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GEOLOGY OF THE ATSION QUADRANGLE
ATLANTIC AND BURLINGTON COUNTIES, NEW JERSEY
OPEN-FILE MAP OFM 134
pamphlet containing table 1 accompanies map

INTRODUCTION

The Atsion 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. 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 into 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, in step with lowering sea level. 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).

Summaries of the aquifers, stratigraphy and depositional settings of the Cohansey and Kirkwood formations, and of the geomorphic history of the map area as recorded by surficial deposits and landforms, are provided below. The age of the deposits and episodes of valley erosion are shown on the Correlation of Map Units. The formations penetrated in wells and borings, as interpreted from drillers' lithologic logs and downhole geophysical logs, are listed in table 1 (in pamphlet).

AQUIFERS

Cross sections AA', BB', and CC' show materials to depths of between 300 and 450 feet, which includes the Cohansey Formation, the Kirkwood Formation, and, on sections AA' and BB', the upper part of the Shark River Formation, which underlies the Kirkwood. Water wells in the quadrangle, which include domestic wells and a few agricultural irrigation wells, tap sands in the Cohansey Formation and upper Kirkwood Formation at depths between 50 and 230 feet. Two wells (wells 3 and 49 in table 1) draw water from sand in the Shark River Formation, known as the Piney Point aquifer (Zapecza, 1989; Sugarman and others, 2018), from depths of 231-291 feet (well 3) and 419-449 feet (well 49). In the Pleasant Mills, Sweetwater, and Gardiners Landing area in the southeast corner of the quadrangle, several domestic wells draw from fluvial-estuarine sand of Pleistocene age (Cape May Formation) at depths between 50 and 100 feet. This sand, and underlying sand in the Kirkwood Formation in this area, is confined in places by clayey silt and fine sand estuarine deposits (Cape May Formation, fine-grained facies). Two wells (42 and 46) drilled through the fine-grained deposits into the underlying sand flowed above land surface when first drilled, demonstrating confinement of the sand.

Several wells in the quadrangle (8, 9, 14, 15, and 16) were drilled as test and observation wells for groundwater-resource studies (Lang, 1961; Rhodehamel, 1973). Downhole gamma-ray logs of these wells, and of well 49, show sand and clay-silt beds in the Kirkwood Formation. One of the sand beds in the Kirkwood Formation (unit 5 on sections AA', BB') is a productive confined aquifer in areas southeast of the quadrangle, where it is known as the "Atlantic City 800-foot sand" (Zapecza, 1989; Sugarman and others, 2020). It may also be an aquifer in the southeastern part of the Atsion quadrangle, although it thins from 50 feet thick at Batsto to 20 feet thick in the central part of the quadrangle and is not tapped by wells. Overlying fine-grained beds of units 2 and 4 in the Kirkwood Formation may act as the confining layers for the unit 5 sand but they pinch out or are eroded away in the northwestern part of the quadrangle (section AA'), where unit 5 directly underlies the Cohansey Formation and is not confined.

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 near New Gretna, 10 miles east of Batsto (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, 2020; Stanford and Sugarman, 2017). These sequences are composed of six lithologic units which were identified and numbered in the Island Beach corehole, located about 32 miles northeast of Batsto (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 Atsion quadrangle (Stanford, 2017), but the other units are traceable updip into the quadrangle.

Units 6 and 5 are in the Lower Member of Owens and others (1998), also known as the Brigantine Member of Miller and others (1997), or the Kirkwood 1a sequence of 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 of 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 of Sugarman and others (1993). Diatoms in this sequence indicate an early to middle? Miocene age (Miller and others, 1998). A boundary between sequences 2a and 2b of Sugarman and others (1993) may be present in the lower part of unit 1.

Gamma-ray logs of wells 8, 9, 14, 16, and 49 (sections AA', BB'), and a lithologic log of well 15, 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 and pinches out updip to the northwest, where it is directly overlain by, or transitions into, the Cohansey Formation (section AA'). Unit 6 in the Atsion quadrangle can be divided into three subunits (6a, 6b, and 6c, from bottom to top) which are identified by thin sands at their bases as observed on gamma-ray logs (section AA'). In the northwestern part of the quadrangle, unit 6 is directly overlain by the Cohansey Formation, and the Kirkwood Formation updip from here to its outcrop belt to the northwest is predominantly fine-grained. The lithology and age of the Kirkwood in a corehole at Ancora, 8 miles southwest of Atsion and along strike with the updip Kirkwood in the Atsion quadrangle, supports this correlation. In the Ancora core the Kirkwood is fine-sandy clay about 100 feet thick (Miller and others, 1999). Shells in the basal 20 feet of the formation at Ancora yield strontium stable-isotope ages of 20.2, 20.9, and 21.2 Ma (Miller and others, 1999), consistent with the age of the unit 6 clay in the Bass River corehole. These patterns and correlations suggest that the Kirkwood members above lithologic unit 6, which is in the Lower or Brigantine Member, 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 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 generally lacks datable marine fossils, particularly in updip areas where it has been weathered. As discussed above, lower parts of the Cohansey in updip settings like in 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, of Sugarman and others, 1993) and may represent the coastal facies of the Kirkwood shallow-shelf deposits.

In the map area, clays in the Cohansey 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 20 feet thick. In outcrop, two clay beds can be traced in the northern and eastern parts of the quadrangle. The lower bed ("2" on fig. 1) is at an elevation of about 35 to 45 feet and is traceable in outcrop in the Deep Run and Springers Brook valleys and part of the Mullica River valley east of Atsion. In this area the bed is a continuation of an extensive clay-sand bed in the Batsto River valley to the north (Stanford, 2015). An outlier of this bed crops out on the east side of the Batso River in the Penn Swamp Branch valley and in another tributary valley just to the south. A discontinuous bed at an elevation of 40 to 50 feet on an upland east of Batsto, which extends to the east to the Tylertown area in the Jenkins quadrangle (Stanford, 2020), may also be an outlier of this lower bed. The upper bed ("1" on fig. 1) is at an elevation between 50 and 70 feet and occurs on the upland north of Penn Swamp in the eastern part of the quadrangle. A clay-sand bed at an elevation of 60 feet on the upland south of Great Swamp Branch on the west edge of the quadrangle may be an outlier of this bed. Gamma-ray and lithologic logs (sections AA', BB', CC') show additional clay beds in the subsurface. The most extensive of these, at an elevation of 0 to 20 feet, is traceable for more than 6 miles from southeast to northwest. A detailed view of this bed is provided by a grid of about 40 observation wells drilled to a depth of 100 feet in a 15-acre area around well 16 along the Mullica River north of Batsto, installed in the 1950s as part of a groundwater resource study (Lang, 1961). These wells were drilled through the bed at depths of 25 to 30 feet and found that it was not present in all borings. In contrast, a lower, thinly bedded clay and sand at a depth of 80 to 90 feet was continuous and had a slight dip to the southeast. This lower clay is unit 2 of the Kirkwood Formation.

The laminated bedding and thin but areally extensive geometry of the clay-sand facies 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 (Stanford, 2012), and possibly above 150 feet east of the map area in the Oswego Lake quadrangle (Stanford, 2017). These elevations and occurrences suggest that the Beacon Hill Gravel formerly covered most of the Atsion quadrangle but has been eroded away. The highest elevation in the quadrangle is about 115 feet on the uplands in the northeast corner, which is at least 30 feet below the presumed base of the Beacon Hill Gravel in this area.

Continued decline of sea level through the late Miocene (approximately 8 to 5 Ma) caused the regional river system to erode into the Beacon Hill plain. As it did, it shifted west of the map area into what is now the Delaware River basin, and then swung eastward across southern New Jersey, depositing sand and gravel in a broad plain south and west of the present Mullica River (Owens and Minard, 1979; Stanford, 2009). This sand and gravel deposit is known as the Bridgeton Formation (unit Tb) and it caps uplands in the southwest corner of the quadrangle at elevations between 60 and 70 feet. The area north and east of the Bridgeton plain, including most of the Atsion quadrangle, became an upland from which local streams drained southward to the Bridgeton plain. 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 ridgetops and uplands above an elevation of between 65 and 110 feet (fig. 1). In the eastern part of the quadrangle the elevation of the base of this gravel descends from about 110 feet in the northeast corner to about 65 feet at Batsto, indicating southerly flow. This direction is supported by the dip of cross beds exposed in a pit dug into the gravel near Batsto, which show flow to the south.

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. The Bridgeton river system shifted farther west, to what is now Delaware Bay and the Delmarva Peninsula, and downcut to form a lower plain, and the Bridgeton plain was abandoned. 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 50 feet below the higher gravels. These deposits today occur east of the Batsto River, where they cap lower interfluves, and form more extensive sheets in headwater areas of tributary valleys, between 50 and 90 feet in elevation. Stream drainage during deposition of these sediments, as inferred from their elevation and slope, was like that of the present drainage, indicating that the general form and southward flow of the Batsto River valley had been established by this time.

Continuing incision in the middle Pleistocene (about 800 to 125 ka) formed the modern valley network (delineated by thin solid green lines, and the solid light blue Qcm1 line where the green lines end, on fig. 1). Fluvial sediments laid down in modern valleys include upper and lower terrace deposits (units Qtu, Qtl, and Qtll), 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. On steeper pediments in the northeast corner of the quadrangle, which grade to the upper terrace at their downslope edge, the deposits are probably of mass movement origin and are mapped as upper colluvium (Qcu). The terrace and colluvial deposits were laid down chiefly during periods of cold climate in the middle and late 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 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 in the Batsto area some of the upper terraces grade to the Cape May 2 marine terrace (see below). In the Hammonton Creek and Nescochague Creek valleys in the southwestern part of the quadrangle, and east of the Batsto River, 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 form the broad lowland between Nescochague Creek and the Batsto River that covers most of the quadrangle. The terrace surface is scribed by a network of shallow braided channels (figs. 2 and 3, also shown as solid blue lines on map). On wet areas of the lower terrace, particularly west and south of the Mullica River, 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 unchanneled terrace. In these areas, the channels were mapped from color infrared aerial imagery taken in 2002 and earlier (1940 and 1951) black and white aerial photography (fig. 2), which show well the vegetation patterns. On drier areas of the lower terrace, particularly between the Mullica and Batsto rivers, the channels, which are generally less than 5 feet deep, but locally as much as 10 feet deep, were mapped from LiDAR imagery (fig. 3). Like the upper terrace deposits, which also are scribed with braided channels in places, the braided channels on the lower terrace 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. 3).

The wide extent of the braidplain in the Atsion quadrangle is partly the result of the focusing of drainage from the Batsto, Mullica, and Nescochague basins in this area as it funnels through the two-mile-wide gap between uplands to the east of Batsto and to the west of Pleasant Mills (fig. 1). This combined drainage was also discharging through a lowland containing estuarine sand and gravel of the Cape May Formation, which formed a thin fill across the lowland with a top elevation of about 50 feet. In several places on the plain, remnants of the Cape May Formation, unit 1 (see below), some protected from erosion by ironstone caps (marked by red cross-hatching on map), rise ten to fifteen feet above the lower terrace. These remnants, and the presence of Cape May remnants on the uplands bordering the lowland to both the east and south, document the former continuity of the deposit. The combination of abundant discharge traversing a low-lying sand and gravel estuarine plain favored the development of an extensive braided channel network when permafrost formed.

Newell and Wyckoff (1989) propose that storm-generated high discharges are necessary to form the braided channels, based in part on large-scale festoon cross beds described in a trench excavation through a channel on the plain by Farrell (1985). These bedforms occur beneath a gravel lag overlain by 1 to 2 feet of rippled sand. Gravel lags commonly mark the base of the terrace deposits, and the festoon cross beds may be tidally influenced bedforms in the Cape May estuarine sediments, or in the Cohansey Formation, rather than fluvial beds in the lower terrace deposits. Both the Cape May and Cohansey formations are exposed beneath a few feet of lower terrace deposits in banks along the Mullica and Batsto rivers and were penetrated in several 5-foot hand-auger holes drilled through terrace sediments on the plain (auger holes and bank exposures shown by red dots on map).

Farrell (1985) proposed that glacial meltwater overflows from the Delaware River valley formed the channels, although there is no evidence for, or known source of, the huge volume of water that would be required to overtop the Mullica-Delaware divide, which would require inundating the entire lower Delaware valley to a depth of as much as 150 feet. Also, similar braidplains occur in valleys that do not share a divide with the Delaware River basin, for example, the Oswego River (Stanford, 2020), and the plain west of Sleeper Branch (fig. 1), where channel orientation indicates flow from the Albertson Brook and Great Swamp Branch valleys, neither of which head at a Delaware divide.

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 quadrangle, sand and gravel of the lower terrace overlie an organic silt dated to 34,890±960 radiocarbon years (39,887 mean age, 39,070-41,130 one sigma error, in calibrated years, all calibrations are determined using radiocarbon calibration program CALIB 8.20 and Reimer and others, 2020) (GX-16789-AMS, Newell and others, 1995). In the Chatsworth quadrangle, northeast of the Atsion quadrangle, organic sediment within lower terrace sand dated to 20,350±80 radiocarbon years (24,440 mean age, 24,570-24,290 one sigma error, in calibrated years) (Beta 309764, Stanford, 2012). These dates indicate deposition of the terrace deposits in the late Wisconsinan.

Along the Mullica and Batsto rivers, small terraces with tops 2 to 3 feet above the present floodplain, and 5 to 10 feet below the main lower terrace, are mapped as a low phase of the lower terrace (unit Qtll). These lie within the narrow inset valleys containing the present floodplain and so postdate the melting of permafrost and incision of the Batsto and Mullica river channels. Peat under a similar terrace along the Wading River in the Jenkins quadrangle east of the map area dates to 2.9 ka (Stanford, 2020), indicating that the terrace sand that overlies the peat there was deposited within the past 2,900 years.

Other features related to permafrost are thermokarst basins, polygonal patterned ground, and dry valleys. Thermokarst basins are shallow closed basins, circular to oval in plan, and less than 5 feet in depth (fig. 4, also shown in blue cross-hatching on map). They are most common on upper terraces but also occur in a few places on the lower terrace and the surface of the Bridgeton Formation. 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, including most of the large basins, are bordered by dunes or occur within eolian deposits (fig. 4). These basins were likely formed, or enlarged from an initial thermokarst basin, by wind erosion (French and Demitroff, 2001).

Patterned ground forms when frozen sediment contracts and cracks in a polygonal network. When thawed, ice in the cracks melts and streams cut shallow channels along the cracks that trace the polygonal pattern. A few of the channels on the lower terrace show this pattern (fig. 2, boxed area).

Dry valleys are narrow channels and gullies that are inset into upper terraces or into uplands bordering the upper terraces (fig. 5). They do not contain surface water today but did when permafrost was present. The channels on the upper terraces are younger than the terraces and formed during the Wisconsinan. The upland channels empty onto the upper terraces and may, in part, date to pre-Wisconsinan cold periods.

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 (fig. 3) are particularly well developed along the lower reaches of the Mullica and Batsto rivers and Nescochague Creek. Most of the incision was completed by around 10 ka, based on radiocarbon dates of 8,900±90 radiocarbon years (GX-26537, 9,995 mean age, 9,890-10,190 one sigma error, in calibrated years) at a depth of 8 feet on basal peat in the Nescochague floodplain and 6,760±90 radiocarbon years (GX-26539, 7,620 mean age, 7,510-7,680 one sigma error, in calibrated years) on basal peat at a depth of 3 feet in the Batsto River floodplain (fig. 1, also plotted on map).

Modern floodplain and wetland deposits (unit Qals) were laid down in floodplains within the past 10 ka (Buell, 1970). 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 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. Peat thickness, as determined in 20 hand-auger transects at 5 sites along the Mullica and Batsto rivers, is generally between 2 and 3 feet thick, but is as much as 6 feet thick in former channels and in organic levees along the present channel (Stanford, 2000). In 8 transects at one site in the Nescochague floodplain, peat is generally 2 to 4 feet thick and as much as 8 feet thick in former channels, which have a meandering form like the present channel (Stanford, 2000). In downstream reaches of these streams near Batsto, the floodplains narrow, streamflow increases, and the floodplain sediments are mostly sand and gravel with little accumulation of peat.

Eolian deposits (Qe) are common in the quadrangle (fig. 1). They include dunes, either as narrow single ridges like those west of Pleasant Mills, or as larger deposits consisting of numerous contiguous dunes, like the area south of Albertson Brook. The crestlines of the dunes (shown by orange lines on the map) generally trend east-west or northeast-southwest. They are as much as a mile long and 15 feet tall, although many are only 3 to 5 feet tall. Some dune ridges are curved or crescentic, with the crescents opening to the west or northwest (fig. 5). 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. The eolian deposit north of Atsion is a silty fine sand in places and has a sheet-like form, like loess deposits just to the north in the Indian Mills quadrangle (Stanford, 2015). Most of the eolian deposits are on upper terraces. Some extend from upper terraces onto older deposits like the Cape May Formation, unit 1, and the upland gravels (fig. 5). The largest dunefields are on the upper terrace bordering the south side of the Nescochague Creek and Albertson Brook valleys, and on the upper terrace on the east side of the Batsto River. Both these locations are downwind from the broad braidplain of the lower terrace, suggesting that the sand was blown from that plain when it was active. Some dunes are on the lower terrace, although these are smaller than those on the upper terrace. A few are on the upland gravel, lower phase and a few also occur on the upland gravel, high phase. This distribution shows that the eolian deposits largely postdate 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). Some of the dunes 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 plain with a top elevation of 55 to 60 feet in the southwest part of the quadrangle around Nesco and Wescoatville and occur as erosional remnants at elevations between 50 and 60 feet, slightly higher than adjacent upper terraces, east of the Batsto River. They also occur in a few small erosional remnants, as described above, within the lower terrace braidplain between Nescochague Creek and the Batsto River. 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, except for the uplands east of the Batsto River and north of Wescoatville, was submerged as a broad shallow estuary or bay during the Cape May 1 highstand.

Remnants of the Cape May 2 terrace occur south and east of Batsto. The Cape May 2 estuary extended up the Batsto, Mullica, and Nescohague valleys but was eroded and covered by lower terrace deposits as sea level fell in the Wisconsinan. Streambank exposures along the lower Mullica River show lower terrace gravels in erosional contact on fine-grained Cape May sand and silt. 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 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, sections AA', CC'). The location of wells with logs reporting this fill show that the Mullica at this time was southwest of its present location north of Pleasant Mills, slightly south of the present location of Nescochague Creek (fig. 1), although there are no wells beyond a mile west of Pleasant Mills and the location of the valley west of there is uncertain.

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) 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). The significantly greater degree of erosion of the Cape May 1 deposits compared to the Cape May 2 or younger deposits also indicate 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 human-made materials such as concrete, asphalt, brick, cinders, glass, and, near Atsion, slag from a former iron furnace. Unstratified to poorly stratified. As much as 15 feet thick. In road and railroad 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.

Qtll LOWER TERRACE DEPOSITS, LOW PHASE—Sediment as in lower terrace deposits (described below) forming terraces along the Batsto and Mullica rivers with surfaces 2 to 3 feet above the modern floodplain, and 5 to 10 feet below the main lower terrace. These low-phase deposits are of Holocene age.

Qald DRY-VALLEY ALLUVIUM—Fine-to-medium sand, 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 with no evidence of active stream flow.

Qe EOLIAN DEPOSITS—Fine-to-medium quartz sand; very pale brown, white. As much as 15 feet thick. Unstratified to poorly horizontally stratified (fig. 6). Form linear to crescentic dune ridges as much as 15 feet tall and a mile long, areas of gentle swell-and-swale topography with less than 5 feet of relief, and less commonly, sheet-like deposits. Mapped where generally more than 3 feet thick.

Qtl LOWER TERRACE DEPOSITS—Fine-to-medium sand, pebble gravel, minor coarse sand; light gray, gray, very pale brown, brown, dark brown, brownish yellow, yellow. As much as 15, but generally less than 10, feet thick. Sand and gravel are quartz with a trace (<1%) of chert and ironstone in places. Form terraces and plains in valley bottoms with surfaces 2 to 15 feet above the modern floodplain. Include both stratified stream deposits (fig. 7) 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 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 (fig. 8) and poorly stratified to unstratified deposits laid down by groundwater seepage on pediments.

Qcu UPPER COLLUVIUM—Sand and gravel as in unit Qtu, unstratified to poorly stratified. as much as 5 feet thick. Forms veneers on steeper footslope pediments in uplands in the northeast part of the quadrangle. These pediments grade into upper terraces at their downslope edge.

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, gray. Sand and gravel are quartz with a trace of chert. As much as 60 feet thick in the Mullica valley fill, as inferred from well records. Forms an eroded terrace east and south of Batsto with a maximum surface elevation of 35 feet and includes sand and gravel fluvial and estuarine deposits in the subsurface in the Mullica River valley (sections AA', CC').

Qcm2f CAPE MAY FORMATION, UNIT 2, FINE-GRAINED FACIES—Silt, clay, very fine-to-fine sand; gray, light gray, yellow, very pale brown; minor peat and wood. As much as 80 feet thick. In subsurface only, in the Mullica valley fill (sections AA', CC'). Observed under lower terrace deposits in several streambanks along the Mullica River near Pleasant Mills; elsewhere, inferred from well records (table 1).

Qcm1 CAPE MAY FORMATION, UNIT 1—Fine-to-coarse sand, slightly clayey in places, pebble gravel; yellowish-brown, yellow, reddish-yellow, very pale brown, light gray. Iron-cemented in places. Generally weakly horizontally stratified to unstratified; in places, sand beds are horizontally laminated to cross bedded. Sand and gravel are quartz with minor (<2%) white and yellow weathered chert. As much as 15 feet thick. East of the Batsto River, occurs in erosional remnants that cap low interfluves with a maximum surface elevation of about 55 feet. In the lowland between the Batsto River and Nescochague Creek, forms a few low hills 10 to 15 feet above the lower terrace. In the Nesco-Wescoatville area, forms a plain with a top surface between 50 and 60 feet.

TQg UPLAND GRAVEL, LOWER PHASE—Fine-to-medium sand, slightly clayey to clayey 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. Clay is chiefly from weathering of chert. Gravel is poorly horizontally stratified to unstratified; sand beds are cross bedded in places. As much as 10 feet thick, generally less than 5 feet thick. Occurs as erosional remnants on interfluves, and as more continuous sheets in headwater areas, between 45 and 70 feet in elevation, east of the Batsto River. Includes stream deposits, deposits laid down by groundwater seepage on pediments, and pebble concentrates formed by winnowing of sand from older surficial deposits and the Cohansey Formation by groundwater sapping 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. Most chert is weathered to white and yellow clay; some chert pebbles are gray to dark gray and unweathered or partially weathered. Clay-size material is chiefly from weathering of chert and feldspar. Gravel is poorly horizontally stratified to unstratified; sand is cross bedded in places (fig. 9). As much as 10 feet thick. Occurs as erosional remnants on the highest ridgetops and plateaus. East of the Batsto River, base of the gravel declines from an elevation of 110 feet in the northeast corner of the quadrangle to 65 feet at Batsto. On the hill south of Great Swamp Branch, the base of the gravel is at about 80 feet in elevation. Includes stream deposits and pebble concentrates formed by washing of sand and clay by groundwater sapping or surface runoff.

Tb BRIDGETON FORMATION—Fine-to-coarse sand, slightly clayey to clayey, and pebble gravel; yellow, brownish-yellow, reddish-yellow. Sand and gravel are quartz with minor chert and a trace of feldspar in the sand. Feldspar and most chert are weathered to white and yellow clay; a few quartz pebbles are slightly weathered and easily fractured. Clay-size material is chiefly from weathering of chert. Sand is commonly cross bedded; gravel is poorly horizontally stratified. As much as 20 feet thick. Forms a plain with a surface elevation between 60 and 70 feet in the southwestern part of the quadrangle.

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 130 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 (figs. 8, 10) to large-scale trough and planar cross-bedding in sets as much as 3 feet thick. Sand is quartz; coarse-to-very coarse sand may include as much as 5% weathered chert and a trace of weathered feldspar. Fine sand may include as much as 10% opaque heavy minerals. 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. 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 5 feet thick, sand beds are commonly 1 to 6 inches thick but are as much as 2 feet thick. 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 260 feet thick in the southeastern part of the quadrangle, thins to about 100 feet in the northern part of the quadrangle. 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 four 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, 1999).

Tsr SHARK RIVER FORMATION—Clayey glauconitic quartz sand with shells, gray to dark green. More than 100 feet thick at Batsto; full thickness not penetrated in quadrangle. Thickness in adjacent areas ranges from between 40 and 100 feet to the north in the Indian Mills quadrangle (Stanford, 2015) to about 200 feet in a corehole at Ancora, in the Hammonton quadrangle to the west (Miller and others, 1999). Middle Eocene in age based on calcareous nannofossils and foraminifera (Miller and others, 1999).

MAP SYMBOLS

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

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

Tchc Concealed bedrock formations—Covered by surficial deposits.

4 ●
●
Qe4/Qtu ● 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.

figure 4 ● Photograph location

10 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.

14 Gamma-ray log—On sections. Radiation intensity 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 and upper terraces.

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

Fluvial scarp—Line at top, ticks on slope.

Dune ridge—Line on crest.

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—Area of extensive iron cementation in Cape May Formation, unit 1.

Excavation perimeter—Line encloses excavated area.

⨯ Sand and gravel pit—Inactive in 2021.

⨯ Sand and gravel pit—Active in 2021.

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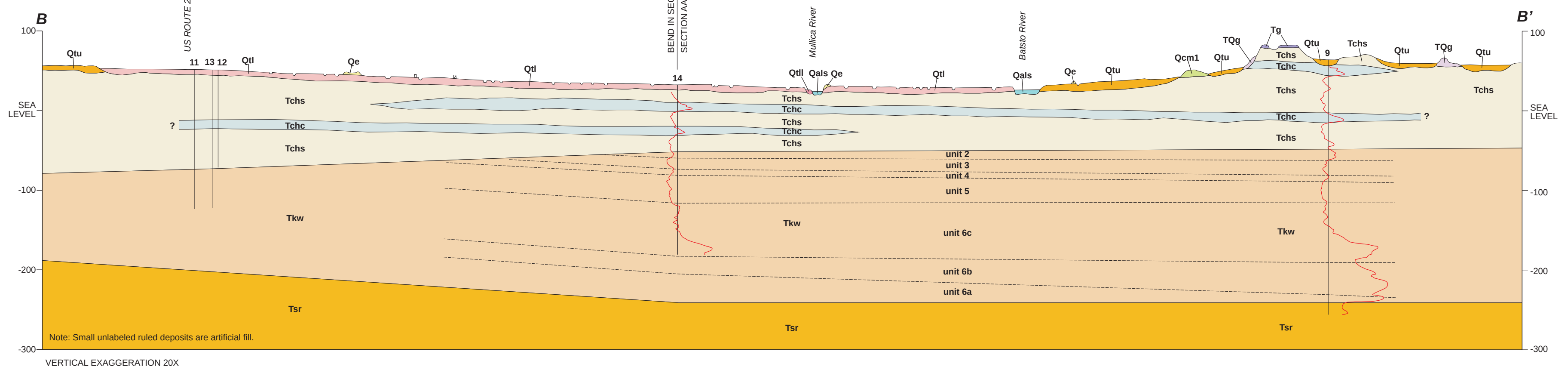
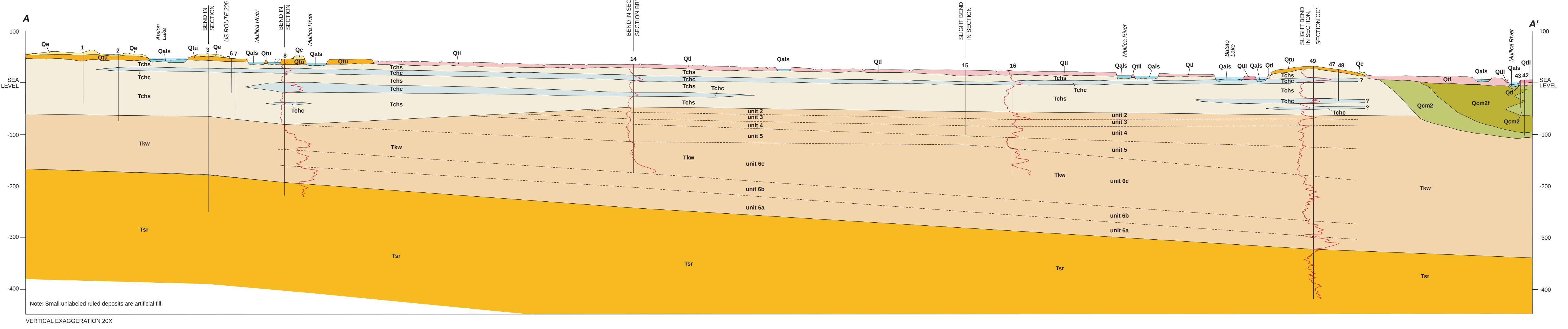
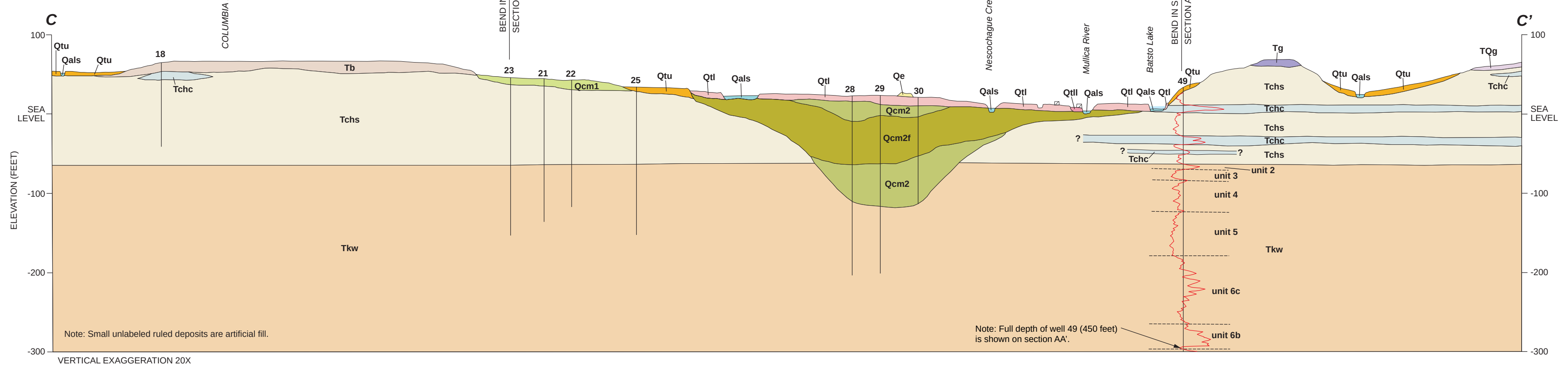






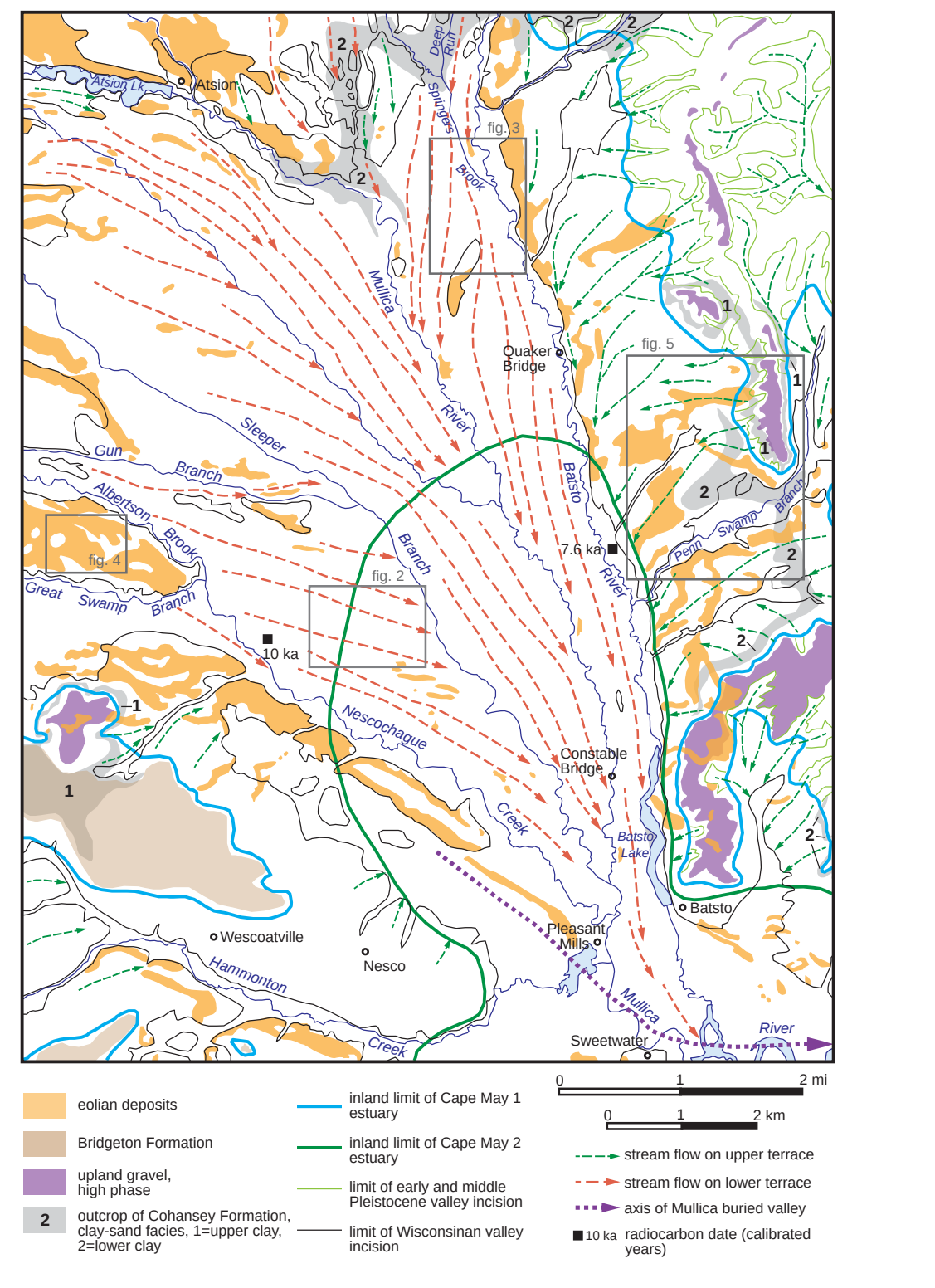


Figure 1. Geomorphic features, selected surficial deposits, and outcrop of Cohansey Formation, clay-sand facies, in the Atsion quadrangle. Stream flow direction on the upper and lower terraces is based on channel trends and terrace slope. The limit of early and middle Pleistocene valley incision is shown only for areas higher than the Cape May 1 estuary (>60 feet in elevation). All valleys and lowlands below 60 feet in elevation were incised before deposition of the Cape May unit 1 estuarine deposit. Areas of figures 2, 3, 4, and 5 shown by gray boxes.

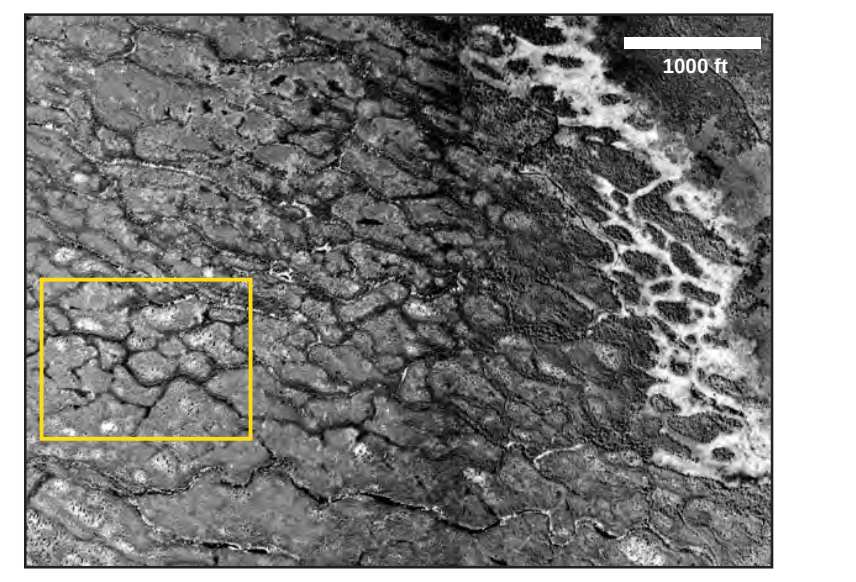


Figure 2. Aerial photograph of braided channels on the lower terrace. Channels are dark where vegetated by shrubs and white where vegetated by grass. Note polygonal pattern in yellow box suggesting that channels formed along frost cracks. Aerial photo taken in 1951. Area of figure 2 shown on figure 1.

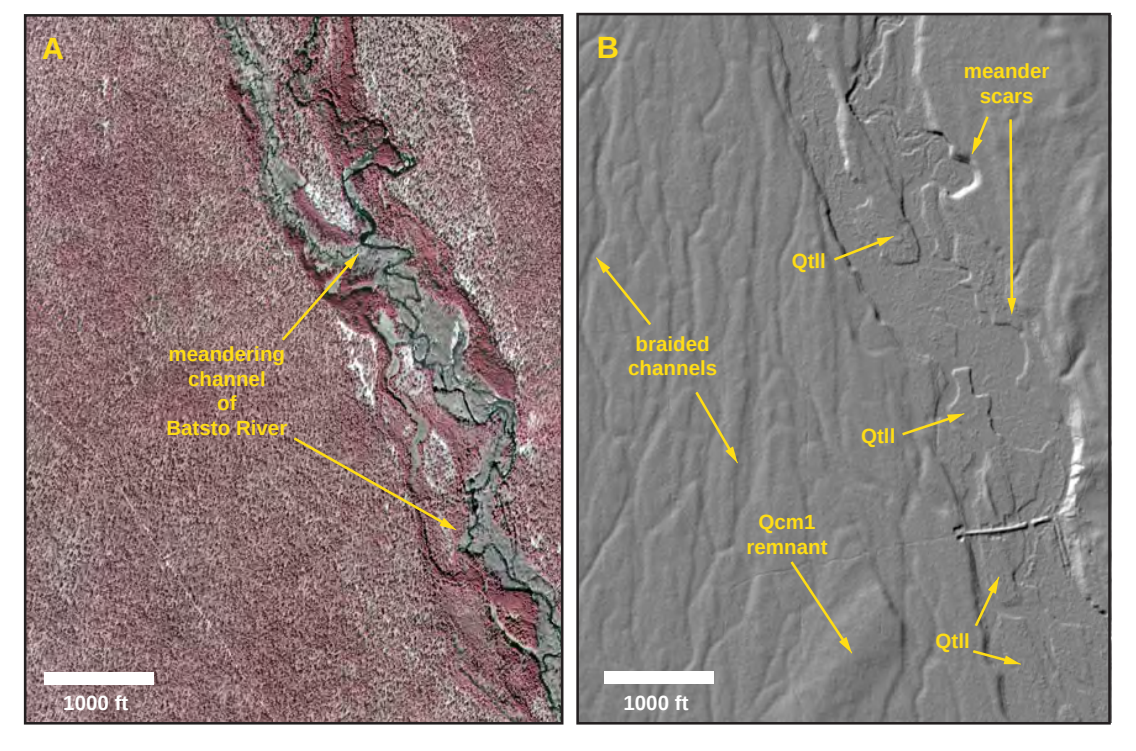


Figure 3. Paired infrared aerial photograph (A) and LiDAR hillshade image (B) showing contrast of braided channels on the surface of the lower terrace and the single meandering channel of the Batsto River on the present floodplain. Also note the low phase of the lower terrace (map unit Qtll) within the present floodplain belt and the erosional remnant of the Cape May unit 1 estuarine deposit (map unit Qcm1) surrounded by the lower terrace. Infrared photo taken 2002. Area of images shown on figure 1.

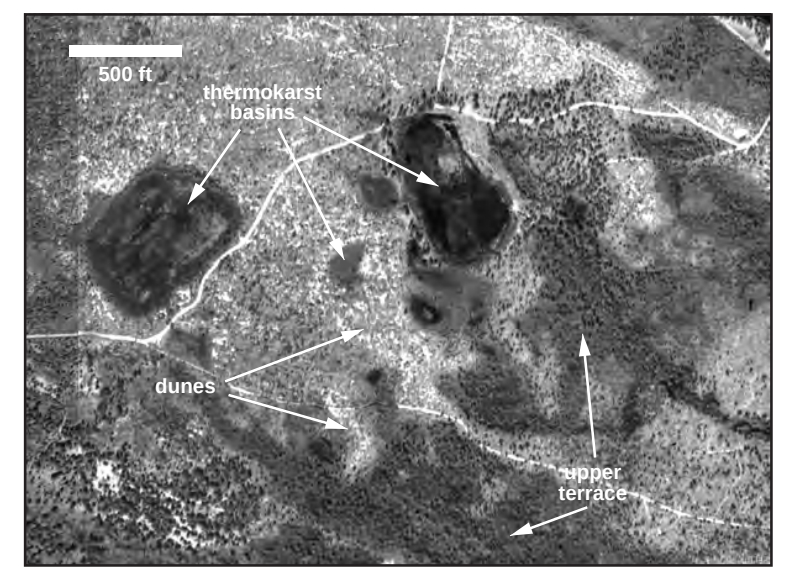


Figure 4. Aerial photograph showing thermokarst basins (dark elliptical ponds) formed on the upper terrace (dark grayish areas with thicker vegetation) and surrounded by eolian dune sand (light grayish to whitish areas). Upper terrace gravels also floor the larger basins. Photograph taken in 1940. Area of photo shown on figure 1.

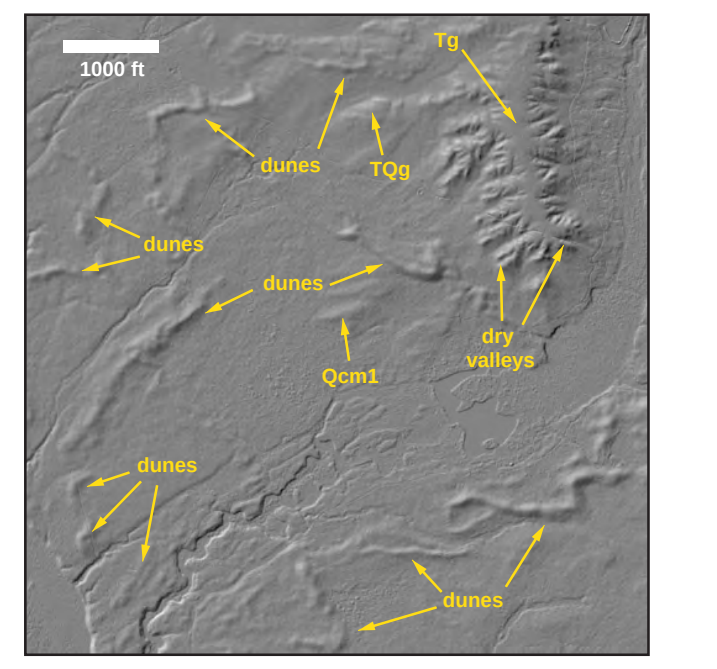


Figure 5. LiDAR hillshade image of dunes on the upper terrace. The trend of the dune crests indicates deposition by winds from the northwest. Also shown are dry valleys scribing the flanks of an upland, and erosional remnants of the upland gravel, high phase (map unit Tg), upland gravel, lower phase (TQg), and Cape May Formation, unit 1 (Qcm1). These remnants are on higher ground above the upper terrace. Area of image shown on figure 1.

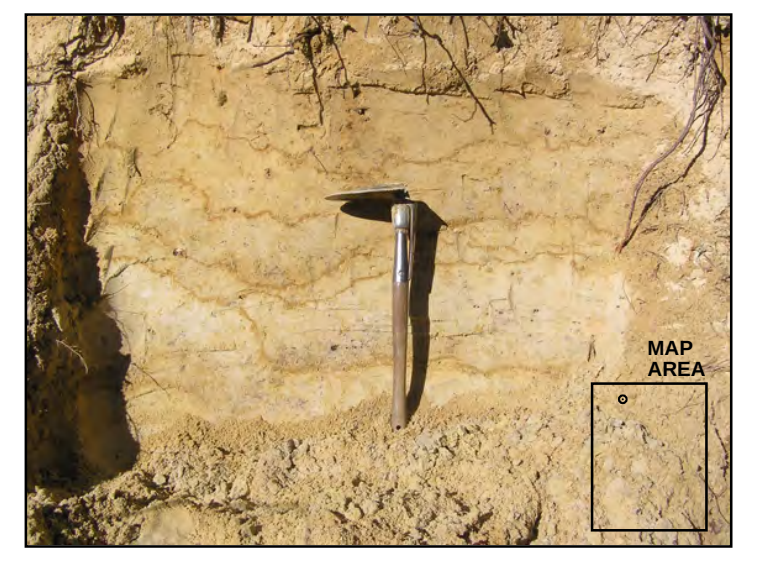


Figure 6. Eolian sand (Qe) exposed in a streambank along the Mullica River. Darker layers are from secondary iron precipitation rather than original deposition. This sand overlies the upper terrace deposit shown in figure 8, which was taken at the same streambank.

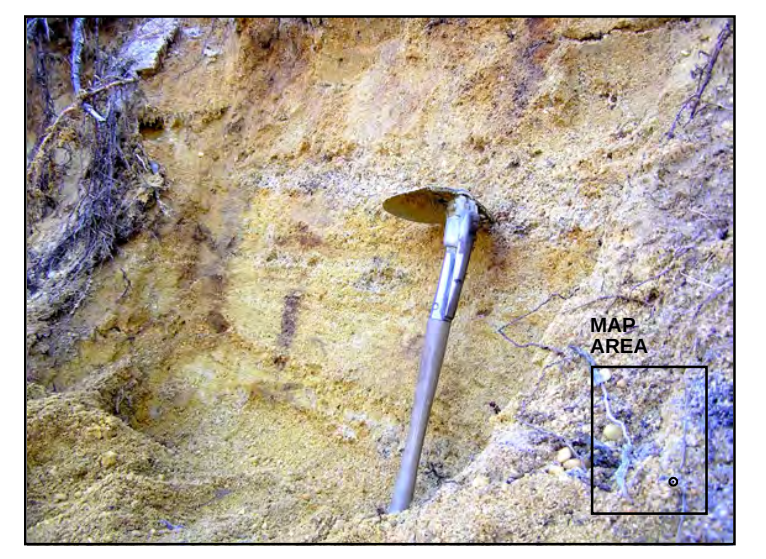


Figure 7. Lower terrace gravel (Qtl) exposed in a streambank along the Mullica River.

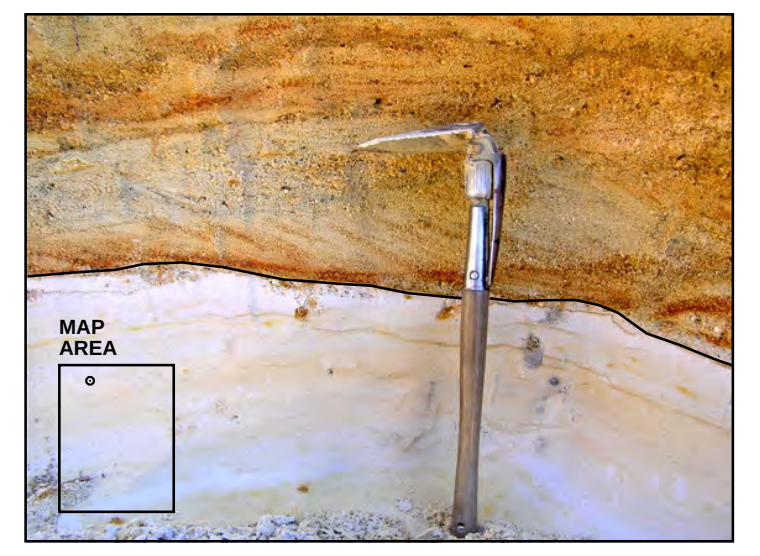
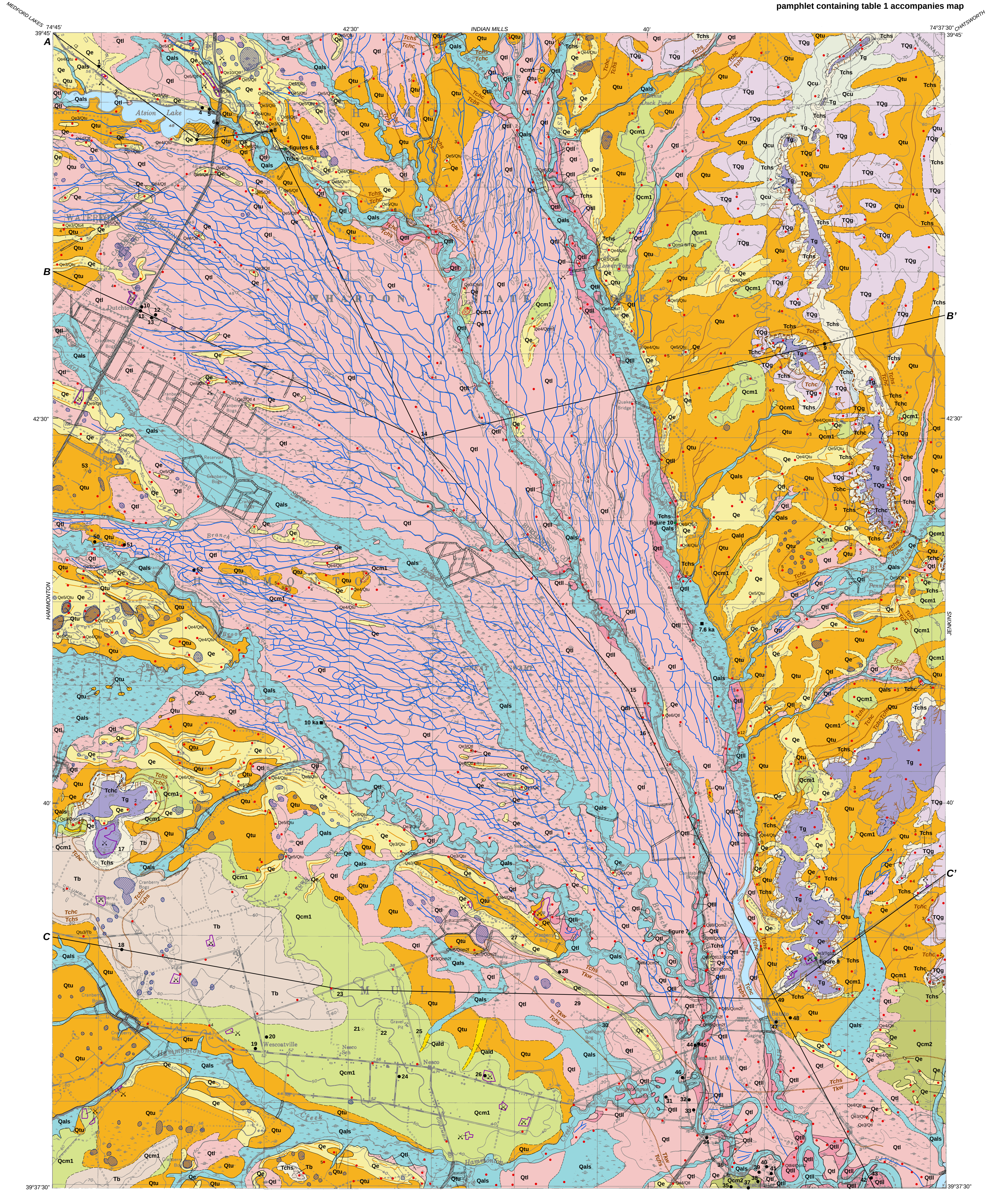
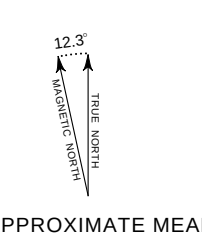


Figure 8. Upper terrace gravel (Qtu) overlying Cohansey Formation, sand facies (Tchs, below line) exposed in a streambank along the Mullica River. Note planar cross bedding in the terrace deposit indicating stream flow towards the right (southeast), and thin horizontal bedding in the Cohansey, which is typical of beach settings. The eolian sand shown in figure 6 overlies the gravel at this location.

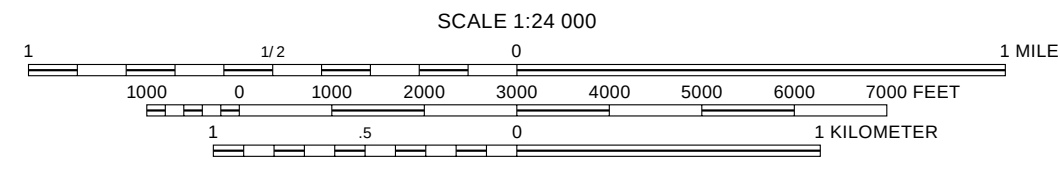


Base from U. S. Geological Survey, 1997.
Topography derived from imagery taken 1951 and other sources.
Photoinspected using imagery dated 1997.
Boundaries revised 1998.
North American Datum of 1927.



APPROXIMATE MEAN DECLINATION, 2021

SCALE 1:24 000



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

LOCATION IN NEW JERSEY

Geology mapped 2020-2021.
Cartography by S. Stanford.

Research supported by the U. S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G20AC00242.

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

By

Scott D. Stanford

2021

Figure 9. Upland gravel (Tg) exposed in a pit near Batsto. Cross bedding in sand to lower left of shovel indicates stream flow to right (south).

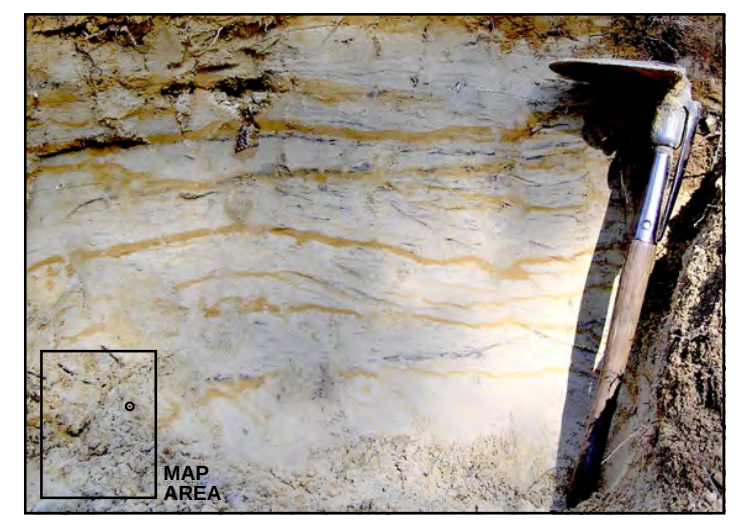
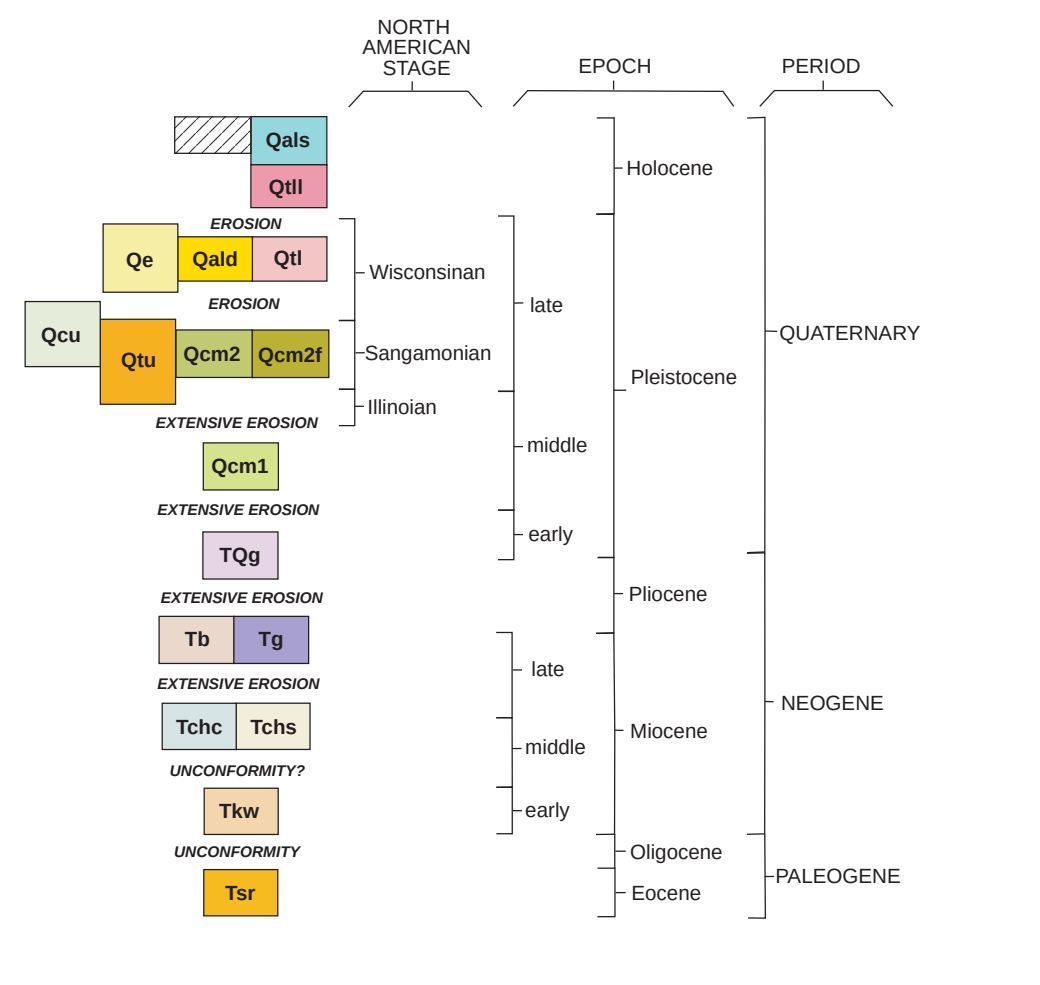


Figure 10. Cohansey Formation, sand facies (Tchs) exposed in a streambank along the Batsto River. Sand is thinly horizontally bedded to low-angle cross bedded. Black layers are enriched in opaque heavy minerals. These layers are indicative of beach settings, where wave action concentrates heavier grains in thin laminae. Orange layers are from secondary iron precipitation rather than primary deposition.

CORRELATION OF MAP UNITS



Geology of the Atsion Quadrangle
Atlantic and Burlington Counties, New Jersey

New Jersey Geological and Water Survey
Open-File Map OFM 134
2021

Pamphlet with table 1 to accompany map

Table 1. Selected well records. Well numbers in boldface indicate wells and borings on cross sections.

Well Number	Identifier[1]	Formations Penetrated[2]
1	32-28915	4 Qe 18 Qtu 54 Tchs 61 Tchc 99 Tchs
2	32-8125	5 Qe 11 Qtu 20 Tchs 40 Tchs+Tchc 67 Tchs 125 Tchs+Tchc 126 Tkw
3	32-24563	12 Qe over Qtu 28 Tchs 33 Tchc 76 Tchs 77 Tchc 119 Tchs 230 Tkw 305 Tsr
4	32-19453	10 Qe 16 Qtu 26 Tchs+Tchc 29 Tchco 34 Tchc 44 Tchco+Tchs 63 Tchs+Tchc
5	32-19729	10 Qe 16 Qtu 26 Tchs+Tchc 29 Tchco 34 Tchc 44 Tchco 63 Tchs+Tchc 74 Tchs 76 Tchc 112 Tchs
6	32-28707	5 Qals 25 Tchs 30 Tchc+Tchs 65 Tchs
7	32-14477	7 Qtu+Tchs 11 Tchc 25 Tchs 45 Tchco 110 Tchs
8	32-457, G	10 Qtu+Tchs 15 Tchs 25 Tchco 40 Tchs 60 Tchc 130 Tchs 235 Tkw 260 Tsr
9	32-1525, well 4D, G	10 Qtu+Tchs 20 Tchc 70 Tchs 80 Tchc 215 Tchs 305 Tkw 314 Tsr
10	32-18636	5 Qtl 50 Tchs 56 Tchc 61 Tchs 72 Tchc+Tchs 142 Tchs 143 Tchc 160 Tchs 170 Tkw
11	32-19142	5 Qtl 50 Tchs 56 Tchc 192 Tchs 143 Tchc 158 Tchs 172 Tkw
12	32-16285	22 Tchc+Tchs 125 Tchs
13	32-19715	5 Qtl 50 Tchs 56 Tchc 61 Tchs 72 Tchc+Tchs 142 Tchs 143 Tchc 165 Tchs 172 Tkw
14	32-1525, well 11D, G	20 Qtl+Tchs 30 Tchc 55 Tchs 60 Tchc 85 Tchs 206 Tkw
15	32-372	15 Qtl 80 Tchs 125 Tkw
16	01-496, Wharton Tract 4H (Clark and others, 1968; Rhodehamel, 1973), G	20 Qtl+Tchs 28 Tchc 80 Tchs 195 Tkw
17	32-533	18 Tchs 31 Tchs+Tchc 40 Tchs 44 Tchs+Tchc 49 Tchc 51 Tchs 57 Tchc 60 Tchco 62 Tchs+Tchc 71 Tchco 87 Tchs 89 Tchc 113 Tchs 120 Tchs+Tchc 126 Tchc 142 Tchs 218 Tkw
18	32-15633	10 Tb 45 Tchc 84 Tchs+Tchc 104 Tchs (with wood)
19	32-8666	9 Qcm1 38 Tchs+Tchc 55 Tchs 59 Tchs+Tchc
20	32-6484	12 Qcm1 20 Tb 35 Tchs 40 Tchc+Tchs 45 Tchc 64 Tchs
21	32-12597	60 Tchs 80 Tchs+Tchco 186 Tchs+Tkw
22	32-518	10 Qcm1 34 Tchs+Tchc 40 Tchs 42 Tchc 54 Tchco 60 Tchs 66 Tchco 111 Tchs 165 Tkw
23	32-12415	140 Tchs 200 Tkw
24	32-14765	10 Qcm1 20 Qcm1 or Tchs+Tchc 30 Tchs 40 Tchs+Tchc 55 Tchs (with wood) 65 Tchs
25	32-15567	40 Tchs+Tchc 140 Tchs 190 Tkw
26	32-14715	15 Qcm1 30 Tchs 45 Tchs+Tchc 80 Tchs
27	32-9568	3 Qtl 52 Qcm2f 65 Tchs
28	32-4810	10 Qtl 14 Qcm2f 49 Qcm2 89 Qcm2f 129 Qcm2f+Qcm2 224 Tkw
29	32-8416	12 Qtl+Qcm2f 23 Qcm2 138 Qcm2+Qcm2f 225 Tkw
30	32-12865	20 Qtl 40 Qcm2f 135 Qcm2
31	32-25843	19 Qtl 26 Qcm2f 65 Qcm2
32	E2011 17504	10 Qtl 40 Qcm2f 55 Qcm2 65 Qcm2f 70 Qcm2
33	32-14496	20 Qtl 90 Qcm2f 120 Qcm2
34	32-22008	12 Qtl 27 Qcm2 57 Qcm2f 90 Qcm2
35	32-13523	60 Qcm2+Qcm2f 82 Qcm2

Well Number	Identifier[1]	Formations Penetrated[2]
36	32-15473	20 Qtl+Qcm2f 63 Qcm2f
37	P2009 10581	40 Qcm2 60 Qcm2f 70 Qcm2
38	32-16315	20 Qcm2 50 Qcm2f 65 Qcm2
39	32-23078	28 Qtl 35 Qcm2f 60 Qcm2
40	E2011 04075	20 Qtl+Qcm2f 50 Qcm2f 60 Qcm2
41	32-15274	10 Qtl+Qcm2f 30 Qcm2f 60 Qcm2
42	32-1 (log by H. Herpers, N. J. Geological Survey, 1948)	20 Qtl+Qcm2f 69 Qcm2 101 Qcm2f 106 Qcm2
43	32-14038	20 Qtl+Qcm2f Qcm2+Qcm2f 45 Qcm2f 57 Qcm2
44	32-18775	30 Qtl+Qcm2 32 Qcm2 50 Qcm2 60 Qcm2f 65 Qcm2
45	32-18743	35 Qtl+Qcm2 45 Qcm2f 61 Qcm2
46	32-14681	14 Qtl+Qcm2 35 Qcm2f 60 Qcm2+Qcm2f 74 Qcm2
47	32-30001	40 Qtu+Tchs 45 Tchco 60 Tchs
48	32-28352	20 Qtu+Tchs 26 Tchco 62 Tchs+Tchc
49	32-913, G	20 Qtu+Tchs 30 Tchc 60 Tchs 72 Tchc 78 Tchs 82 Tchc 95 Tchs 350 Tkw 450 Tsr
50	32-29685	28 Qtu 42 Tchs 46 Tchs+Tchc 48 Tchs
51	E2017 14407	25 Qtu
52	32-25196	3 Qtl 11 Tchs
53	32-22210	20 Qtu+Tchs+Tchc 40 Tchs 60 Tchs+Tchc 135 Tchs

[1] Identifiers of the form 32-xxxxx, Exxx xxxxx, and Pxxx xxxxx are N. J. Department of Environmental Protection well-permit numbers. Permit number 32-1525 covers several wells, which are identified by their well number following the permit number. Identifier of the form “01-496” is the U. S. Geological Survey Ground Water Site Inventory well number with a lithologic log in the cited publications. A “G” following the identifier indicates that a gamma-ray log is available for the well.

[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 34 to bottom of hole at 62 feet. Abbreviations are: Qe, Qtl, Qtu, Qcm1, Qcm2, Tb = yellow and white sand, clayey sand, and gravel (sand and gravel surficial deposits); Qcm2f = gray clay, silt, muddy sand, silty sand, fine sand, with wood, peat, or organic material (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). Tsr = green clay, black and green sand, shells (Shark River Formation). A “+” sign indicates that units cannot be separately identified based on the log or are mixed or interbedded. 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 some well logs, surficial deposits cannot be distinguished from sands in the Cohansey Formation; thus, the uppermost Tchs unit in well logs may include overlying surficial deposits.