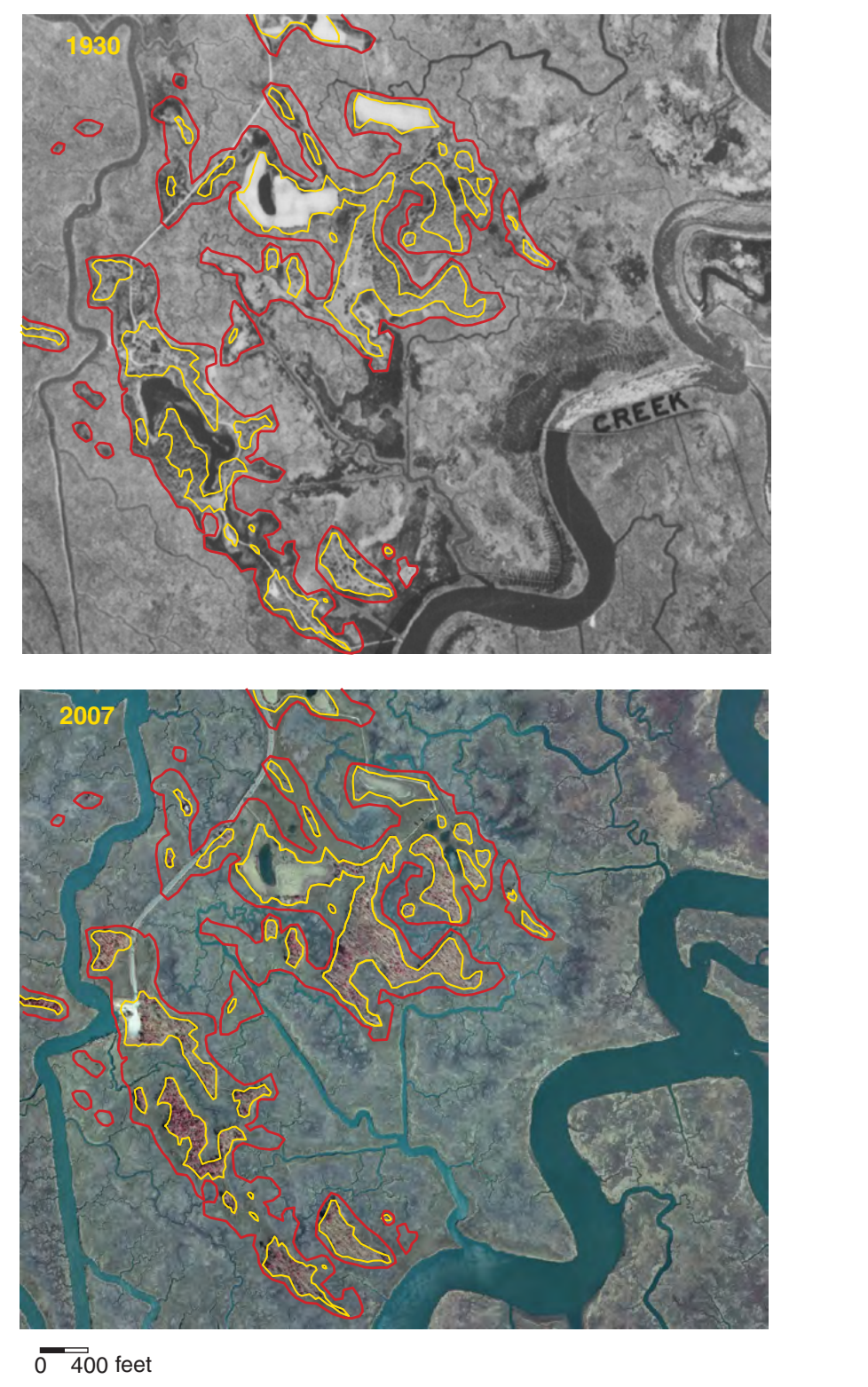
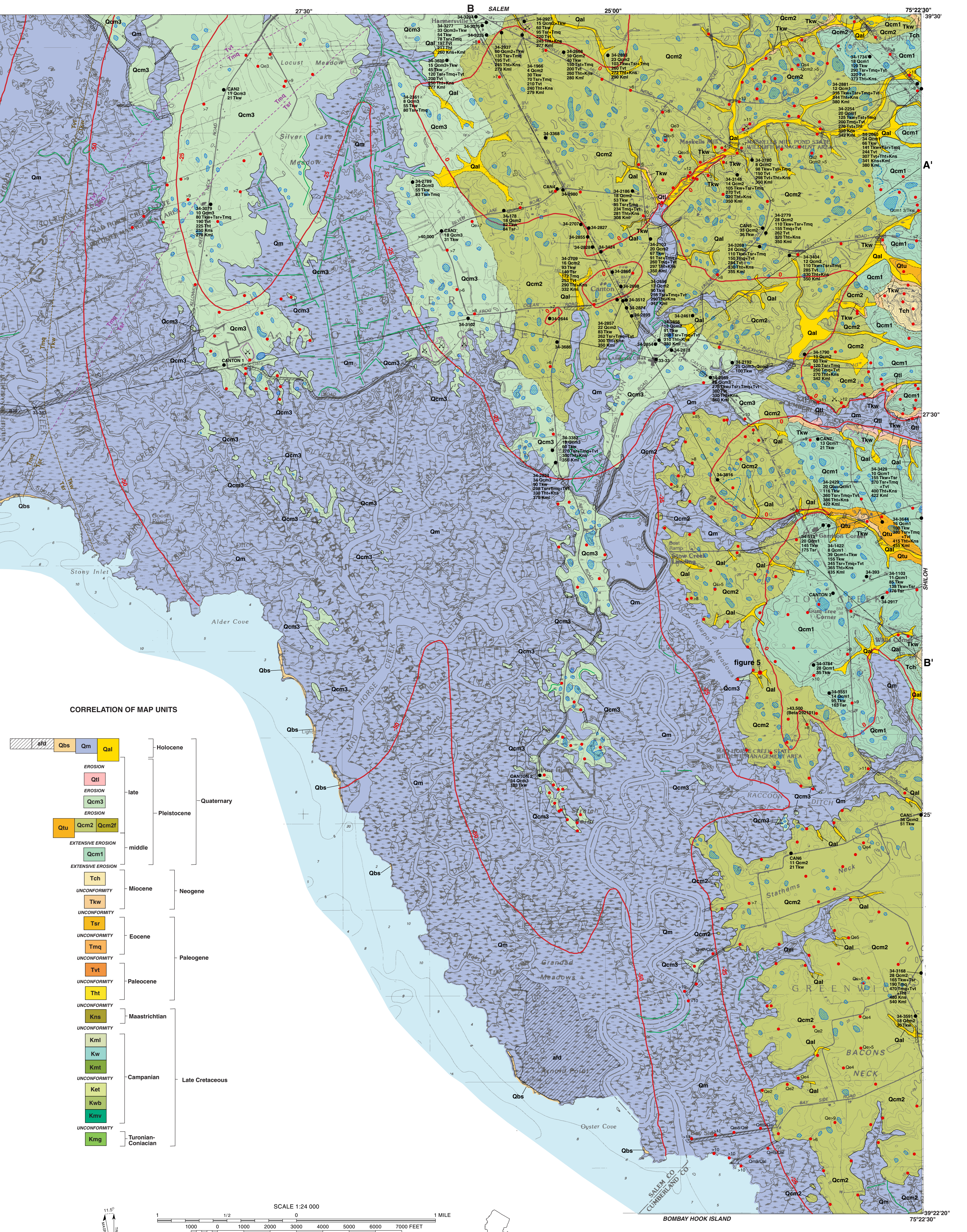


Figure 4. Limit of salt marsh in 1930 (red lines, top photo) and in 2007 (yellow lines, bottom photo). Area of photos shown in figure 2. Imagery from N. J. Department of Environmental Protection, Office of Information Resources Management, Bureau of Geographic Information Systems (1930 imagery) and N. J. Office of Information Technology, Office of Geographic Information Systems (2007 imagery).

Figure 5. Interbedded clay (white layers) and fine-to-medium sand (gray layers) in the Cape May Formation, unit 2. Some clay lamina drape cross-beds in the sand layers. The interbedding and draping are indicative of intertidal deposition. Location shown on map and inset.



CORRELATION OF MAP UNITS

Map unit		Epoch or age	Period
▨ afd Qbs Qm Qal		Holocene	Quaternary
EROSION	late	Pleistocene	
Qtl			
EROSION			
Qcm3			
EROSION			
Qtu Qcm2 Qcm2f			
EXTENSIVE EROSION	middle		
Qcm1			
EXTENSIVE EROSION			
Tch		Miocene	Neogene
UNCONFORMITY			
Tkw			
UNCONFORMITY			
Tsr		Eocene	Paleogene
UNCONFORMITY			
Tmq			
UNCONFORMITY			
Tvt		Paleocene	
UNCONFORMITY			
Tht			
UNCONFORMITY			
Kns		Maastrichtian	Late Cretaceous
UNCONFORMITY			
Kml Kw Kmt		Campanian	
UNCONFORMITY			
Ket Kwb Kmv			
UNCONFORMITY			
Kmg		Turonian-Coniacian	

11.5°
MAGNETIC NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 1993

SCALE 1:24 000
1 1/2 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 5 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geology mapped 2010-2011
Drilling by G. Steidl and J. Curran
Cartography by S. Stanford

Base from U. S. Geological Survey Canton (1993) and Taylors Bridge (1999) quadrangles

Corner ticks are on North American Datum of 1983

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GEOLOGY OF THE CANTON AND TAYLORS BRIDGE QUADRANGLES
SALEM AND CUMBERLAND COUNTIES, NEW JERSEY

by
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2011