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GEOLOGY OF THE INDIAN MILLS QUADRANGLE
BURLINGTON COUNTY, NEW JERSEY
OPEN-FILE MAP SERIES OFM 108
pamphlet containing table 2 accompanies map

INTRODUCTION

The Indian Mills quadrangle is in the Pine Barrens region of the New Jersey Coastal Plain, in the southern part of the state. Outcropping sediments in the quadrangle include surficial deposits of late Miocene to Holocene age that overlie the Cohansey Formation, a marginal marine deposit of middle-to-late Miocene age. The surficial deposits include river, wetland, hillslope, and windblown sediments. The Cohansey Formation was deposited in coastal settings when sea level was more than 150 feet higher than at present in this region. As sea level lowered in the late Miocene, rivers flowing on the emerging Coastal Plain deposited the Beacon Hill Gravel, forming a broad regional river plain. With continued lowering of sea level, the regional river system shifted to the west of the Indian Mills quadrangle, and local streams began to erode into the Beacon Hill plain. Through the latest Miocene, Pliocene, and Pleistocene (about 8 million to 10,000 years ago), 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.

A summary of the stratigraphy and depositional setting of the Cohansey Formation is provided below. The geomorphic history of the quadrangle, as recorded by surficial deposits and landforms, is also discussed below. The age of the deposits and episodes of valley erosion are shown on the correlation chart. Lithologic logs for three test borings drilled for this study (Indian Mills 1 through 3) are provided in table 1. Table 2 (in pamphlet) reports the formations penetrated by selected wells and test borings, as interpreted from drillers' lithologic descriptions and geophysical logs.

Cross sections AA', BB', and CC' show deposits to a depth of 300 to 400 feet, which includes the Cohansey Formation, the underlying Kirkwood Formation, of early and middle Miocene age, and, in the northern and western parts of the quadrangle, six pre-Kirkwood formations of Paleogene and Cretaceous age. Two test holes in the quadrangle (wells 66 and 119 in table 2) penetrated below 400 feet, to total depths of 852 and 952 feet, respectively. The formations penetrated in these holes are listed in Kasabach and Scudder (1961). Deeper formations beneath the quadrangle are also shown and discussed in Owens and others (1998).

Most wells in the quadrangle draw water from sand of the Cohansey Formation at depths of 50 to 100 feet. Many wells in the northern and western parts of the quadrangle, where the Cohansey and Kirkwood formations thin, tap the Mount Laurel Formation, which is a Cretaceous sand that is a productive regional aquifer (Rush, 1968), at depths of 300 to 450 feet (for example, wells 1, 7, 8, 11, 14-16, 21, 24, 26-28, 38-43, and 52 in table 2). Other wells in the northern and western parts of the quadrangle tap sand in the Shark River Formation, a glauconitic sand of Eocene age that directly underlies the Kirkwood Formation, at depths of 175 to 300 feet (for example, wells 109, 110, and 111 in table 2). The Kirkwood Formation, and formations between the Shark River and the Mount Laurel, are not significant aquifers in the map area.

COHANSEY FORMATION

The Cohansey Formation consists of stacked successions composed of sand deposited in beach and nearshore settings (Sand Facies, Tchs) overlain by interbedded sand and clay deposited in tidal flats, bays, and coastal wetlands (Clay-Sand Facies, Tchc) (Carter, 1972, 1978). Pollen and dinoflagellates recovered from peat beds in the Cohansey at Legler, about 30 miles northeast of Indian Mills, indicate a coastal swamp-tidal marsh environment (Rachele, 1976). The Legler pollen (Greller and Rachele, 1983), pollen obtained 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 late middle to early late Miocene age for the Cohansey. The Cohansey generally lacks marine fossils, particularly in updip areas like the Indian Mills quadrangle where it has been weathered, and is therefore difficult to date. Lower parts of the Cohansey in updip areas may be age-equivalent to the younger sequences of the Kirkwood Formation downdip (the Kirkwood 2 and 3 sequences of Sugarman and others, 1993) of middle Miocene age. The Cohansey sediments may be coastal facies of the Kirkwood shallow-shelf deposits. The pronounced westward thinning of the Kirkwood in the quadrangle (sections AA', BB', CC'), from 160 feet to between 40 and 70 feet, may reflect this facies transition.

In the Indian Mills quadrangle, clays in the Cohansey are in beds as much as two feet thick, but generally less than six inches thick, and are interbedded with sand. Most are oxidized and multicolored but black to brown organic clay was penetrated in several hand-auger holes and is reported in logs of wells (noted as "Tchco" on map and in table 2). Clayey strata are as much as 30 feet thick, and some are continuous for more than eight miles both downdip (northwest to southeast) and along strike (northeast to southwest) (fig. 1). The clay stratum beneath the Batsto River valley (bed 1 on fig. 1), and a thinner, overlying clay in the northwestern corner of the quadrangle (bed 2 on fig. 1) are continuous with clays mapped in the adjacent Chatsworth quadrangle (Stanford, 2012), demonstrating continuity of the beds over distances of as much as 15 miles. The laminated bedding and thin but areally extensive geometry 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 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, a weathered chert-quartz gravel which does not occur in the map area, but caps hills and uplands above an elevation of 180 feet to the east of the quadrangle (Stanford, 2010, 2012), is the earliest record of this drainage. Flow direction inferred from cross-beds, slope of the deposit, and gravel provenance, indicate that the Beacon Hill was deposited by rivers draining southward from the Valley and Ridge province in northwestern New Jersey and southern New York (Stanford, 2009).

Continued decline of sea level through the late Miocene and early Pliocene (approximately 8 to 3 million years ago [Ma]) caused the regional river system to erode into the Beacon Hill plain. As it did, it shifted to the west of the Indian Mills quadrangle. The map area became an upland from which local streams drained southeastward to the Atlantic. 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 100 feet below the level of the former Beacon Hill plain. These deposits are mapped as Upland Gravel, High Phase (unit Tg). Stream drainage during deposition of the gravels, as inferred from the elevation and orientation of their erosional remnants, is shown by orange arrows on figure 1. Today, owing to topographic inversion, they cap hilltops.

A renewed period of lowering sea level in the early Pleistocene (approximately 2.5 Ma to 800,000 years ago [800 ka]) led to another period of valley incision. Groundwater seepage and channel and slope erosion reworked the Upland gravels and deposited the Upland Gravel, Lower Phase (unit TQg) in shallow valleys 20 to 50 feet below the Upland Gravel, High Phase. These deposits today cap interfluves and low hills and mantle some upper slopes around the higher gravel remnants. Stream drainage at this time, inferred from the elevation and orientation of the interfluve deposits, and from paleocurrent measurements on cross beds near Hampton Gate, is shown by green arrows on figure 1.

Continuing incision in the middle and late Pleistocene (about 800 to 10 ka) formed the modern valley network. Sediments laid down in modern valleys include Upper and Lower Terrace Deposits (units Qtu, Qtuo, and Qtl), inactive deposits in dry valleys (unit Qald), and active floodplain and wetland deposits (Qals) 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 5 to 40 feet above modern valley bottoms. They may include sediments laid down during periods of cold climate, and during periods of temperate climate when sea level was high, in the middle and late Pleistocene. During cold periods, permafrost impeded infiltration of rainfall and snowmelt and this, in turn, accelerated groundwater seepage and slope erosion, increasing the amount of sediment entering valleys. During periods of high sea level, the lower reaches of streams in the quadrangle, below an elevation of 60 feet, may have been close to sea level, favoring deposition.

Upper Terrace Deposits are divided into two units: an older, higher deposit (Qtuo) that caps the broad, flat divide between the Rancocas basin and the Batsto basin, and also occurs on small erosional remnants on several low hilltops in the Batsto River valley, and a younger, lower deposit (Qtu) within present-day valleys. The older deposit caps a broad area with surface elevation of 80 to 110 feet and does not show an overall slope, except where it feathers up onto older uplands. This distribution suggests that it was deposited by groundwater seepage and local headwater streams before incision of present-day stream valleys. The younger, lower deposits, which form terraces 5 to 20 feet above present floodplains, record the early stages of fluvial deposition as streams downcut into the older terrace.

The headwaters of the Batsto River, at and upstream of the Hampton Gate area, were able to broaden their valleys more rapidly than the headwaters of Friendship Creek, because the clay bed beneath the Batsto valley concentrated groundwater discharge and enhanced seepage erosion at the base of the uplands at the valley edge. This enhanced erosion allowed the Batsto River to capture part of the drainage of the Friendship Creek basin. This seepage erosion continues today, particularly at the base of the upland west of Hampton Gate and at the base of the uplands in the Friendship Creek headwaters. Similar captures occurred in the Chatsworth area just east of the quadrangle (Stanford, 2012).

Lower Terrace Deposits (unit Qtl) form low, generally wet, terraces less than 5 feet above modern valley bottoms. They formed from stream and seepage erosion of the Upper Terrace Deposits, and Cohansey Formation, probably during or slightly after the last period of cold climate around 25-15 ka, based on radiocarbon dates on organic material from lower terrace deposits elsewhere in the New Jersey Coastal Plain (Stanford and others, 2002; Stanford, 2012). Dry-valley alluvium (unit Qald) was likely also laid down at this time. Eolian deposits (Qe) form dunes, chiefly atop the upper terraces and older surfaces. In places, such as the Skit Branch and Roberts Branch lowlands, dunes also formed atop lower terraces. This distribution indicates that the eolian deposits postdate the upper terraces and continued to form, in places, after deposition of the lower terraces, but predate formation of modern floodplains. This age range, in turn, indicates that most of the windblown sediment was deposited during periods of cold climate in the Wisconsinan stage of the late Pleistocene (between 80 and 11 ka), when reduced forest cover, increased alluviation in valley bottoms, and dry, windy conditions promoted eolian erosion and deposition (French and others, 2007).

Windblown deposits are particularly widespread in the northwestern part of the quadrangle, where they include a sand facies with dune morphology (mapped as Qe where greater than 3 feet thick, shown as dot pattern on fig. 1) and a silt to fine sand (known as "loess") facies without dune morphology (dot-dash pattern on fig. 1). The dunes vary from small, low swells and swales with a few feet of relief to narrow, elongate ridges (shown as line symbol on map and on fig. 1) as tall as 15 feet and as long as a mile (fig. 2). These elongate dunes are typically oriented northeast-southwest to east-west, and some are asymmetric in profile, with gentle northwest slopes and steeper southeast slopes. Some are crescentic in plan, or consist of crescentic segments, with the axis of the crescents oriented northwest-southeast. These features indicate that winds were blowing from the west and northwest when the dunes formed. The loess facies occurs downwind (south and east) of the main dunefield. The silty texture of the loess retains moisture, in contrast to the dry quartz sand of the Cohansey Formation and surficial deposits typical of uplands in the Pine Barrens. The moist soils developed on the loess support vegetable and sod farms in the area between Tabernacle and Indian Mills, and holly-gum forest in unfarmed areas, an unusual land use and forest type in the Pine Barrens. The silt and fine sand of the loess was blown from outcropping Kirkwood Formation, and silty terrace deposits, in the Rancocas basin north of the quadrangle.

Modern floodplain and wetland deposits (unit Qals) were laid down within the past 10 ka, based on radiocarbon dates on basal peat in other alluvial wetlands in the Pine Barrens (Buell, 1970; Florer, 1972; Stanford, 2000). In many valleys and lowlands the modern wetland deposits are inset only one or two feet into the lower terraces. In these settings, the modern wetland deposits are distinguished from lower terrace deposits chiefly by their thicker peat.

Several other landform features in the quadrangle are the product of cold climate, including thermokarst basins, braided channels, and polygonal patterned ground. Thermokarst basins are shallow depressions, circular to oval in plan, that form when subsurface ice lenses melt (Wolfe, 1953; French and others, 2005). These basins (symboled on map) typically form in sandy deposits in lowlands with shallow water table, or in upland settings where fine-grained deposits provide a perched water table (fig. 2). Basins that border eolian deposits were likely formed or enlarged by wind erosion (French and Demitroff, 2001). Several large, and, in three places, overlapping, basins occur at the west edge of the Batsto River valley. These basins may mark the sites of ice lenses that grew unusually large because they were fed by groundwater from the upland to the west perched atop the clay bed flooring the valley.

Braided-channel networks (symboled on map) scribe the lower-terrace surface in the Batsto River valley. The channels are a foot or two lower than the terrace surface, and so are wetter than the terrace. Many are visible on aerial photographs as grass and shrub glades, distinct from pine forest on the terrace surface. Braided channels formed when permafrost impeded infiltration and thus increased groundwater seepage and runoff. The increased seepage and runoff washed sediment from uplands into valleys, choking streams with sand and gravel, which caused channels to aggrade and split, forming a braided pattern. The braided channels are inactive today (although some conduct overflow drainage during periods of high water table) and contrast strikingly with the meandering, single-channel modern streams that receive little to no upland runoff and sediment. One network of channels on the lower terrace two miles southwest of Hampton Furnace has a polygonal pattern rather than a braided pattern. This polygonal pattern was formed by the growth of frost cracks in the terrace deposits, which filled with ice to become ice wedges that later became drainage channels when the ice melted.

DESCRIPTION OF MAP UNITS

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

aft TRASH FILL—Trash mixed and covered with clay, silt, sand, and minor gravel. As much as 40 feet thick.

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 6 feet thick. Sand and gravel consist chiefly of 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.

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 consist of quartz. In dry valley bottoms forming headwater reaches of streams. These valleys lack channels or other signs of surface-water flow. They may have formed under cold-climate conditions when permafrost impeded infiltration, raising the water table and increasing surface runoff. The deposits are therefore largely relict. Several narrow dry valleys south of High Crossing, in the southeast corner of the quadrangle, are shown by line symbol rather than as a map unit.

Qe EOLIAN DEPOSITS—Fine-to-medium quartz sand; very pale brown, white. As much as 20 feet thick; mapped only where more than 3 feet thick. Form dune ridges and dunefields, including several large fields in the northwestern part of the quadrangle and smaller deposits in the Batsto River valley. The deposits in the northwest were blown from terrace sand and fine sand of the Kirkwood Formation in the Rancocas basin north of the quadrangle. The Batsto valley deposits are of local origin and formed where sand of the Cohansey Formation, and upper and lower terrace sand, were exposed to wind erosion. Dunes vary from narrow, single-crested ridges as much as a mile long and 15 feet tall to low swells with only 2 to 3 feet of relief. Silty very fine-to-fine sand eolian deposits ("loess") are widespread in the western half of the quadrangle (fig. 1). These deposits are generally less than 4 feet thick but may be as much as 8 feet thick. Loess deposits are not shown as a map unit but are identified by the label "ls" where penetrated in hand-auger holes.

Qtl LOWER TERRACE DEPOSITS—Fine-to-medium sand, pebble gravel, minor coarse sand; light gray, brown, dark brown. As much as 10 feet thick. Sand and gravel consist almost entirely of quartz. Form terraces and pediments in valley bottoms with surfaces 2 to 5 feet above modern floodplains. Include both stratified stream-channel deposits 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. In places, gravel is more abundant in lower terrace deposits than in upper terrace deposits due to winnowing of sand from the upper terrace deposits 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 20 feet thick, generally less than 10 feet thick. Sand and gravel consist almost entirely of quartz. Form terraces and pediments with surfaces 5 to 20 feet above modern floodplains. Include stratified stream-channel deposits and poorly stratified to unstratified deposits laid down by groundwater seepage on pediments.

Qtuo UPPER TERRACE DEPOSITS, OLDER PHASE—Sand and pebble gravel as in unit Qtu, with a trace (<1%) of weathered chert in places. Cemented by iron in places in the Batsto valley. Form a broad terrace on the Batsto-Rancocas divide, and occur in erosional remnants on hilltops in the Batsto valley, with surfaces 20 to 30 feet above upper terraces. As much as 20 feet thick.

TQg UPLAND GRAVEL, LOWER PHASE—Fine-to-medium sand, clayey in places, and pebble gravel; minor coarse sand; yellow, very pale brown, reddish-yellow. Sand and gravel consist of quartz with a trace of white weathered chert in the coarse sand-to-fine pebble gravel fraction. Clay is chiefly from weathering of chert. As much as 20 feet thick, generally less than 5 feet thick. Occurs in erosional remnants on interfluves and hilltops, and as a patchy mantle on upper slopes adjacent to hilltop remnants of the Upland Gravel, High Phase, between 70 and 140 feet in elevation. Base of the deposits generally declines in elevation from north to south across the quadrangle, indicating southerly fluvial drainage during their deposition. Southerly paleoflow is also indicated by the dip of cross beds exposed at two sites in the former sand pit west of Hampton Gate. Includes stratified stream-channel deposits, poorly stratified 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 in places, and pebble gravel; yellow, brownish-yellow, reddish-yellow, very pale brown. Sand and gravel consist of quartz, with a trace of chert, and weathered feldspar, in the coarse sand-to-fine pebble gravel fraction. Chert is weathered to white and yellow clay; some chert is gray to dark gray and partially weathered. Clay-size material chiefly is from weathering of chert and feldspar. As much as 15 feet thick. Occurs as erosional remnants on hilltops, between 90 and 150 feet in elevation. Elevation of the base of the deposits declines from 140 to 90 feet from north to south across the quadrangle, indicating southerly fluvial drainage during their deposition. Includes stratified and cross-bedded stream-channel deposits and poorly stratified to unstratified pebble concentrates formed by washing of sand and clay from the Beacon Hill Gravel by groundwater sapping or surface runoff.

COHANSEY FORMATION—The Cohansey Formation is a 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 test drilling, gamma-ray well logs, and surface mapping using 5-foot hand-auger holes, exposures, and excavations. Total thickness of the Cohansey in the Indian Mills quadrangle is as much as 140 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. Well-stratified to unstratified; stratification ranges from thin, planar, subhorizontal beds (fig. 3) to large-scale trough and planar cross-bedding. 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. 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 120 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. 4). Clays are white, yellow, very pale brown, reddish-yellow, light gray; sands are yellow, brownish-yellow, very pale brown, reddish-yellow. Rarely, clays are brown to dark brown to black and contain organic matter. As much as 25 feet thick, generally less than 15 feet thick.

Tkw KIRKWOOD FORMATION—Fine sand, silty fine sand, sandy clay, clay, fine-to-medium sand; gray, dark gray, brown. Sand is quartz with some mica. Small area of subcrop in the northwest corner of the quadrangle is covered by surficial deposits. The extent of subcrop here is based on mapping in the Pemberton quadrangle to the north (Owens and Minard, 1964). As much as 170 feet thick in the eastern part of the quadrangle, thins to between 40 and 70 feet at the western edge. Kirkwood sediments in the Indian Mills quadrangle are within the "lower Kirkwood sequence" of Sugarman and others (1993) and within the lower and Shiloh Marl members of Owens and others (1998). These members are of early Miocene age, based on strontium stable-isotope ratios and diatoms (Sugarman and others, 1993).

Tsr SHARK RIVER FORMATION—Clayey glauconitic quartz sand, gray to dark green. In subsurface only. As much as 100 feet thick to east, thins to 40 feet to west. Middle Eocene in age based on calcareous nannofossils and foraminifers (Miller and others, 1999).

Tmq MANASQUAN FORMATION—Silty clay to clayey sand, slightly glauconitic, gray to greenish-gray. In subsurface only, 25-30 feet thick. Early Eocene in age based on calcareous nannofossils and foraminifers (Miller and others, 1999).

Tvt VINCENTOWN FORMATION—Clayey glauconitic quartz sand with calcareous shell debris, gray to greenish-gray. In subsurface only, approximately 60 feet thick. Late Paleocene in age, based on calcareous nannofossils (Sugarman and others, 2010).

Tht HORNERSTOWN FORMATION—Glauconite clay, green to dark green. In subsurface only, 10 to 15 feet thick. Paleocene in age, based on calcareous nannofossils and foraminifers (Sugarman and others, 2010).

Kns NAVESINK FORMATION—Clayey glauconitic quartz sand with calcareous shell debris, black, dark green, brown. In subsurface only, 30 feet thick. Late Cretaceous (Maastrichtian) in age, based on calcareous nannofossils (Sugarman and others, 2010).

Kml MOUNT LAUREL FORMATION—Glauconitic quartz medium sand with calcareous shell debris, light gray, gray, greenish-gray, yellow. In subsurface only, approximately 70 feet thick. Late Cretaceous (Campanian) in age, based on strontium stable-isotope ratios (Sugarman and others, 2010).

MAP SYMBOLS

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

Contact of Cohansey facies—Approximately located. Dashed where exposed, dotted where covered by surficial deposits. Solid triangle indicates contact observed in outcrop. Open triangle indicates contact penetrated in hand-auger hole.

4 ● Qe5/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.

(Tchc) Concealed formation—Covered by surficial deposits.

Tchc ● Isolated occurrence of Cohansey Formation, clay-sand facies—Within areas mapped as Cohansey Formation, sand facies.

Tchco ● Organic clay penetrated in hand-auger hole—Black to brown organic clay of Cohansey Formation, clay-sand facies.

ls 4 ● Qe 2 ● Eolian sediment penetrated in hand-auger hole—Silt and very fine-to-fine sand ("loess", abbreviated "ls") or sand (Qe) overlying mapped unit. Number indicates thickness, in feet, of loess or sand.

fig. 3 ● Photograph location

47 ● Well or test boring—Location accurate to within 200 feet. List of formations penetrated provided in table 2.

74 ⊙ Well or test boring—Location accurate to within 500 feet. List of formations penetrated provided in table 2.

Indian Mills 2 ● Test boring—Log in table 1.

Gamma-ray log—On sections. Radiation intensity increases to right.

Seepage scarp—Line at foot of scarp, water drains downslope from scarp.

Abandoned channel—Line in channel axis. Delineates relict braided channels on lower-terrace surfaces.

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

Dry channel—Line in channel axis. Narrow, dry fluvial channel with no evidence of present-day flow.

Dune ridge—Line on crest.

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

Iron-cemented sand—Extensive iron cementation or hardening in mapped unit.

Excavation perimeter—Line encloses excavated area.

Sand pit—Inactive in 2015.

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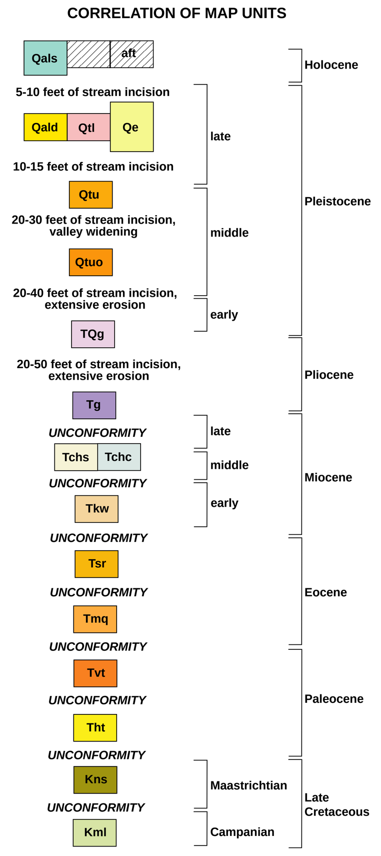
CORRELATION OF MAP UNITS



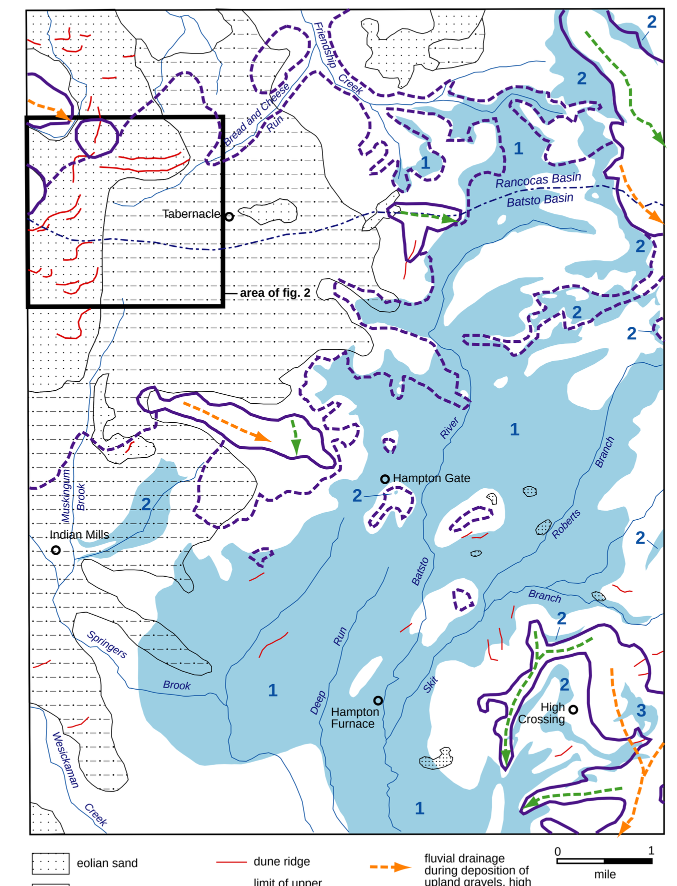


Figure 1.--Eolian deposits, subcrop of Cohansey Formation, Clay-Sand Facies, and geomorphic features in the Indian Mills quadrangle.

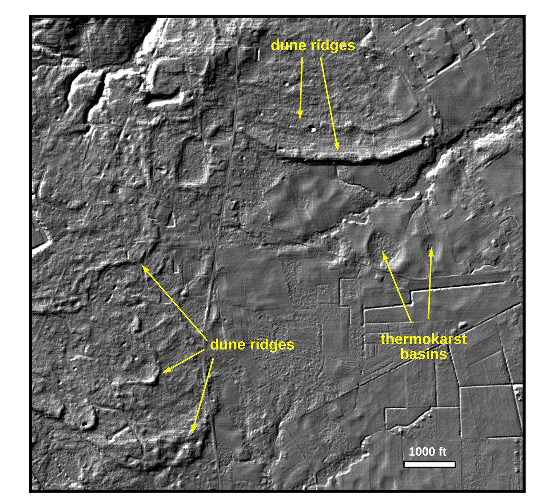


Figure 2.--Shaded relief image showing dune ridges and thermokarst basins on upper terrace, older phase, west of Tabernacle. Location shown on figure 1.

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

N. J. permit number and identifier	Lithologic log	
	Depth (feet below land surface)	Description (map unit assignment in parentheses)
E201501323 Indian Mills 1	0-5	brown, yellowish-brown silty very fine-to-fine sand (Qe)
	5-15	light yellowish-brown to brownish-yellow fine-to-medium sand with a few fine quartz pebbles (Qtu)
	15-52	yellow to reddish-yellow fine-to-medium sand with some medium-to-coarse sand (Tchs)
	52-80	yellow fine sand (Tchs)
	80-104	gray fine sand, slightly micaceous (Tkw)
E201501324 Indian Mills 2	0-5	very pale brown, yellow, reddish-yellow clayey fine-to-medium sand with thin beds and laminae of very pale brown and white clay (Tchc)
	5-62	yellow to brownish-yellow medium-to-coarse sand, some fine-to-medium sand, with few to some fine quartz pebbles (Tchs)
	62-98	gray to dark gray fine-to-medium sand, some medium-to-coarse sand, a very few fine quartz pebbles (Tchs)
	98-104	dark gray fine sand, slightly micaceous (Tkw)
E201501325 Indian Mills 3	0-10	brownish-yellow to yellowish-brown fine-to-medium sand with a few fine quartz pebbles (Qtu)
	10-12	yellow to brownish-yellow fine sand (Tchs)
	12-21	yellow fine sand with thin beds and laminas of white to very pale brown clay (Tchc)
	21-51	yellow to brownish-yellow fine sand (Tchs)
	51-62	brownish-yellow to reddish-yellow fine-to-medium sand (Tchs)
	62-81	dark gray fine sand, some fine-to-medium sand (Tchs)
	81-104	dark gray very fine-to-fine sand, slightly micaceous (Tkw)

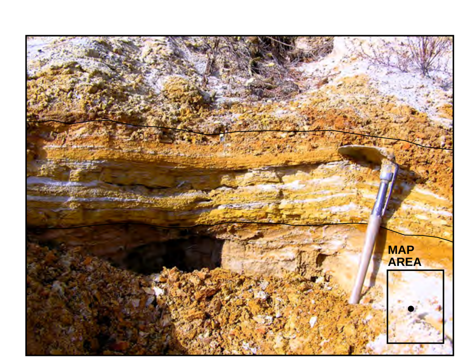


Figure 4. Thinly bedded clay (between lines) and sand (above and below lines) of the Cohansey Formation, Clay-Sand Facies. Alternating thin beds of clay and sand are characteristic of tidal-flat deposits. Inset shows location.

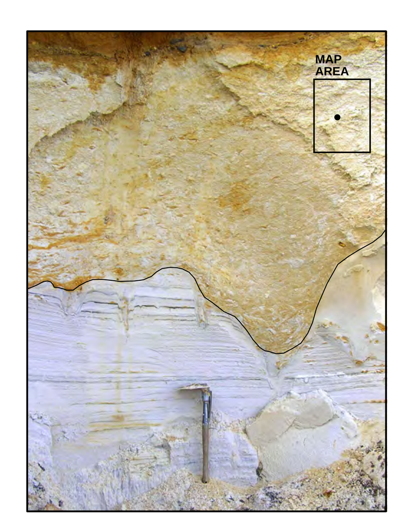


Figure 3. Cohansey Formation, Sand Facies, showing laminated bedding (below line) overlain by nonstratified sand. Cohansey sand is cut into the laminated sand. Laminations are defined by thin beds of black heavy minerals. Note burrowing in the laminated sand near the contact. Laminated sands are beach deposits. The channel may be tidal or from storm overwash. Inset shows location.

Base map from U. S. Geological Survey, 1995.
Corner ticks are on North American Datum of 1983.

APPROXIMATE MEAN DECLINATION, 1999

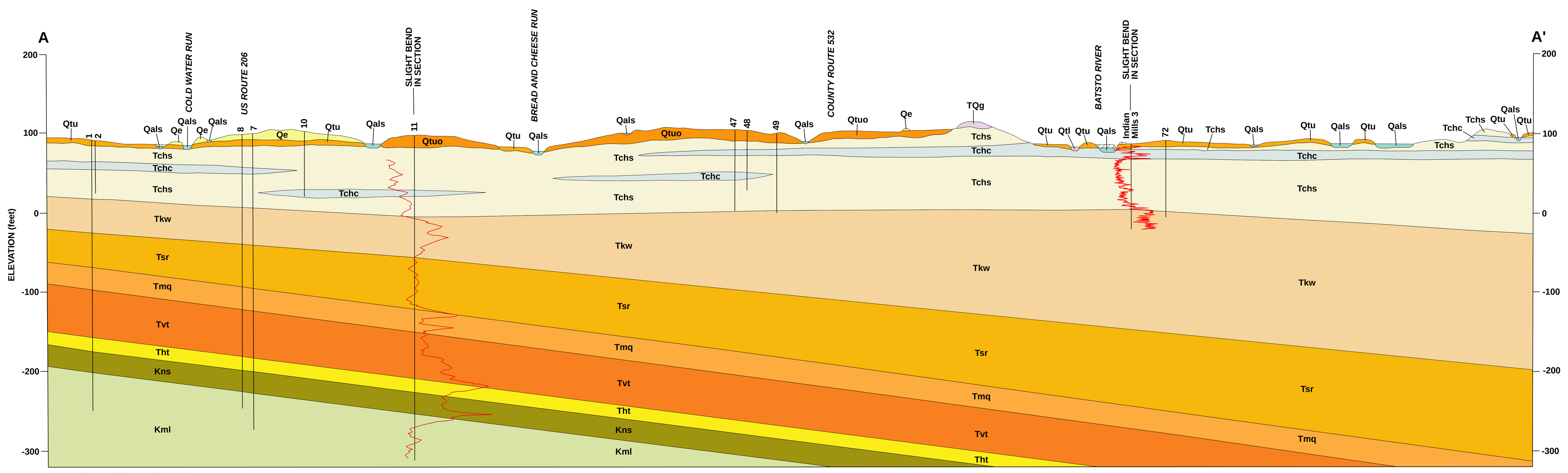
SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

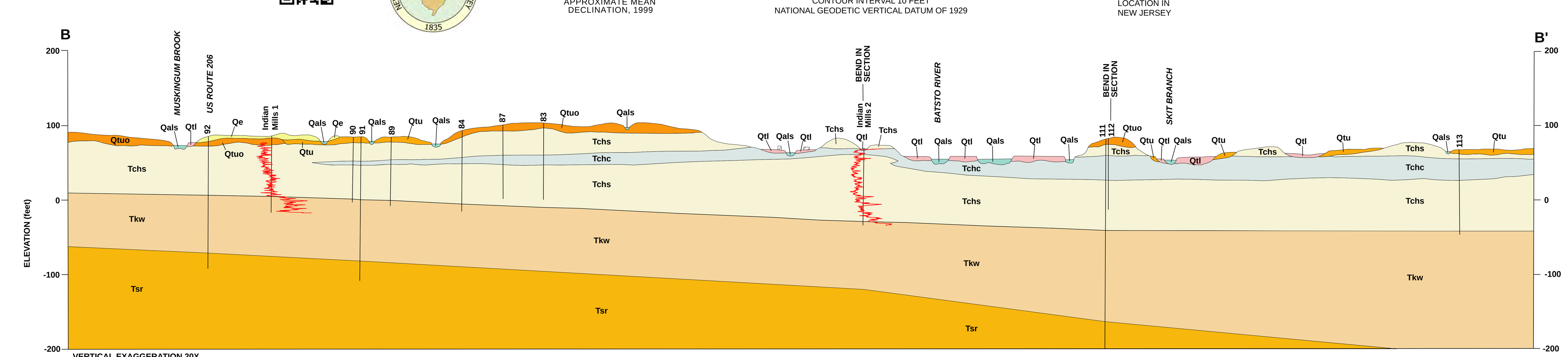
LOCATION IN NEW JERSEY

Geology mapped 2011, 2014-2015
Cartography by S. Stanford
Drilling by B. Buttari and G. Steidl
Geophysical logging by M. Gagliano
Drilling assistance by M. French, I. Snook, and M. Castelli

Research supported by the U. S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G14AC00238.



VERTICAL EXAGGERATION 20X



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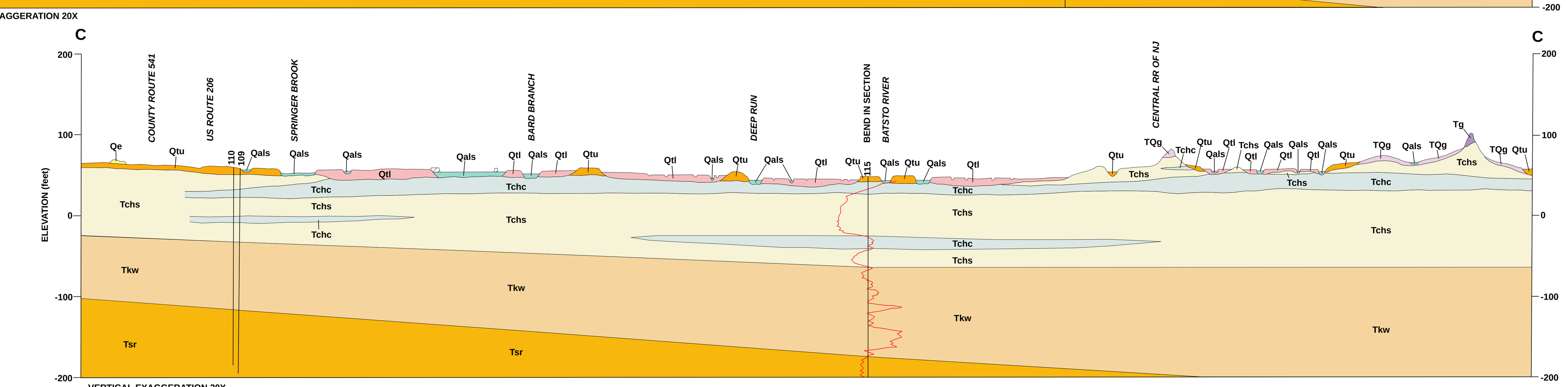

VERTICAL EXAGGERATION 20X

GEOLOGY OF THE INDIAN MILLS QUADRANGLE BURLINGTON COUNTY NEW JERSEY

by
Scott D. Stanford
2015

Geology of the Indian Mills Quadrangle
Burlington County, New Jersey

New Jersey Geological and Water Survey
Open-File Map OFM 108
2015

pamphlet with table 2 to accompany map

Table 2. Selected well records.

Well Number	Identifier[1]	Formations Penetrated[2]
1	32-12820	8 Tchs+Tchc 23 Tchs 31 Tchc 73 Tchs 112 Tkw 210 Tsr+Tmq 290 Tvt+Tht+Kns 340 Kml
2	32-9347	25 Tchs 28 Tchs+Tchc 35 Tchc 40 Tchs 47 Tchc+Tchs 49 Tchs 62 Tchc 68 Tchs
3	32-14619	10 Q 25 Tchs 32 Tchc 45 Tchs 55 Tchs+Tchc 75 Tchs
4	32-13138	17 Q 24 Tchc 30 Tchs 33 Tchc 75 Tchs 78 Tchc 92 Tchs
5	32-11734	57 Tchs
6	32-11562	27 Tchs+Tchs 60 Tchs 66 Tchc 100 Tchs
7	32-13087 (to 80) and 32-14414 (98-372)	16 Tchs 18 Tchc 45 Tchs 51 Tchc 80 Tchs 98 Tch 129 Tkw 302 Tsr+Tmq+Tvt+Tht 330 Kns 372 Kml
8	32-7922	45 Tchs 68 Tchs+Tchc 82 Tchs 125 Tkw 260 Tsr+Tmq 331 Tvt+Tht+Kns 340 Kml
9	32-12320	23 Tchs 28 Tchc 32 Tchs+Tchc 57 Tchs 58 Tchco or Tkw
10	32-14721	27 Tchs 35 Tchc 74 Tchs 80 Tchco or Tkw
11	32-25769, G	70 Tchs 75 Tchc 102 Tchs 155 Tkw 225 Tsr 250 Tmq 310 Tvt 320 Tht 350 Kns 420 Kml
12	32-12165	15 Tchs 25 Tchc 35 Tchs 50 Tchs+Tchc 65 Tchs
13	32-7805	5 Q 31 Tchs 44 Tchs+Tchc 49 Tchc 58 Tchs 70 Tchc+Tchs
14	32-10523	64 Tchs 101 Tchs+Tchc 155 Tkw 375 Tsr+Tmq+Tvt+Tht+Kns 405 Kml
15	32-12506	50 Tchs 98 Tchs+Tchc 150 Tkw 330 Tsr+Tmq+Tvt+Tht 370 Kns 400 Kml
16	32-9286	47 Tchs 52 Tchc+Tchs 60 Tchs 65 Tchs+Tchc 105 Tchc+Tchs 155 Tkw 296 Tsr+Tmq+Tvt 374 Tht+Kns 412 Kml
17	32-14163	10 Tchc+Tchs 15 Tchc 25 Tchs 36 Tchs 43 Tchc 100 Tchs
18	32-2261	2 Tchs 35 Tchs+Tchc 56 Tchs
19	32-14666	10 Q 18 Tchc 25 Tchs 32 Tchc 60 Tchs 70 Tchs+Tchc 80 Tchs
20	32-13487	14 Q 80 Tchs
21	32-15724	73 Tch 147 Tkw 317 Tsr+Tmq+Tvt 385 Tht+Kns 440 Kml
22	32-534	18 Q 27 Tchs 36 Tchs+Tchc 37 Tchc 51 Tchs 60 Tchc+Tchs
23	32-9979	8 Qe 16 Q 39 Tchs 44 Tchc+Tchs 54 Tchs 65 Tchc
24	32-8649	125 Tchs 205 Tkw 355 Tsr+Tmq+Tvt 415 Tht+Kns 455 Kml
25	32-7841	8 Q 27 Tchs
26	32-15830	90 Tchs 110 Tkw 266 Tsr+Tmq+Tvt 308 Tht+Kns 348 Kns+Kml
27	32-14260	8 Tchc+Tchs 82 Tchs 108 Tkw 180 Tsr+Tmq 248 Tvt 329 Tht+Kns 372 Kml
28	32-14113	26 Tchs+Tchc 65 Tchs 102 Tkw 250 Tsr+Tmq+Tvt 320 Tht+Kns 360 Kml
29	32-5246	53 Tchs 120 Tkw 180 Tsr
30	32-3967	55 Tchs 116 Tkw 180 Tsr
31	32-3965	64 Tchs 135 Tkw 178 Tsr
32	32-3962	63 Tchs 134 Tkw 178 Tsr
33	32-3959	39 Tchs 59 Tchc 106 Tkw 177 Tsr
34	32-3929	65 Tchs 123 Tkw 184 Tsr
35	32-3934	62 Tchs 115 Tkw 183 Tsr
36	32-5244	31 Tchs 70 Tchs+Tchc 78 Tchs 120 Tkw 175 Tsr

Well Number	Identifier[1]	Formations Penetrated[2]
37	32-3942	52 Tchs 74 Tchc 84 Tchs 126 Tkw 180 Tsr
38	32-15825	60 Tchs 135 Tkw 320 Tsr+Tmq+Tvt 375 Tht+Kns 380 Kns 435 Kml
39	32-12827	60 Tchs 88 Tchco+Tchs 139 Tkw 288 Tsr+Tmq 320 Tvt+Tht 355 Kns 400 Kml
40	32-13780	78 Tchs 82 Tchc 96 Tkw
41	32-12411	60 Tchs 88 Tchc 139 Tkw 277 Tsr+Tmq 322 Tvt+Tht 350 Kns 393 Kml
42	32-13305	14 Q 62 Tchs 72 Tchco 93 Tchs 134 Tkw 260 Tsr+Tmq 344 Tvt+Tht+Kns 400 Kml
43	32-11936	60 Tchs 88 Tchco 139 Tkw 277 Tsr+Tmq 322 Tvt+Tht 350 Kns 402 Kml
44	32-13107	12 Q 16 Tchc 84 Tchs 100 Tkw
45	32-15508	8 Tchc+Tchs 72 Tchs 90 Tkw
46	32-14524	30 Tchs 40 Tchc 65 Tchs+Tchc 80 Tchs
47	32-13643	49 Tchs 65 Tchc 100 Tchs
48	32-13252	25 Tchs 30 Tchc 55 Tchs 60 Tchc 75 Tchs
49	32-14279	25 Q+Tchs 29 Tchc 94 Tchs 100 Tchs or Tkw
50	32-14723	30 Tchs 40 Tchc+Tchs 50 Tchc 60 Tchc+Tchs 80 Tchs
51	32-13243	30 Tchs 45 Tchs+Tchc 80 Tchs
52	33-62, E	90 Tch 310 Tkw+Tsr+Tmq+Tvt 320 Tht 360 Kns 436 Kml
53	32-14586	42 Tchs 44 Tchs+Tchc 87 Tchs 88 Tkw
54	32-4623	11 Tchs 33 Tchs+Tchc 75 Tchs
55	32-14212	30 Tchs 35 Tchs+Tchc 40 Tchc 60 Tchs
56	32-14214	30 Tchs 35 Tchs+Tchc 40 Tchc 60 Tchs
57	32-14221	30 Tchs 35 Tchs+Tchc 40 Tchc 55 Tchs+Tchc 65 Tchs
58	32-10002	35 Tchs 68 Tchc+Tchs 74 Tchc 79 Tchs 80 Tkw
59	32-15383	38 Tchs 55 Tchco+Tchs 72 Tchco 81 Tchs 86 Tkw
60	32-5009	43 Tchs 61 Tchc 76 Tchs 80 Tchco
61	32-13952	60 Tchs 61 Tchco
62	32-5830	52 Tchs
63	32-10896	20 Tchs 28 Tchc 35 Tchs+Tchc 56 Tchs 60 Tchc 75 Tchs
64	32-12642	20 Tchs 25 Tchc 40 Tchs+Tchc 80 Tchs
65	32-679	6 Tchs 40 Tchs+Tchc 65 Tchs 100 Tchs+Tchc
66	5-465, Transco 9, E	100 Tch 295 Tkw 400 Tsr+Tmq+Tvt 410 Tht 440 Kns 570 Kml 852 TD
67	32-1098	16 Q 26 Tchc 55 Tchs 56 Tchs+Tchc
68	32-13470	28 Q 33 Tchc 56 Tchs 61 Tchc 80 Tchs
69	32-7659	52 Tchs 65 Tchc 78 Tchs 79 Tchc 82 Tchs
70	32-9758	10 Tchs 22 Tchs+Tchc 45 Tchc 80 Tchs
71	32-571	10 Q 21 Tchs 26 Tchs+Tchc 93 Tchs 95 Tkw
72	32-11637	9 Tchs+Tchc 16 Tchc 21 Tchs+Tchc 62 Tchs 67 Tchco 88 Tchs 95 Tchs or Tkw
73	32-29629	14 Q 18 Tchc 92 Tchs 182 Tkw 211 Tsr+Tmq
74	32-11386	20 Q 40 Tchc 60 Tchs 80 Tchc+Tchs 100 Tchs
75	32-11536	22 Tchs 28 Tchs+Tchc
76	32-22987	30 Tchs+Tchc 63 Tchs 90 Tchco+Tchs 120 Tchs 215 Tkw 240 Tsr
77	32-26388	26 Q 48 Tchc+Tchs 59 Tchc 100 Tchs
78	32-19878	52 Tchs 55 Tchc 110 Tchs
79	32-27023	11 Q 53 Tchs 57 Tchs+Tchc 59 Tchco 70 Tchs
80	32-22994	7 Q 16 Tchc 52 Tchs 60 Tchc 105 Tchs
81	32-15813	22 Tchs 48 Tchc+Tchs 96 Tchs 100 Tchc+Tchs
82	32-11865	50 Tchc+Tchs 125 Tchs
83	32-18584	6 Q 48 Tchs 56 Tchc 75 Tchc+Tchs 105 Tchs
84	32-12153	15 Tchc+Tchs 33 Tchs 35 Tchc 61 Tchs 67 Tchc 77 Tchs 95 Tchs+Tchc 109 Tchs
85	32-22724	30 Tchs 38 Tchc 63 Tchs 75 Tchs+Tchc 90 Tchs
86	32-13318	19 Tchc+Tchs 29 Tchs 40 Tchc 45 Tchs 72 Tchc 100 Tchs
87	32-11581	17 Tchc+Tchs 28 Tchs 39 Tchc+Tchs 45 Tchs+Tchc 71 Tchc 77 Tchs+Tchc 82 Tchc+Tchs 96 Tchs 97 Tchc
88	32-26680	15 Tchc 35 Tchs 50 Tchco 80 Tchs
89	32-23644	10 Tchs 30 Tchs+Tchc 36 Tchc 95 Tchs
90	32-20390	4 Tchs+Tchc 36 Tchs 44 Tchc 51 Tchs+Tchc 83 Tchs 86 Tchco
91	32-22840	6 Tchs 28 Tchc+Tchs 36 Tchs 48 Tchc+Tchs 91 Tchs 176 Tkw 200 Tsr
92	32-14360	8 Qe 40 Q+Tchs 85 Tchs 157 Tkw 180 Tsr

Well Number	Identifier[1]	Formations Penetrated[2]
93	32-13930	4 Qe 12 Q 43 Tchs 46 Tchc 67 Tchs 70 Tkw
94	32-12236	8 Qe 33 Tchs 41 Tchc+Tchs 63 Tchs 65 Tkw
95	32-13845	28 Tchs 32 Tchc 59 Tchs 65 Tkw
96	32-13900	40 Tchs 55 Tchs+Tchc 60 Tchco 65 Tchs 170 Tkw 200 Tsr
97	32-14231	63 Tchs 174 Tkw 210 Tsr
98	32-10908	41 Tchs 55 Tchs+Tchc 60 Tchco 65 Tchs 170 Tkw 198 Tsr
99	32-9003	30 Tchs 35 Tchs+Tchc 45 Tchc+Tchs 68 Tchs 178 Tkw 208 Tsr
100	32-9916	87 Tchs 175 Tkw 210 Tsr
101	32-8266	100 Tchs 153 Tkw 211 Tsr
102	32-15731	9 Qe or Tchs+Tchc 16 Tchc 22 Tchc+Tchs 52 Tchs 56 Tchc+Tchs 64 Tchco 68 Tchc+Tchs 110 Tchs 120 Tchc+Tchs
103	32-13792	6 Q 48 Tchc 62 Tchs, iron-cemented 76 Tchs 78 Tchc 83 Tchs 93 Tchc+Tchs 113 Tchs 117 Tkw or Tchco
104	32-14775	8 Q 33 Tchs 51 Tchs+Tchc 57 Tchc 78 Tchs 92 Tkw or Tchco+Tchs
105	32-7501	2 Q 9 Tchc+Tchs 25 Tchs 60 Tchs+Tchc 78 Tchs 80 Tchc 105 Tchs
106	32-7518	5 Q 12 Tchc+Tchs 25 Tchs 33 Tchs+Tchc 39 Tchc 50 Tchs+Tchc 55 Tchc 71 Tchs+Tchc 103 Tkw or Tchs
107	32-11136	10 Q 15 Tchs 22 Tchc 50 Tchs 57 Tchc 60 Tchs, iron-cemented 80 Tchs
108	32-9392	25 Tchs+Tchc 48 Tchs 57 Tchc 69 Tchs
109	32-5879	27 Tchs 34 Tchs+Tchc 58 Tchs 64 Tchc+Tchs 71 Tchs+Tchc 176 Tkw 235 Tsr
110	32-14107	6 Tchc+Tchs 90 Tchs 173 Tkw 245 Tsr
111	32-22352	40 Tchs+Tchc 57 Tchc 79 Tchs 88 Tchs+Tchc 120 Tchs 243 Tkw 312 Tsr
112	32-14146	20 Q+Tchs 27 Tchc 43 Tchs+Tchc 55 Tchco 95 Tchs
113	32-25428	10 Tchs+Tchc 14 Tchs 20 Tchc 45 Tchs+Tchc 99 Tchs 112 Tkw
114	32-537	12 fill 16 Q 49 Tchs+Tchc 132 Tchs 134 Tkw
115	5-417, G	20 Tchc 75 Tchs 90 Tchc 110 Tchs 220 Tkw 245 Tsr
116	32-9869	25 Tchs+Tchco 33 Tchs 36 Tchco 78 Tchs 84 Tkw
117	32-7214	12 Tchc+Tchs 22 Tchs+Tchc 89 Tchs
118	32-683	7 Tchs 12 Tchc 21 Tchs+Tchc 40 Tchc+Tchs 80 Tchs
119	5-463, Transco 12, E	160 Tch 250 Tkw 460 Tsr+Tmq+Tvt 470 Tht 505 Kns 570 Kml 952 TD
120	32-15273	5 Tchc 8 Tchs 14 Tchco 63 Tchs 176 Tkw 205 Tsr

[1]Identifiers of the form 32-xxxxx are N. J. Department of Environmental Protection well-permit numbers. Identifiers of the form 5-xxx are U. S. Geological Survey Ground-Water Site Inventory identification numbers. The “Transco” wells are deep gas exploration wells drilled for the Transcontinental Gas Pipeline Corporation in 1951. Formations below the Mount Laurel in these wells are described in 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 34 to bottom of hole at 62 feet. Abbreviations, and drillers’ descriptive terms used to infer formations, are: Q=yellow and white sand, clayey sand, and gravel surficial deposits (map units Qals, Qe, Qtl, Qtu, TQg, Tg); Qe=white, yellow, brown sand, clay, fine sand, clayey sand, identified only where distinct from underlying gravelly surficial units; Tchs=white, yellow, gray, brown (minor red, orange) fine, medium, and coarse sand (and minor fine gravel) of the Cohansey Formation; Tchc=yellow, white, gray (minor red, orange) clay, silty clay, and sandy clay of the Cohansey Formation; Tchco=black, brown clay, wood of the Cohansey Formation; Tch=Cohansey Formation, sand and clay not differentiated; Tkw=gray and brown clay, silt and fine sand of the Kirkwood Formation; Tsr and Tmq=green, black, gray clay, sand, marl, “coffee grounds”, “pepper”, shells; Tvt=green, black clay, sand, “coffee grounds”; Tht=green, black clay, shells; Kns=gray, green, black clay, shells; Kml=green sand, “pepper” sand. A “+” sign between Tchs and Tchc indicates that the units are mixed or interbedded, with the unit listed first being most abundant. A “+” sign between units below the Cohansey indicates that they cannot be distinguished in the well log. “TD” indicates total depth of deep wells for which units below Kml 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. 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 most well logs, surficial deposits cannot be distinguished from the Cohansey Formation; thus, the uppermost Tch unit in well logs generally includes overlying surficial deposits.