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INTRODUCTION

The Jenkins quadrangle is in the Pine Barrens region of the New Jersey Coastal Plain, in the southeastern part of the state. Outcropping and shallow subsurface geologic materials in the map area include surficial deposits of late Miocene to Holocene age that overlie the Cohansey and Kirkwood formations, which are marginal marine deposits of Miocene age. The surficial deposits include estuarine, river, hillslope, wetland, and windblown sediments. The Kirkwood Formation was deposited in marine delta and shallow shelf settings in the early and middle Miocene. The Cohansey Formation was deposited in coastal settings in the middle and late Miocene, when sea level was at times more than 200 feet higher than at present in this region. As sea level lowered after deposition of the Cohansey, rivers flowing on the emerging Coastal Plain deposited fluvial gravel. Continued lowering of sea level caused streams to erode into the gravel and the underlying Cohansey Formation. During the latest Miocene, Pliocene, and Pleistocene, about 8 million years ago (8 Ma, Ma = million years) to 11,000 years ago (11 ka, ka = thousand years), stream and hillslope sediments were deposited in several stages as valleys were progressively deepened by stream incision, and widened by seepage erosion, as sea level lowered. During at least two interglacial periods in the middle and late Pleistocene, when sea level was higher than at present, estuarine sediments were laid down in terraces in the valleys at elevations below 60 feet. Most recently, alluvial and wetland deposits were laid down during the Holocene (11 ka to present).

A brief summary of the stratigraphy and depositional settings of the Kirkwood and Cohansey formations, and of the geomorphic history of the map area as recorded by surficial deposits and landforms, is provided below. The age of the deposits and episodes of valley erosion are shown on the correlation chart. The formations penetrated in wells and borings, as interpreted from drillers' lithologic logs and downhole geophysical logs, are listed in table 1.

Cross sections AA' and BB' show materials to a depth of 350 to 400 feet, which includes the Cohansey Formation and most of the Kirkwood Formation. Water wells in the quadrangle, which include about 50 domestic wells and a few agricultural irrigation wells, tap sands in the Cohansey Formation or upper Kirkwood Formation at depths between 50 and 195 feet. A thick aquifer sand lower in the Kirkwood Formation (unit 5 on sections AA', BB') is also tapped by at least one well (well 33) in the quadrangle. This sand, where confined in downdip areas, is known as the "Atlantic City 800-foot sand" aquifer (Zapecza, 1989). A well drilled in 1866 at Harrisville (well 27) flowed with a static water level at 8 feet above ground level when this sand was encountered between 196 and 231 feet in depth, indicating that the sand is confined there (Woolman, 1893, p. 288). Overlying fine-grained beds of units 2 and 4 in the Kirkwood Formation act as the confining layers for the unit 5 aquifer sand in the southern and eastern parts of the quadrangle, but pinch out or are eroded away in the northern half of the quadrangle (section AA'), where unit 5 directly underlies the Cohansey Formation and is not confined. Two gas-storage exploration test holes in the quadrangle (wells 28 and 29, Transcontinental Gas Pipeline Corporation [Transco] wells 15 and 16) were drilled to total depths of 1,701 and 1,658 feet, respectively. The formations below the Kirkwood penetrated in these test holes are listed in Kasabach and Scudder (1961) and a lithologic log for well 28 is provided in Johnson (1961).

KIRKWOOD FORMATION

The Kirkwood Formation consists of four sequences of back-bay, marine-delta, and shallow-shelf sediments as sampled in the Bass River corehole, which is six miles southeast of Harrisville in the New Gretna quadrangle (Miller and others, 1998). These sequences can be traced using geophysical well logs through southern Ocean County and southeastern Burlington County to the east of the quadrangle (Stanford, 2013, 2014, 2017; Stanford and Sugarman, 2017). These sequences are composed of six lithologic units which were identified and numbered in the Island Beach corehole, located about 25 miles northeast of Harrisville (Miller and others, 1994). In the Bass River corehole, the basal unit, unit 6, is prodelta clay overlain by delta-front sand (unit 5), in turn overlain by thin prodelta clay (unit 4) and thin nearshore sand (unit 3). Unit 3 is overlain by thick inner-shelf to prodelta clay (unit 2), which is overlain by interbedded inner-shelf, nearshore, and back-bay sand and clay (unit 1). Unit 1 pinches out east of the Jenkins quadrangle (Stanford, 2017), but the other units are traceable updip into this quadrangle.

Units 6 and 5 are in the lower member of Owens and others (1998), also known as the Brigantine Member (Miller and others, 1997), or the Kirkwood 1a sequence (Sugarman and others, 1993). Shells at the base of unit 6 in the Bass River corehole yield strontium stable-isotope ages of 20.8, 20.9, 21.1, and 21.4 Ma (Miller and others, 1998), indicating an early Miocene age for this sequence. Unit 4 and most of unit 3 are in the Shiloh Marl member of Owens and others (1998), or the Kirkwood 1b sequence (Sugarman and others, 1993). The upper part of unit 3, unit 2, and unit 1 are in the Wildwood Member of Owens and others (1998), or the Kirkwood 2 sequence (Sugarman and others, 1993). Diatoms in this sequence indicate an early to middle? Miocene age (Miller and others, 1998).

Gamma-ray logs of wells 1, 26, and 32, and a lithologic log of well 27 (sections AA', BB'), allow mapping of these units into the map area (shown by tielines on sections). Units 2, 3, and 4 thin and pinch-out, or are eroded away, from southeast to northwest (section AA'). Unit 5 also thins or is eroded updip to the northwest, where it is directly overlain by the Cohansey Formation (section AA'). This pattern suggests that the Kirkwood members either transition updip to coastal sediments in the lower part of the Cohansey Formation or were eroded before deposition of the Cohansey.

COHANSEY FORMATION

The Cohansey Formation consists of stacked successions composed of beach and shoreface sand (Tchs, sand facies) overlain by interbedded sand and clay (Tchc, clay-sand facies) deposited in tidal flats, bays, and coastal swamps (Carter, 1972, 1978). Pollen and dinoflagellates recovered from peat beds in the Cohansey Formation at Legler, in northern Ocean County, are indicative of a coastal swamp-tidal marsh environment (Rachele, 1976). The Legler pollen (Greller and Rachele, 1983), pollen recovered from a corehole near Mays Landing, New Jersey (Owens and others, 1988), and dinocysts obtained from coreholes in Cape May County, New Jersey (deVerteuil, 1997; Miller and others, 2001), indicate a middle to early late Miocene age for the Cohansey. The Cohansey Formation generally lacks datable marine fossils, particularly in updip areas where it has been weathered. As discussed above, lower parts of the Cohansey Formation in updip settings like the map area may be age-equivalent to the upper Kirkwood downdip (for example, Kirkwood sequence 2, about 17-15 Ma, and sequence 3, 12-14 Ma, Sugarman and others, 1993) and may represent the coastal facies of the Kirkwood shallow-shelf deposits.

In the map area, clays in the Cohansey Formation are in beds or laminas generally less than 6 inches thick, but as much as 5 feet thick, and are interbedded with sand. In outcrop, they commonly are oxidized and multicolored but, in the subsurface, dark organic clays are reported in a few drillers' logs (abbreviated as "Tchco" in table 1). Clay-sand facies strata are generally less than 25 feet thick. In outcrop, two clay beds can be traced in the northwestern half of the quadrangle. The upper bed ("1" on fig. 1) is at an elevation of between 65-80 feet. It occurs on Jemima Mount, Stormy Hill, and the uplands west of Mount and north of Washington. A lower bed ("2" on fig. 1) is at an elevation of about 40-50 feet and is traceable in outcrop in the West Branch and Tulpehocken Creek valleys north of Godfreys Bridge, but pinches out, or is eroded away, south of there. The clay bed around Tylertown at an elevation of about 50 feet may be an outlier of this bed. Discontinuous clay beds at similar elevation to the east in the Oswego Lake quadrangle (Stanford, 2017) and a more continuous bed to the north beneath the Tulpehocken Creek valley in the Chatsworth quadrangle (Stanford, 2012) may be the same stratum. Gamma-ray and lithologic logs (sections AA', BB') show additional clay beds in the subsurface. Two of these, one at about sea level and one at an elevation of about -40 feet, seem to be continuous for more than 6-8 miles from southwest to northeast but are less than 3-5 miles in extent from northwest to southeast, perhaps approximating the dimensions of a back-barrier bay behind a northeast-southwest trending shoreline.

The laminated bedding and thin but areally extensive geometry of the clayey beds are indicative of bay or estuarine intertidal settings. Alluvial clays generally are thicker and more areally restricted because they are deposited in floodplains and abandoned river channels. The repetitive stacking of bay clays and beach sand (chiefly tidal-delta and shoreface deposits) indicates that the Cohansey was deposited during several rises and falls of sea level during a period of overall rising sea level.

SURFICIAL DEPOSITS AND GEOMORPHIC HISTORY

Sea level in the New Jersey region began a long-term decline following deposition of the Cohansey Formation. As sea level lowered, the inner continental shelf emerged as a coastal plain. River drainage was established on this plain. The Beacon Hill Gravel, which caps the highest elevations in the Coastal Plain, is the earliest record of this drainage. It occurs at elevations above 180 feet to the north and northeast of the map area in the Chatsworth and Woodmansie quadrangles, and possibly above 150 feet east of the map area in the Oswego Lake quadrangle. The Beacon Hill most likely covered the entire Jenkins quadrangle, but has been eroded away. The highest elevation in the quadrangle is about 100 feet on Jemima Mount, which is at least 50 feet below the presumed base of the Beacon Hill in this area. The Beacon Hill is quartz and chert gravel deposited by rivers draining southward from the Valley and Ridge province in northwestern New Jersey and southern New York (Stanford, 2009). In the Beacon Hill, and in younger gravels reworked from the Beacon Hill, chert pebbles containing coral, brachiopod, and pelecypod fossils of Devonian age indicate that some of these rivers drained from north of what is now Kittatinny and Shawangunk Mountains, where chert-bearing Devonian rocks crop out.

Continued decline of sea level through the late Miocene and early Pliocene (approximately 8 to 3 Ma) caused the regional river to erode into the Beacon Hill plain. As it did, the river shifted to the west of the map area into what is now the Delaware River basin. The map area became an upland from which local streams drained southward to the Atlantic Ocean. These local streams eroded shallow valleys into the Beacon Hill Gravel. Groundwater seepage, slope erosion, and channel erosion reworked the gravel and deposited it in floodplains, channels, and pediments, between 50 and 80 feet below the level of the former Beacon Hill plain. These deposits are mapped as upland gravel, high phase (unit Tg). Today, owing to topographic inversion, they cap a few isolated hilltops and uplands above an elevation of between 70 and 100 feet (fig. 1). The small surviving remnants of this gravel are insufficient to infer stream drainage during its deposition but the general decline in elevation from north to south suggests southerly flow, as do more extensive upland gravels to the west in the Atsion quadrangle.

A renewed period of lowering sea level in the late Pliocene and early Pleistocene (approximately 3 Ma to 800 ka) led to another period of valley incision. Groundwater seepage and channel and slope erosion reworked the upland gravel, high phase and deposited the upland gravel, lower phase (unit TQg) in shallow valleys 15 to 30 feet below the higher gravels. Today these deposits cap uplands between 60 and 80 feet in elevation. Stream drainage during deposition of these sediments, inferred from their elevation and from cross bedding exposed in a pit near Jenkins, is shown by red arrows on figure 1. Flow was predominantly to the south, as it was during the deposition of the older higher gravels.

Continuing incision in the middle and late Pleistocene (about 800 to 11 ka) formed the modern valley network. Fluvial sediments in modern valleys include upper and lower terrace deposits (units Qtuo, Qtu, and Qtl), inactive floodplain deposits in dry valleys (unit Qald), and active floodplain and wetland (Qals) deposits in valley bottoms. Like the upland gravels, the terrace and floodplain deposits represent erosion, transport, and redeposition of sand and gravel reworked from older surficial deposits and the Cohansey Formation by streams, groundwater seepage, and slope processes. Wetland deposits are formed by accumulation of organic matter in swamps and bogs.

Upper terrace deposits form terraces and pediments 10 to 25 feet above modern floodplains. They also occur as thin fills in some headwater valleys that do not contain active streams. They were laid down chiefly during periods of cold climate in the middle Pleistocene. During cold periods, permafrost impeded the infiltration of rainfall and snowmelt and this, in turn, accelerated groundwater seepage, runoff, and slope erosion, increasing the amount of sediment entering valleys, leading to terrace deposition. Some of the deposits may have been laid down during periods of temperate climate when sea level was high, because at their downstream limit some of the upper terraces grade to the Cape May 2 marine terrace (see below). Also, in the Wading River valley at and downstream of Harrisville, the upper terraces are inset into the Cape May 2 terrace. These topographic relationships indicate that some of the upper terrace deposits aggraded both during and after the Cape May 2 highstand. Near Maxwell, a slightly higher phase of the upper terrace (Qtuo) has a top surface about 10 feet above the adjacent main upper terrace. This location is at the inland limit of the Cape May 2 and the higher phase may have aggraded during the maximum Cape May 2 highstand. Later, it was incised, along with the Cape May 2, to form the main upper terrace as sea level lowered. The upper terraces are inset into the Cape May 1 estuarine deposits, indicating that they are younger than the Cape May 1 highstand (see below).

Lower terrace deposits (unit Qtl) form terraces with surfaces between 2 and 15 feet above modern valley bottoms. They are inset into the upper terrace and the Cape May 2 terrace and were laid down in shallow valleys and lowlands that were cut after deposition of the Cape May 2. This cutting occurred during a period of lower-than-present sea level and colder-than-present climate known as the Wisconsinan stage, between about 80 ka and 11 ka. The approximate extent of Wisconsinan valley erosion is shown by black lines on figure 1.

Lower terraces are most prominent in the Tulpehocken Creek, Wading River, West Branch, Little Hauken Run, and Oswego River valleys. In many places the lower terrace is scribed by a network of shallow braided channels (fig. 2, also shown as lines on map). On wet areas of the lower terrace, these channels are wetter than the adjacent unchanneled terrace and are marked by grass and shrub glades, distinct from pine forest on the slightly higher terrace. In these areas the channels were mapped from infrared aerial imagery. In some areas where cranberry bogs obscure natural topography, the channels were mapped from historic aerial photographs (1930, 1940, 1951) taken before bog construction. On drier areas of the lower terrace the channels, which are up to 5 feet deep, were mapped from LiDAR imagery (fig. 2). The braided channels formed when permafrost impeded infiltration and thus increased seepage and runoff. The increased runoff washed sand from uplands into valleys, choking streams with sediment and causing channels to aggrade and split to form a braided pattern. The braided channels on the lower terrace contrast with the meandering, generally single, channel of the modern streams, which do not receive sediment from upland runoff (fig. 2).

The lower terrace deposits were probably laid down chiefly during or slightly after the last period of cold climate between 25 and 15 ka. Near Manahawkin in Ocean County, northeast of the Jenkins quadrangle, sand and gravel of the lower terrace overlie an organic silt dated to 34,890±960 radiocarbon years (39,385 mean age, 38,410-40,550 one sigma error, in calibrated years, all calibrations are determined using radiocarbon calibration program CALIB 7.10 and Reimer and others, 2013) (GX-16789-AMS, Newell and others, 1995). In the Chatsworth quadrangle, north of the Jenkins quadrangle, organic sediment within lower terrace sand dated to 20,350±80 radiocarbon years (24,434 mean age, 24,450-24,150 one sigma error, in calibrated years) (Beta 309764, Stanford, 2012). These dates indicate deposition of the terrace deposits in the late Wisconsinan. Dry-valley alluvium (unit Qald), which grades downvalley to lower terraces in places, was also likely laid down during this time, when permafrost caused runoff in headwater valleys that are dry today. Deposition on the lowest parts of the lower terrace, generally those subterraces within the limits of the meander scars etched into the main lower terrace (fig. 2) that are less than 5 feet above the present floodplain, continued through the Holocene, as described below.

Another feature related to permafrost are thermokarst basins. These are shallow closed basins, circular to oval in plan, and less than 5 feet in depth (fig. 3, also symboled on map). They are most common on upper terraces and the Cape May 1 and 2 terraces but also occur in a few places on the lower terrace and the surface of the upland gravel, lower phase deposits. Most formed when ice-rich lenses at shallow depth in the frozen sediments melted, leaving small depressions (Wolfe, 1953; French and others, 2005). Some basins are bordered by dunes or occur within eolian deposits. These basins ("blow-out basins" on fig. 3) were likely formed, or enlarged from an initial thermokarst basin, by wind erosion (French and Demitroff, 2001).

As permafrost melted around 15 ka, sand was no longer washed into valleys and streams began to cut down into the lower terrace deposits. The intricate pattern of meander scars, abandoned oxbow channels, and terrace scarps cut into the lower terrace during this incision are particularly well developed along the West Branch, Wading River, and Oswego River, which have the largest discharges in the map area and where erosion is therefore more vigorous (fig. 2). Most of the incision was completed by around 12 ka, based on radiocarbon dates of 10,485±240 radiocarbon years (12,280 mean age, 12,035-12,682 one sigma error, in calibrated years) at a depth of 7-8 feet (Buell, 1970) and 8,050±40 radiocarbon years (GX-26535) (8,952 mean age, 8,790-9,023 one sigma error, in calibrated years) at a depth of 7 feet (Stanford, 2000) on basal peat at two spots in the Oswego River floodplain upstream of Martha (fig. 1, also plotted on map).

Modern wetland and alluvial deposits (unit Qals) were laid down in floodplains within the past 12 ka. These deposits consist of sand and gravel deposited in stream channels and peat formed by the accumulation of plant matter in wetlands on valley bottoms away from stream channels. Peat, which is as much as 8 feet thick, generally overlies channel deposits, although peat is interbedded with sand along main channels in a few places where sand was washed out of channels during floods. In a few places along the Wading River, West Branch, and Oswego River, the floodplain along the main channel is slightly inset (less than 2 feet) into backswamp and oxbow swamp peats away from the main channel, suggesting some continuing incision of the channels in the Holocene.

Holocene incision is also indicated by a radiocarbon date of 2,800±30 radiocarbon years (Beta 556185) (2,900 mean age, 2,860-2,940 one sigma error, in calibrated years) on wood from a peat bed under 4 feet of sand and gravel on a low terrace along the West Branch near the junction with Hospitality Brook (fig. 1, also plotted on map). This terrace is about 3 feet above the present channel and active floodplain in a constricted segment of the floodplain. The date indicates that the sand and gravel over the peat was deposited, and then incised to form the present low terrace, within the past 2,900 years.

Eolian deposits (Qe) are common in the quadrangle. They include dunes, either as narrow single ridges like those north and east of Crowleytown, or as larger deposits consisting of numerous contiguous dunes. The long axes of the dunes are generally oriented east-west, northeast-southwest, or north-south. They are as much as a half-mile long and 25 feet tall, although many are only 3-5 feet tall. Some dune ridges are curved or crescentic, with the crescents opening to the west or northwest (fig. 3). These orientations suggest that the dunes were formed by winds blowing from the west and northwest. Other areas of eolian sand lack distinct dune ridges and instead show subdued swell-and-swale topography (fig. 4). The eolian deposits occur chiefly on the Cape May 1 and 2 and upper terraces. A few are on the upland gravel, lower phase and a few also occur on the lower terrace. This distribution shows that the eolian deposits largely postdate the Cape May 2 and the upper terrace deposits and, in places are the same age as, or slightly younger than, the lower terrace deposits. These relations indicate that deposition was mostly during the Wisconsinan stage (80-11 ka). Deposits on older surfaces, such as the Cape May 1 terrace or upland gravels, may be older.

During at least two periods of higher-than-present sea level in the middle and late Pleistocene, beach and estuarine deposits were laid down in lowland areas of the quadrangle (fig. 1). These marine deposits are grouped into the Cape May Formation. The Cape May includes an older, eroded terrace (Cape May Formation, unit 1, Qcm1) with a maximum surface elevation of 60-65 feet, and a younger, less eroded terrace with a maximum surface elevation of 35 feet (Cape May Formation, unit 2, Qcm2. The Cape May 1 deposits form a broad gravel plain with a top elevation of 55-60 feet in the southwest quarter of the quadrangle, and also occur as small erosional remnants at elevations between 50-60 feet, slightly higher than adjacent upper terraces, in the Tulpehocken Creek, upper West Branch, and Oswego River valleys. Although extensive, the Cape May 1 deposits are generally less than 10 feet thick. The extent and thickness of these deposits indicate that most of the quadrangle was submerged as a broad shallow estuary or bay during the Cape May 1 highstand. The gravel deposits forming the broad plain in the Washington-Tylertown area are probably reworked and concentrated from the upland gravels which border the plain on its northwestern edge at slightly higher elevation.

The Cape May 2 terrace is inset into the Cape May 1 along the southern edge of the quadrangle and in the downstream parts of the Wading and Oswego River valleys. During one or more periods of low sea level following the Cape May 1 highstand, but before the Cape May 2 highstand, the Mullica River incised slightly more than 100 feet below present sea level. During the Cape May 2 highstand this incised valley was filled with fine-grained estuarine deposits (unit Qcm2f, section BB') over a thin basal fluvial sand and gravel. A similar fill likely also occurs beneath the downstream part of the Wading River valley, although there is no well data in the quadrangle in this area and there is no evidence of a thick valley fill upstream of Harrisville.

Amino-acid racemization ratios (AAR), optically stimulated luminescence ages, and radiocarbon dates from the Delaware Bay area (Newell and others, 1995; Lacovara, 1997; O'Neal and others, 2000; O'Neal and Dunn, 2003; Sugarman and others, 2007; Stanford and others, 2016) suggest that the Cape May 1 is of middle Pleistocene age (possibly marine-isotope stage 11, 420 ka, or stage 9, 330 ka, or older) and that the Cape May 2 is of Sangamonian age (stage 5, 125-80 ka). AAR data from vibracores on the inner continental shelf off Long Beach Island east of the quadrangle indicate that the Cape May correlate there is of Sangamon age (Uptegrove and others, 2012). Clayey soils in the uneroded parts of the broad Cape May 1 gravel plain, which are not observed in the Cape May 2 or younger deposits but do occur in the upland gravels, support a significantly older age for the Cape May 1 than the Cape May 2.

DESCRIPTION OF MAP UNITS

ARTIFICIAL FILL—Sand, pebble gravel, minor clay and organic matter; gray, brown, very pale brown, white. In places includes man-made materials such as concrete, asphalt, brick, cinders, and glass. Unstratified to poorly stratified. As much as 15 feet thick. In road embankments, dams, and dikes around cranberry bogs.

Qals WETLAND AND ALLUVIAL DEPOSITS—Fine-to-medium sand and pebble gravel, minor coarse sand; light gray, yellowish-brown, brown, dark brown; overlain by brown to black peat and gyttja. Peat is as much as 8, but generally less than 5, feet thick. Sand and gravel are chiefly quartz and are generally less than 3 feet thick. Sand and gravel are stream-channel deposits; peat and gyttja form from the vertical accumulation and decomposition of plant debris in swamps and marshes. In alluvial wetlands on modern valley bottoms.

Qe EOLIAN DEPOSITS—Fine-to-medium quartz sand; very pale brown, white. As much as 25 feet thick. Form linear to crescentic dune ridges as much as 25 feet tall and a half-mile long, and areas of gentle swell-and-swale topography with less than 5 feet of relief (fig. 4).

Qald DRY-VALLEY ALLUVIUM—Fine-to-medium sand and pebble gravel, minor coarse sand; very pale brown, white, brown, dark brown, light gray. As much as 5 feet thick. Sand and gravel are quartz. In dry valley bottoms forming headwater reaches of streams.

Qtl LOWER TERRACE DEPOSITS—Fine-to-medium sand, pebble gravel, minor coarse sand; light gray, very pale brown, brown, dark brown. As much as 15 feet thick. Sand and gravel are quartz with a trace (<1%) of chert and ironstone in places. Form terraces and pediments in valley bottoms with surfaces 2 to 15 feet above the modern floodplain, and narrow valley-bottom plains in a few dry headwater valleys. Include both stratified stream deposits (fig. 5) and unstratified pebble concentrates formed by seepage erosion of older surficial deposits. Sand includes gyttja in places and peat less than 2 feet thick overlies the sand and gravel in places. The gyttja and peat are younger than the sand and gravel and accumulate due to poor drainage. Gravel generally is more abundant in lower terrace deposits than in upper terrace deposits and the Cape May Formation due to removal of sand by seepage erosion.

Qtu UPPER TERRACE DEPOSITS—Fine-to-medium sand, pebble gravel, minor coarse sand; very pale brown, brownish-yellow, yellow. As much as 15 feet thick. Sand and gravel are quartz with a trace of chert and ironstone in places. Form terraces and pediments with surfaces 10 to 25 feet above the modern floodplain, and 5 to 10 feet above adjacent lower terraces. Also forms valley-bottom plains in a few dry headwater valleys. Include stratified stream-channel deposits and poorly stratified to unstratified deposits laid down by groundwater seepage on pediments (fig. 6).

Qtuo UPPER TERRACE DEPOSITS, OLDER PHASE—Sand and gravel as in unit Qtu forming an eroded terrace near Maxwell with a top surface about 10 feet higher than the adjacent upper terrace.

CAPE MAY FORMATION—Fluvial-estuarine and beach sand and gravel deposits of middle and late Pleistocene age forming an upper (Qcm1) and lower (Qcm2) marine terrace, and fine-grained estuarine valley-fill deposits in the Mullica River valley (Qcm2f).

Qcm2 CAPE MAY FORMATION, UNIT 2—Fine-to-medium sand, pebble gravel, minor clayey sand and coarse sand; yellow, very pale brown, yellowish-brown. Sand and gravel are quartz with a trace of chert. As much as 30 feet thick. Forms an eroded terrace with a maximum surface elevation of 35 feet and includes a valley-bottom fluvial gravel in the subsurface in the Mullica River valley (section BB').

Qcm2f CAPE MAY FORMATION, UNIT 2, FINE-GRAINED FACIES—Silt, clay, minor sand; gray, light gray. As much as 100 feet thick. In subsurface only (section BB'). Forms a valley fill in the Mullica River valley.

Qcm1 CAPE MAY FORMATION, UNIT 1—Fine-to-coarse sand, clayey sand, sandy clay, pebble gravel, trace fine cobbles; yellowish-brown, yellow, reddish-yellow, very pale brown, light gray. Clayey matrix in gravel is common on the plain in the Washington-Tylertown area, where it may be chiefly from weathering and soil development; elsewhere the clay is from original deposition. Gravel beds are horizontally stratified to unstratified, sand beds are horizontally laminated to cross bedded (fig. 7). Sand and gravel are quartz with minor (<2%) white and yellow weathered chert. As much as 20 feet thick. Forms a dissected plain in the southwestern part of the quadrangle with a top surface between 50 and 60 feet in elevation and caps low hilltops and uplands elsewhere in the quadrangle, with a maximum surface elevation of 65 feet.

TQg UPLAND GRAVEL, LOWER PHASE—Fine-to-medium sand, clayey sand to sandy clay in places, and pebble gravel; minor coarse sand; yellow, very pale brown, reddish-yellow. Sand and gravel are quartz with minor (<2%) white, yellow, and brown weathered and decomposed cherts in the coarse sand-to-pebble gravel fraction. Iron-cemented in places. Clay is chiefly from weathering and soil development. Gravel is horizontally stratified to unstratified (fig. 8); sand beds are cross bedded in places. As much as 20 feet thick, generally less than 10 feet thick. Occurs as erosional remnants on uplands above an elevation of 55-60 feet in the central part of the quadrangle and above 60-70 feet in the northern part of the quadrangle. Includes stream deposits, deposits laid down by groundwater-fed seepage on pediments, and pebble concentrates formed by winnowing of sand from older surficial deposits and the Cohansey Formation by seepage or surface runoff.

Tg UPLAND GRAVEL, HIGH PHASE—Fine-to-medium sand, some coarse sand, clayey sand to sandy clay in places, and pebble gravel, trace fine cobbles; yellow, brownish-yellow, reddish-yellow, very pale brown, rarely red. Sand and gravel are quartz, with minor chert, and traces of weathered feldspar, in the coarse sand-to-fine pebble gravel fraction. Iron-cemented in places. Most chert is weathered to white and yellow clay; some chert pebbles are gray to dark gray and unweathered to partially weathered. Clay-size material chiefly is from weathering of chert and feldspar and from soil development. Horizontally stratified to unstratified; rarely cross bedded. As much as 10 feet thick. Occurs as erosional remnants on hilltops, above an elevation of 70 feet near Mount, above 80 feet on Stormy Hill and north of Washington, and above 100 feet on Jemima Mount. Includes stream deposits and pebble concentrates formed by washing of sand and clay by groundwater sapping or surface runoff.

COHANSEY FORMATION—Fine-to-medium quartz sand, with some strata of medium-to-very coarse sand, very fine sand, and interbedded clay and sand, deposited in estuarine, bay, beach, and inner shelf settings. The Cohansey is here divided into two map units: a sand facies and a clay-sand facies, based on gamma-ray well logs and surface mapping using 5-foot hand-auger holes, exposures, and excavations. Total thickness of the Cohansey in the map area is as much as 200 feet.

Tchs Sand Facies—Fine-to-medium sand, some medium-to-coarse sand, minor very fine sand, minor very coarse sand to very fine pebbles, trace fine-to-medium pebbles; very pale brown, brownish-yellow, white, reddish-yellow, rarely reddish-brown, red, and light red. Well-stratified to unstratified; stratification ranges from thin, planar, subhorizontal beds to large-scale trough and planar cross-bedding in sets as much as 3 feet thick (fig. 8). Sand is quartz; coarse-to-very coarse sand may include as much as 5% weathered chert and a trace of weathered feldspar. Coarse-to-very coarse sands commonly are slightly clayey; the clays occur as grain coatings or as interstitial infill. This clay-size material is from weathering of chert and feldspar rather than from primary deposition. Pebbles are chiefly quartz with minor gray chert and rare gray quartzite. Pebbles commonly are subangular. Some chert pebbles are light gray, partially weathered, pitted, and partially decomposed; some are fully weathered to white clay. In a few places, typically above clayey strata, sand may be hardened or cemented by iron oxide, forming reddish-brown hard sands or ironstone masses. Locally, sand facies includes isolated lenses of interbedded clay and sand like those within the clay-sand facies described below. The sand facies is as much as 110 feet thick.

Tchc Clay-Sand Facies—Clay interbedded with clayey fine sand, very fine-to-fine sand, fine-to-medium sand, less commonly with medium-to-coarse sand and pebble lags. Clay beds are commonly 0.5 to 3 inches thick, rarely as much as 2 feet thick, sand beds are commonly 1 to 6 inches thick but are as much as 2 feet thick (fig. 6). Clays are white, yellow, very pale brown, reddish-yellow, light gray; sands are yellow, brownish-yellow, very pale brown, reddish-yellow. Rarely, clays are black, dark gray, and dark brown and contain organic matter. As much as 20 feet thick.

Tkw KIRKWOOD FORMATION—Fine sand, fine-to-medium sand, sandy clay, and clay, minor medium-to-coarse sand; gray, dark gray, brown. Sand is quartz with some mica and lignite. In subsurface only. Approximately 300 feet thick in the southeastern part of the quadrangle, thins to about 200 feet in the northern part of the quadrangle, based on well data in the adjacent Chatsworth and Oswego Lake quadrangles (Stanford, 2012, 2017). Consists of five clay-sand units traceable on gamma-ray logs and sampled in the Bass River and Island Beach coreholes (Miller and others, 1994, 1998, see discussion under "Kirkwood Formation" above). These units are shown by tielines on sections AA' and BB'. The upper three units either pinch-out up-dip to the north or were eroded prior to deposition of the Cohansey Formation. The Kirkwood in the quadrangle is of early to middle Miocene age, based on strontium stable-isotope ratios and diatoms (Miller and others, 1998).

MAP SYMBOLS

Contact of surficial deposits—Solid where well-defined by landforms as visible on 1:12,000 stereo airphotos and LiDAR imagery, long-dashed where approximately located, short-dashed where gradational or featheredged, dotted where excavated.

Contact of bedrock formations—Approximately located. Dotted where covered by surficial deposits.

Tchc Concealed bedrock formation—Covered by surficial deposits.

4 • / • / Qe4/Qtu • / e2 • / Tchc • / Tchs4/Tchc • Material penetrated by hand-auger hole or observed in exposure or excavation—Number indicates thickness of surficial material, in feet, where penetrated. Symbols within surficial deposits without a thickness value indicate that surficial material is more than 5 feet thick. 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. An "e" followed by a number indicates thickness of eolian sand overlying the mapped unit at isolated occurrences outside of map unit Qe. "Tchc" indicates isolated occurrences of Cohansey Formation, clay-sand facies, below surficial deposits, or below indicated thickness of Cohansey Formation, sand facies.

figure 4 • Photograph location

8.9 ka ■ Radiocarbon date—Age in mean calibrated years. See text for details.

7 ● Well or test boring—Location accurate to within 200 feet. Formations penetrated shown in table 1.

4 ⊙ Well or test boring—Location accurate to within 500 feet. Formations penetrated shown in table 1.

4 7 Geophysical log—On sections. Red line indicates gamma-ray log, radiation intensity increases to right. Blue line indicates resistivity or resistance log, resistivity or resistance increases to right.

Head of seepage valley—Line at top of scarp at head of small valleys and hillslope embayments formed by seepage erosion.

Paleocurrent direction—Arrow indicates direction of stream flow as inferred from dip of planar cross beds observed at point marked by "x".

Abandoned channel—Line in channel axis. Shows relict braided channels on lower terrace.

Dry valley—Line in bottom of narrow, incised stream channel with no evidence of active drainage.

Fluvial scarp—Line at top, ticks on slope. Within unit Qtl.

Dune ridge—Line on crest.

Gravel ridge—Line on crest. Low ridges on unit TQg mapped from LiDAR imagery, morphologically like small dune ridges but formed on gravel. Origin uncertain.

Shallow topographic basin—Line at rim, pattern in basin. Includes thermokarst basins formed from melting of permafrost and deflation basins, bordered by eolian deposits, formed from wind erosion.

Iron-cemented sand and gravel—Extensive iron cementation in upland gravels or in Cohansey Formation.

Excavation perimeter—Line encloses excavated area.

Sand pit—Inactive in 2020.

Sand pit—Active in 2020.

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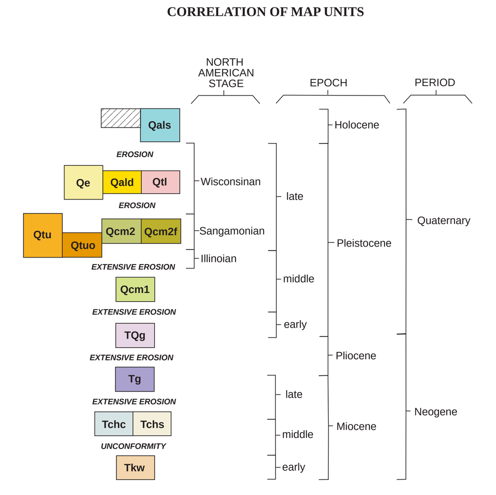
CORRELATION OF MAP UNITS



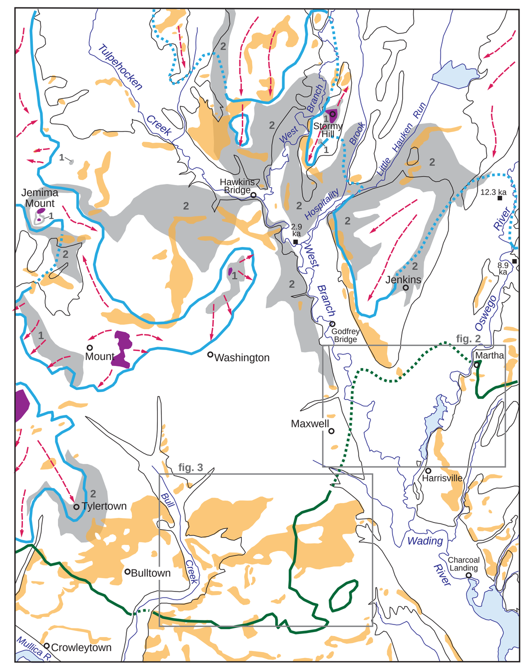


Figure 1. Geomorphic features, eolian deposits, high upland gravels, and outcrop of Cohansey clay-sand facies, in the Jenkins quadrangle.

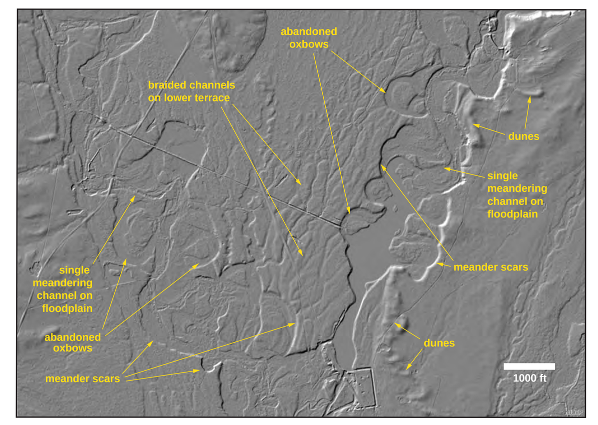


Figure 2. LiDAR shaded relief image showing braided channels on lower terrace, meander scars and abandoned oxbows cut into lower terraces, and dunes on upper terraces. Note that present streams flow in single channels on floodplains. Area of image shown on figure 1.

Table 1. Selected well records.

Well Number	Identifier[1]	Formations Penetrated[2]
1	32-1525 well 13D, G	60 Tchs 68 Tchc 140 Tchs 302 Tkw
2	32-19217	3 Qe 13 Tchs 24 Tchc 42 Tchs 54 Tchc+Tchs 114 Tchs 118 Tchc 152 Tchs
3	32-27138	8 Qtu 20 Tchs 40 Tchs+Tchc 52 Tchc 72 Tchs
4	32-16946	42 Qtl+Tchs 51 Tchs+Tchc 56 Tchc 62 Tchs+Tchc 64 Tchc 112 Tchs
5	32-17623	9 Qtl 17 Tchs 19 Tchc 42 Tchs 52 Tchc 112 Tchs
6	32-28134	8 Qtu 9 Tchc+Tchs 11 Tchc 21 Tchs 23 Tchc 33 Tchs 34 Tchc 61 Tchc+Tchs 66 Tchs 67 Tchc 71 Tchs
7	32-14903	10 Qtu 30 Tchc 40 Tchs+Tchc 55 Tchs
8	32-18237	2 Qtu 17 Tchc 26 Tchs 28 Tchc 47 Tchs 53 Tchc 57 Tchs 62 Tchc 97 Tchs
9	32-28445	22 Tchs+Tchc 45 Tchs 60 Tchs+Tchco 98 Tchs
10	32-455	15 TQg 85 Tchs+Tchc 131 Tchs 133 Tchc
11	32-13664	15 Tchs+Tchc 52 Tchs 67 Tchs+Tchco 127 Tchs 142 Tchs+Tchc 169 Tchs
12	32-20966	25 Qcm1+Tchs 47 Tchc 60 Tchs
13	32-22195	7 Qtl 37 Tchs 52 Tchs+Tchc 97 Tchs 112 Tchs+Tchc 195 Tchs
14	32-13665	10 Tchs+Tchc 35 Tchc+Tchco 105 Tchs+Tchc 175 Tchs
15	32-12063	90 Tchs
16	32-16551	7 Qtl 105 Tchs
17	E2012 13772	8 Tchs+Tchc 89 Tchs 93 Tchc 120 Tchs 126 Tchs+Tchc 154 Tchs 158 Tchc 179 Tchs
18	E2010 00780	28 Tchs 62 Tchs+Tchc 72 Tchco 100 Tchs
19	E2013 12179	18 Tchs+Tchc 23 Tchs 40 Tchs+Tchc 68 Tchs 71 Tchc 87 Tchs 92 Tchc 144 Tchs
20	32-17399	12 Qtu 14 Tchc 19 Tchs 23 Tchc 40 Tchs 46 Tchc 97 Tchs
21	E2017 04708	3 Qtu 24 Tchs+Tchc 101 Tchs
22	32-523	10 fill+Qtu 80 Tchs 83 Tchc 105 Tchs+Tchc 108 Tchc 116 Tchs+Tchc 117 Tchc 193 Tchs 194 Tkw
23	32-524	12 fill+Qtu 14 Tchs 21 Tchs+Tchc 39 Tchs 41 Tchs+Tchc 46 Tchs 54 Tchs+Tchc 126 Tchs 127 Tchs+Tchc 131 Tchco 152 Tchs
24	32-8265	8 Tchs 14 Tchc+Tchs 41 Tchc 45 Tchs 50 Tchc+Tchs 53 Tchs 59 Tchc 61 Tchs 74 Tchc 103 Tchs
25	32-25195	7 Qe 8 Qtu 17 Tchs
26	32-1525 well 6D, G	82 Tchs 110 Tchc 120 Tchs 264 Tkw (unit 5 sand below 185)
27	52-22 (Woolman, 1893)	35 Qtu+Tchs 85 Tchs 98 Tchs+Tchc 108 Tchc 375 Tkw (unit 5 sand from 196-306)
28	32-46 Transco 15, E and lithologic log	20 Qtu 41 Tchs 51 Tchs+Tchc 81 Tchs 101 Tchs+Tchc 113 Tchc+Tchs 418 Tkw (unit 5 sand from 260-350) 1701 TD
29	32-47 Transco 16, E	120 Tch 435 Tkw (unit 5 sand from 250-350) 1658 TD
30	32-10400	5 fill 6 Qtu 11 Tchc 38 Tchs 42 Tchc+Tchs 48 Tchc 58 Tchs 62 Tchc 69 Tchco 104 Tchs 114 Tchc+Tchs 191 Tkw
31	32-14791	13 Qcm1 18 Tchc 33 Tchs 50 Tchco 80 Tchs 85 Tchs+Tchc
32	32-1525 well 12D, G	5 Qe 15 Qcm1 25 Tchs 35 Tchc 90 Tchs 100 Tchc 110 Tchs 370 Tkw (unit 5 sand from 190-340)
33	32-1124	4 fill 15 Qtl 100 Qcmf 116 Qcm2 165 Tkw (unit 5 sand below 150)
34	32-15789	12 fill+Qtl? 84 Qcmf
35	32-14667	35 Qcm2+Tchs 45 Tchs+Tchc 55 Tchc 70 Tchs+Tchc 95 Tchs
36	P2009 04308	20 Tchs+Tchc 40 Tchs 50 Tchco 65 Tchs
37	E2014 14528	16 Tchs 56 Tchs+Tchc 62 Tchc 85 Tchs
38	32-14073	20 Tchs 40 Tchc 56 Tchs
39	32-26262	27 Tchs 42 Tchco 75 Tchs
40	32-9965	30 Qtu+Tchs 60 Tchs 120 Tchs+Tchc 187 Tchs 205 Tkw

[1]Identifiers of the form 32-xxxxx, 52-xx, Exxx xxxxx, and Pxxx xxxxx are N. J. Department of Environmental Protection well-permit numbers. The driller's log for well 52-22 is from Woolman (1893). The "Transco" wells are deep gas exploration wells drilled for the Transcontinental Gas Pipeline Corporation in 1951. Formations below the Kirkwood in these wells are described in Johnson (1961) and Kasabach and Scudder (1961). A "G" following the identifier indicates that a gamma-ray log is available for the well; an "E" indicates that an electric log (resistivity and spontaneous potential) is available.

[2]Number is depth (in feet below land surface) of base of unit indicated by abbreviation following the number. Final number is total depth of well rather than base of unit. For example, "12 Tchs 34 Tchc 62 Tchs" indicates Tchs from 0 to 12 feet below land surface, Tchc from 12 to 34 feet, and Tchs from 38 to bottom of hole at 62 feet. Abbreviations are: Qe, Qtl, Qtu, Qcm1, Qcm2, TQg = yellow and white sand, clayey sand, and gravel (sand and gravel surficial deposits); Qcmf = gray clay, muddy sand, silty sand, fine sand (fine-grained facies of the Cape May Formation); Tchs = white, yellow, gray, brown (minor red, orange) fine, medium, and coarse sand and minor fine gravel (sand of the Cohansey Formation); Tchc = yellow, white, gray (minor red, orange) clay, silty clay, and sandy clay (clay of the Cohansey Formation); Tchco = black clay, peat, wood (organic clay of the Cohansey Formation); Tkw = gray and brown clay, silt and sand (Kirkwood Formation). A "+" sign indicates that units are mixed or interbedded. "TD" indicates total depth of deep wells for which units below Tkw are not listed. Units are inferred from drillers' lithologic descriptions on well records filed with the N. J. Department of Environmental Protection, or from geophysical well logs where lithologic descriptions are not available. Units shown for wells may not match the map and sections due to variability in drillers' descriptions and the thin, discontinuous geometry of many clay beds. In many well logs, surficial deposits cannot be distinguished from Cohansey sands; thus, the uppermost Tchs unit in well logs generally includes overlying surficial deposits.

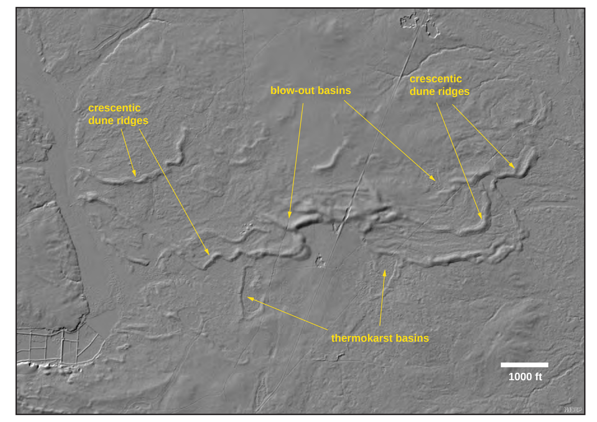


Figure 3. LiDAR shaded-relief image showing dunes, thermokarst basins, and blow-out basins south of Maxwell. Area of image shown on figure 1.

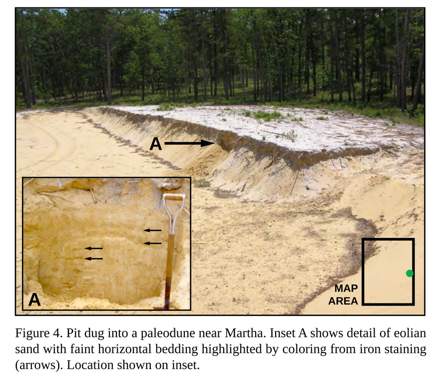


Figure 4. Pit dug into a paleodune near Martha. Inset A shows detail of eolian sand with faint horizontal bedding highlighted by coloring from iron staining (arrows). Location shown on inset.

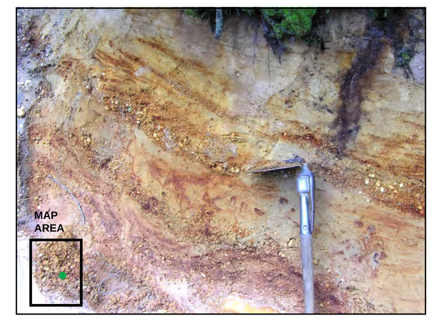


Figure 5. Lower terrace deposits exposed in a streambank along the West Branch of the Wading River. Note subhorizontal and cross bedding highlighted by coloring from iron staining. Location shown on inset.

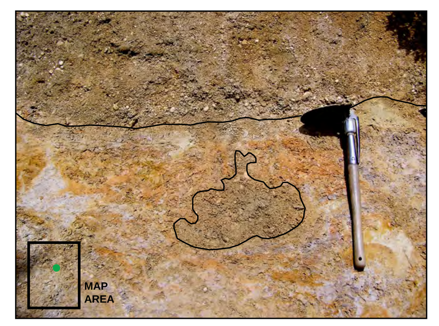


Figure 6. Upper terrace deposits (above top line) over Cohansey Formation, clay-sand facies, exposed in a bank along the West Branch of the Wading River. Clay beds in the Cohansey are gray and orange; sand beds are brown and yellow. Cryoturbation has deformed the bedding and caused a mass of terrace gravel (outlined) to settle downward into the Cohansey. Location shown on inset.

Figure 7. Sand and gravel of the Cape May Formation, unit 1, exposed in a pit near Bulltown. Note horizontal and low-angle cross bedding in sand beds. Location shown on inset.

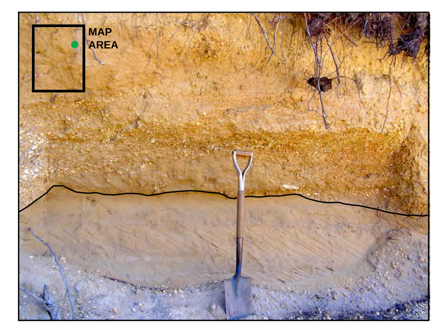
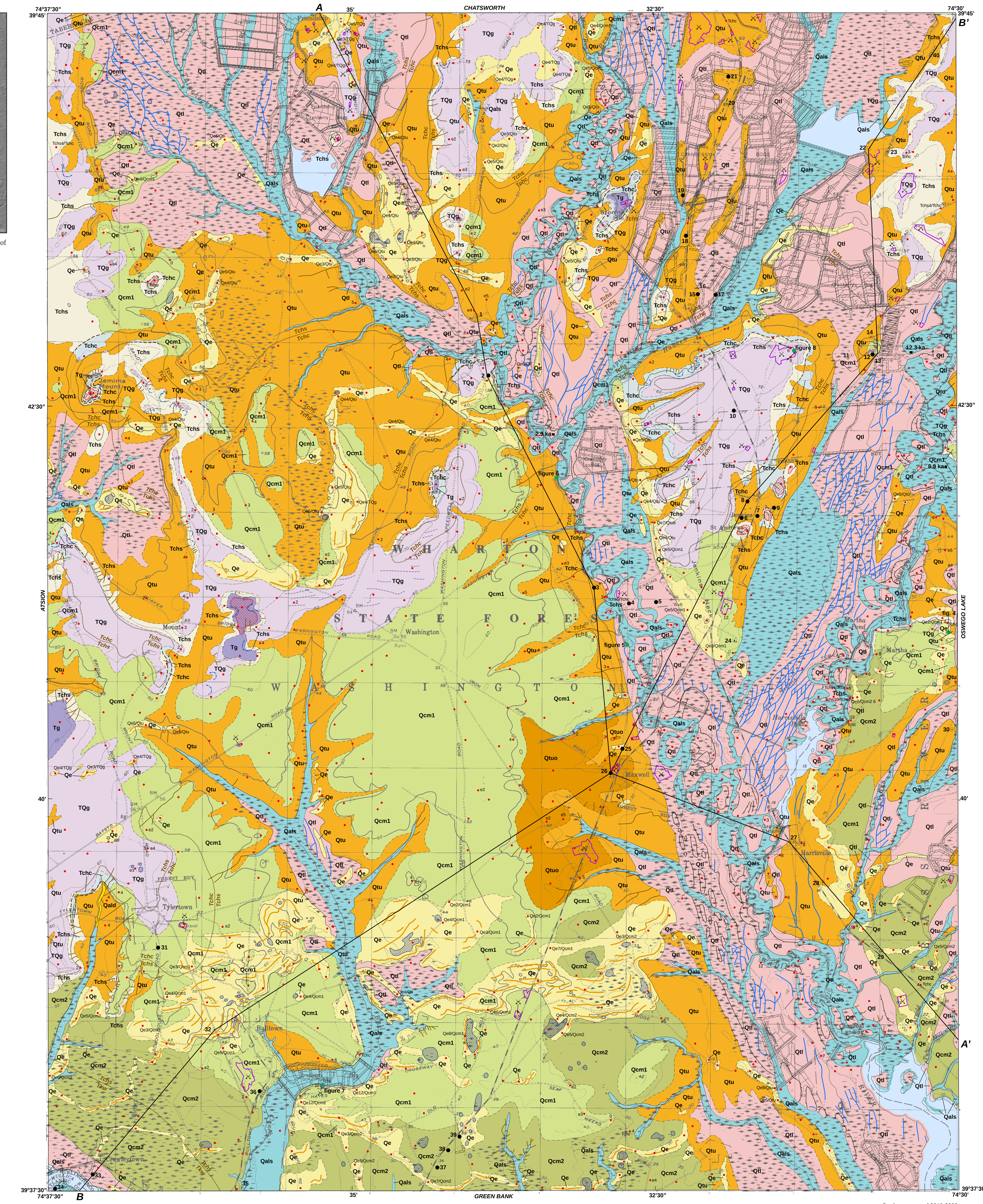


Figure 8. Upland gravel, lower phase (above line) over Cohansey Formation, sand facies, exposed in a pit near Jenkins. Note faint horizontal bedding in the upland gravel and tabular-planar cross bedding in the Cohansey Formation. Location shown on inset.



Base from U. S. Geological Survey, 1997.
Topography compiled 1955. Planimetry derived from imagery taken 1951 and other sources.
Photoinspected using imagery dated 1997.
Boundaries revised 1998.
North American Datum of 1927.

APPROXIMATE MEAN DECLINATION, 1998

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

LOCATION IN NEW JERSEY

Geology mapped 2019-2020.
Cartography by S. Stanford.

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GEOLOGY OF THE JENKINS QUADRANGLE
BURLINGTON AND ATLANTIC COUNTIES, NEW JERSEY

by
Scott D. Stanford
2020