Prepared in cooperation with the
U. S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM

INTRODUCTION

The Chatsworth quadrangle is in the Pine Barrens region of the New Jersey Coastal Plain, in the southeastern part of the state. Geologic materials that crop out 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 about 12 to 11 million years ago (Ma), when sea level was more than 180 feet higher than at present in this region. As sea level lowered after 11 Ma, rivers flowing on the emerging Coastal Plain deposited the Beacon Hill Gravel, forming a broad regional river plain. As sea level continued to lower, the regional river system shifted to the west of the quadrangle, and local streams began to erode into the Beacon Hill plain. Through the latest Miocene, Pliocene, and Pleistocene (about 8 Ma 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 brief summary of depositional settings of the Cohansey Formation, and of the geomorphic history of the quadrangle as recorded by surficial deposits and landforms, is provided in the two following sections. The age of the deposits and episodes of valley erosion are shown on the correlation chart. Lithologic logs of four test borings drilled for this study (Chatsworth 1 through 4) are in table 1. Table 2 lists the formations penetrated in selected wells and test borings, as interpreted from drillers' lithologic descriptions and geophysical logs.

This map shows materials to a depth of 250-350 feet, which includes the Cohansey Formation and the uppermost part of the Kirkwood Formation. Several test holes in the quadrangle (wells 1, 2, 17, 18, 19, 59, and 91 in table 2) penetrated below the Kirkwood, to total depths of as much as 2,297 feet. A lithologic log of well 59 (Transcontinental Gas Pipeline Corporation well 1) is in Johnson (1961), formation assignments for wells 1, 2, 17, 18, and 91 (Transcontinental Gas Pipeline Corporation wells 1, 10, 8, 3, and 14, respectively) are in Kasabach and Scudder (1961), and a gamma log and formation and aquifer correlations for well 9 (U. S. Geological Survey Butler Place 1 test well) are in Zapecza (1989) and Owens and others (1998). Formations below the Kirkwood are not shown or discussed on this map.

COHANSEY FORMATION

The Cohansey Formation has been interpreted as either 1) a deltaic deposit with inner-shelf sand at the base, grading upward into interbedded delta-front sand and clay, in turn overlain by fluvial sand and gravel and alluvial clay (Markiewicz, 1969; Rhodehamel, 1973; Newell and others, 2000), or 2) two or three stacked sequences composed of beach and shoreface sand overlain by tidal-flat sand and clay (Carter, 1972, 1978). Newell and others (2000) mapped inner-shelf and overlying delta-front facies in the Chatsworth quadrangle, implying a single transgression of sea level. Carter (1972) indicated two or three stacked transgressive sequences in the map area. Pollen and dinoflagellates recovered from peat beds in the Cohansey at Legler, about 20 miles northeast of Chatsworth, indicate a coastal swamp-tidal marsh environment (Rachele, 1976). The Legler pollen (Greller and Rachele, 1983), pollen from a corehole near Mays Landing, New Jersey (Owens and others, 1988), and dinocysts from coreholes in Cape May County, New Jersey (deVerteuill, 1997; Miller and others, 2001) indicate a late middle to early late Miocene age for the Cohansey.

In the Chatsworth quadrangle, clays in the Cohansey are in beds generally less than 6 inches, but as much as 2 feet, thick, and are interbedded with sand. Most are oxidized to white, yellow, or red, but black to brown organic clay was penetrated in several hand-auger holes and exposed in two excavations (symboled on map). Clayey strata are generally less than 15 feet thick, and some are continuous for more than 5 miles, both downdip (northwest to southeast) and along strike (northeast to southwest) (fig. 1). The laminated bedding and thin but areally extensive shape of the strata are indicative of bay or estuarine intertidal settings. Alluvial clays generally are thicker and more areally restricted because they are deposited in flood plains and abandoned river channels. Clayey strata occur throughout the entire thickness of the Cohansey in the quadrangle, and there is no up-section transition to coarser fluvial sediments. Similar relationships are observed to the east of the quadrangle (Stanford, 2010, 2012). These observations favor the stacked beach-tidal-flat model of Carter (1972) for the Cohansey in this area, and imply that the Cohansey was deposited during several rises and falls of 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 Apple Pie Hill, the highest elevation in the quadrangle, is the earliest record of this drainage. It is a deeply weathered quartz-chert gravel preserved in erosional remnants of a large river plain that formerly covered much of the New Jersey Coastal Plain. Flow direction, inferred from crossbeds, slope of the deposit, and gravel provenance, indicates 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 in the late Miocene and early Pliocene (approximately 8 to 3 Ma) caused the regional river system to erode into the Beacon Hill plain. As it did, it shifted to the west of the quadrangle. The area of the quadrangle became an upland from which local streams drained eastward to the Atlantic and westward to the regional trunk river. 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 flood plains, channels, and pediments, 20 to 50 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 hilltops.

A renewed period of lowering sea level in the late Pliocene and early Pleistocene (approximately 2 Ma to 800,000 years ago [800 ka]) led to another period of valley incision. Groundwater seepage and channel and slope erosion reworked both the Beacon Hill and 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 of the upper slopes of Apple Pie Hill. Stream drainage at this time, inferred from interfluve deposits, is shown by yellow 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 and Qtl), inactive deposits in dry valleys (unit Qald), and active flood plain and wetland deposits (Qals) in valley bottoms. Like the upland gravels, the terrace and flood plain deposits are formed by 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 and sediment in swamps and bogs.

Upper Terrace Deposits form terraces and pediments 5 to 20 feet above modern wetlands and are the most widespread deposit in modern valleys. 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 washing into valleys. During periods of high sea level, the lower reaches of streams in the quadrangle may have been close to sea level, favoring deposition.

Upper Terrace Deposits extend across divides between the Rancocas Creek basin and the Wading or Batsto River basins at three locations: 1) in the northeastern corner of the quadrangle, between Cooper Branch (in the Rancocas Creek basin) and Tibbs Branch (in the Wading River basin), 2) at the head of South Branch (Rancocas basin) northwest of Chatsworth, and 3) between South Branch and Roberts Branch (in the Batsto River basin) at Whitehorse. This pattern, and the configuration of uplands in these areas, suggest that headwaters of the West Branch of the Wading River (Tibbs Branch, Gates Branch, and Reeds Branch) and Batsto River (Roberts Branch) captured part of the Rancocas drainage during deposition of the Upper Terrace Deposits. Clays at shallow depth in all three areas (beds 3 and 4 in the Reeds Branch headwaters, bed 2 in the South Branch headwaters, fig. 1) may have enabled these captures by directing groundwater seepage southward into the Wading and Batsto basins.

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, probably during or slightly after the last period of cold climate about 25-15 ka. A radiocarbon date of 20,350±80 yrs. BP (24450-24150 calibrated yrs. BP) (Beta 309764) on organic sediment beneath 4 feet of lower-terrace sand west of Hedger House (plotted on map) confirms this age. Dry-valley alluvium (unit Qal), which grades down-valley to the lower terraces, and windblown deposits (unit Qe) were probably also laid down at this time. In places, for example, at the head of the Tulpehocken Creek valley, windblown deposits form dunes atop lower-terrace deposits, indicating that they are younger than the terraces in these locations. Most dunes, however, are on upper terraces.

Modern flood plain and wetland deposits (unit Qals) were laid down in the past 10 ka, based on basal radiocarbon dates on 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.

Landforms and hydrologic features indicate that groundwater seepage is an important geomorphic agent in the Chatsworth quadrangle, and in the Pine Barrens in general. Active seepage occurs in places along the base of the Apple Pie Hill upland, the upland in the northwest corner of the quadrangle, and in shallow swales in the upper terrace between Tibbs Branch and Cooper Branch in the northeast corner of the map (seepage lines are symboled on map). At these locations, seepage is focused atop clay beds in the Cohansey Formation. Seepage is also common along upland margins of units Qtl and Qals. As time passes, seepage erosion at the base of uplands causes escarpments to retreat, forming broad, flat lowlands. In the quadrangle, present-day lowlands took shape in the early and middle Pleistocene, between deposition of units TQg and Qtu, and continued to expand somewhat during the late Pleistocene and Holocene. The lowlands in the Tulpehocken Creek-Featherbed Branch-Shane Branch valley in the southwest corner of the map area, in the Risley Branch valley east of Chatsworth, and in the South Branch valley, formed in this way. In these locations, seepage was concentrated atop continuous clays that underlie the valley bottoms at shallow depth.

During cold climate at glacial maximums in the middle and late Pleistocene, permafrost was present in the Pine Barrens region (Wolfe, 1953; French and others, 2003, 2007). During thaws, permafrost at depth acted as an impermeable layer and supported the water table at a higher elevation than in temperate climate. Seepage features, including inactive scarps and amphitheater-shaped hollows, were developed in topographic positions that are dry today. These are indicated by dark blue lines on the map. Other permafrost-related features include thermokarst basins, braided channels, and cryoturbation structures. Thermokarst basins are shallow depressions that form when subsurface ice lenses melt (Wolfe, 1953). These basins (shown by blue cross-hatching on map) typically form in sandy deposits in lowlands with a high water table, or, more rarely, in upland settings where shallow clay layers produce a perched water table. Basins that border eolian deposits were likely formed or enlarged by wind erosion (French and Demitroff, 2001). Braided-channel networks (shown by light blue lines on map) scribe the lower-terrace surface in the Tulpehocken Branch valley and the West Branch Wading River valley (where they are visible on 1930 aerial photography but are now obscured by cranberry bogs). Braided channels formed when permafrost impeded infiltration and thus increased erosion by groundwater seepage and runoff. The erosion choked streams with sand and gravel, causing channels to aggrade and split, forming a braided pattern. The braided channels are inactive today (although they 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. Cryoturbation structures are folds and involutions in the upper several feet of surface materials. These structures formed by density flow of waterlogged sediment during melting of permafrost (French and others, 2005).

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, dikes around cranberry bogs, and excavation-spoil mounds.

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 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.

Qald — DRY-VALLEY ALLUVIUM—Fine-to-medium sand and pebble gravel, minor coarse sand; very pale brown, white, brown, dark brown, light gray. As much as 5 feet thick. Sand and gravel are almost entirely quartz. In dry valley bottoms forming headwater reaches of streams. These valleys lack channels or other signs of surface-water flow. In places, they grade down-valley to lower terrace deposits. They may have formed under cold-climate conditions when permafrost impeded infiltration, increasing surface runoff. The deposits are therefore largely relict.

Qe — EOLIAN DEPOSITS—Fine-to-medium quartz sand; very pale brown, white. As much as 20 feet thick. Form dune ridges and dunefields, particularly in the Skit Branch, Tulpehocken Creek, Featherbed Branch, Shoal Branch, and Risley Branch valleys, and west of Chatsworth. Formed where sand of the Cohansey Formation and upper and lower terrace deposits was exposed to wind erosion. Dunes vary from narrow, single-crested ridges as much as 4,000 feet long and 15 feet tall to low ovoid mounds only 2 to 3 feet higher than adjacent terrace surfaces.

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 are almost entirely quartz. Form terraces and pediments in valley bottoms with surfaces 2 to 5 feet above modern wetlands. 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 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 are almost entirely quartz. Form terraces and pediments with surfaces 5 to 20 feet above modern wetlands. Include stratified stream-channel deposits and poorly stratified to unstratified deposits laid down by groundwater seepage on pediments.

TQg — UPLAND GRAVEL, LOWER PHASE—Fine-to-medium sand, clayey in places, and pebble gravel; minor coarse sand; yellow, very pale brown, reddish-yellow (fig. 2). Sand and gravel are mostly quartz with a trace (<1%) of white weathered chert in the coarse sand-to-fine-pebble gravel fraction. Clay is chiefly from weathering of chert. As much as 10 feet thick, generally less than 5 feet thick. Occurs as erosional remnants on interfluves and hilltops, and as a patchy mantle on upper slopes of Apple Pie Hill, between 70 and 140 feet in elevation. 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 from 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 are chiefly quartz, with as much as 5 percent 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 to partially weathered. Clay-size material chiefly is from weathering of chert and feldspar. As much as 25 feet thick. Occurs as erosional remnants on hilltops, between 150 and 170 feet in elevation. Includes stratified and cross-bedded stream-channel deposits and poorly stratified to unstratified pebble concentrates (fig. 3) formed by washing of sand and clay from the Beacon Hill Gravel by groundwater sapping or surface runoff.

Tbh — BEACON HILL GRAVEL—Clayey fine-to-medium sand, pebble gravel; reddish-yellow to brownish-yellow. Clay-size material chiefly originates from weathering of chert and feldspar. Sand and gravel are mostly quartz and as much as 15 percent brown and dark gray chert. Most chert is weathered to white and yellow clay-size material. As much as 10 feet thick. Generally unstratified, or poorly stratified, owing to weathering, cryoturbation, and bioturbation. Preserved only on summit of Apple Pie Hill, above 185 feet in elevation.

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 divided here 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 Chatsworth quadrangle is as much as 250 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 of 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 to large-scale trough and planar crossbedding (fig. 4). Sand is mostly quartz; coarse-to-very-coarse sand may include as much as 5 percent 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 originates 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 in 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. 5). 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 (fig. 2). 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. Contains mollusk shells in places. In subsurface only, penetrated by wells 17, 18, 19, 58, 59, 76, 81, 82, 83, 84, 91, 93, and 94 (table 2). Approximately 200 feet thick in map area. Kirkwood sediments in the Chatsworth 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).

MAP SYMBOLS

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

Contact of Cohansey facies—Approximately located. Dotted where concealed by surficial deposits.

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

figure 2 ● Photograph location

(Tchc) Concealed Cohansey Formation facies—Covered by surficial deposits.

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

●47 Well or test boring showing formations penetrated—Location accurate to within 200 feet. Formations penetrated listed in table 2.

⊙77 Well or test boring showing formations penetrated—Location accurate to within 500 feet. Formations penetrated listed in table 2.

Chatsworth 3 ● Test boring—Log in table 1.

Geophysical log—On sections. Gamma-ray log is indicated by red line with radiation intensity increasing to right. Resistivity log is indicated by blue line with resistance increasing to right.

Head of seepage valley—Line at top of scarp, ticks on slope. Marks head of small embayed valleys formed by seepage erosion. Seepage is generally inactive in these valleys.

Active seepage scarp—Line at foot of scarp, at position of groundwater emergence. Water drains downslope from this position.

Inactive seepage scarp—Line at foot of scarp. No seepage occurs today along these scarps.

Abandoned channel—Line in channel axis. Delineates relict braided channels on lower-terrace surfaces. Channels along West Branch Wading River are drawn from 1930 aerial photos and are now obscured by cranberry bogs.

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

Excavation perimeter—Line encloses excavated area.

Sand pit—Active in 2012.

Sand pit—Inactive in 2012.

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Figure 2. Upland gravel, lower phase (above line) over Cohansey Formation, clay-sand facies (above shovel) over dark organic clay of Cohansey Formation, clay-sand facies. Location shown on map and inset.

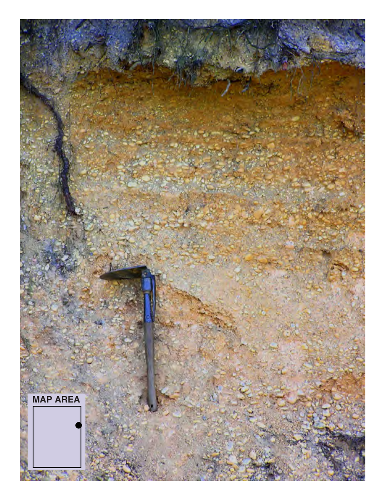
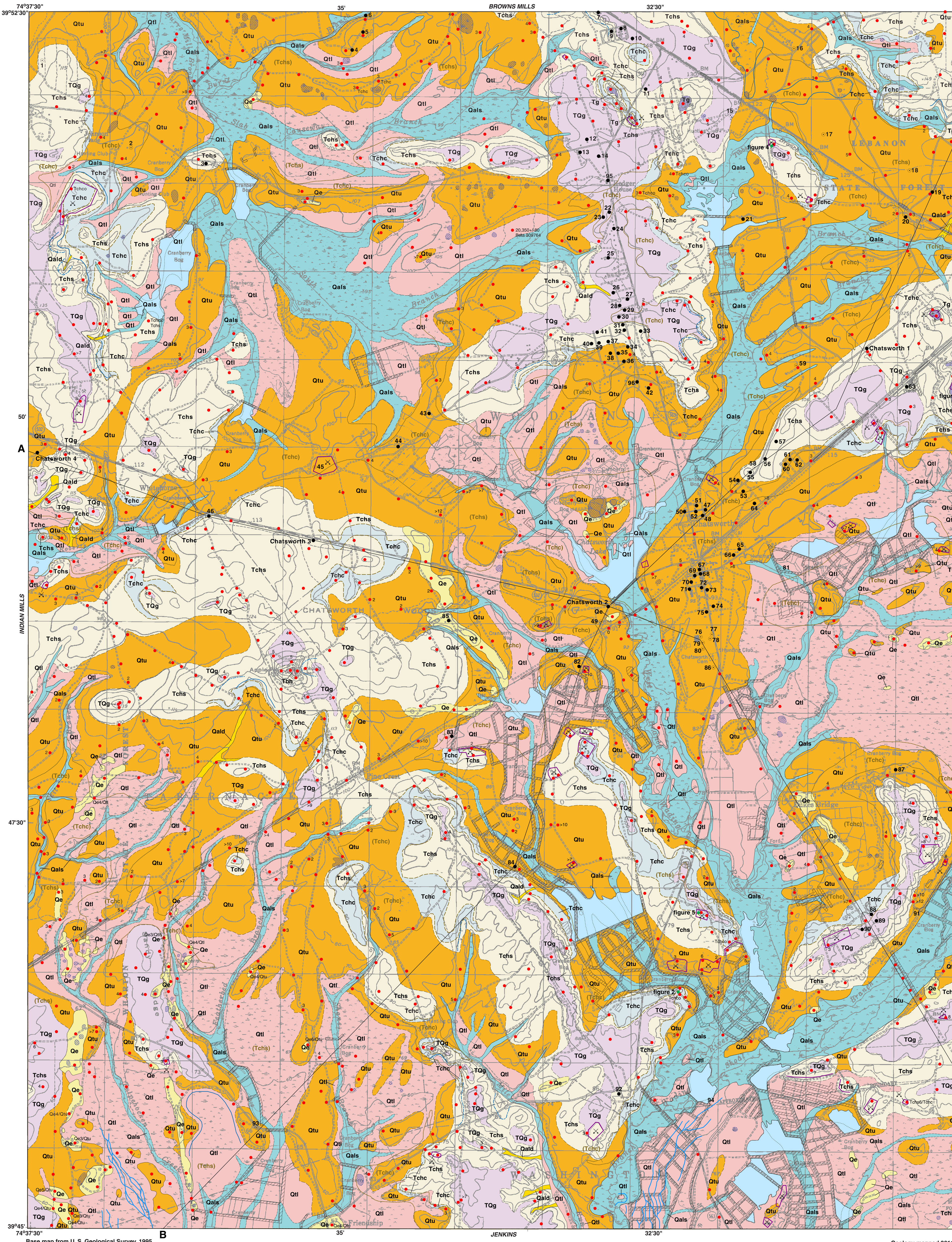


Figure 3. Upland gravel, high phase. Note crude horizontal bedding in gravel. The deeper yellow color than that in the lower phase of the upland gravel (fig. 2) indicates a longer period of weathering. Location shown on map and inset.



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

Geology mapped 2011-2012
Cartography by S. Stanford
Drilling by G. Steidl and J. Curran
Assisted by M. French, I. Snook, M. Girard, R. Bousenberry, H. Rancan

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APPROXIMATE MEAN DECLINATION, 1999

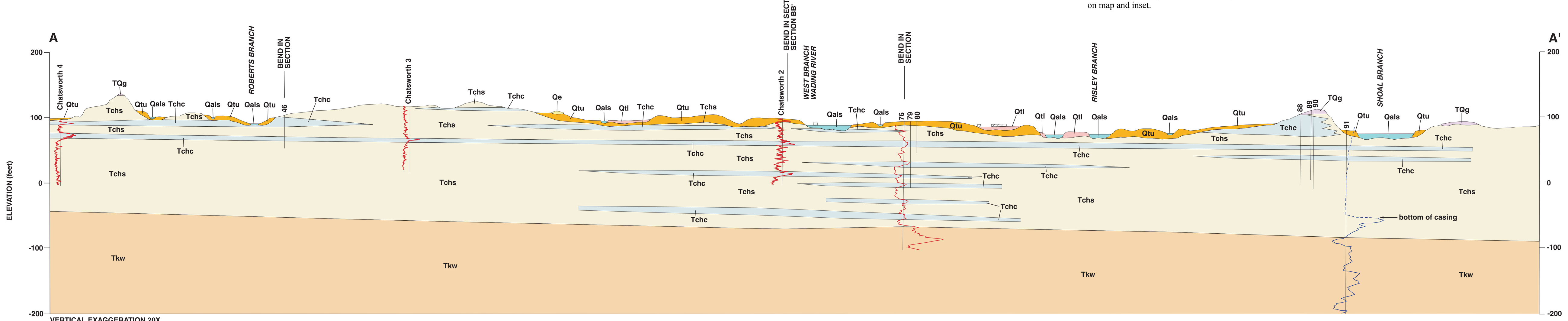
SCALE 1:24 000

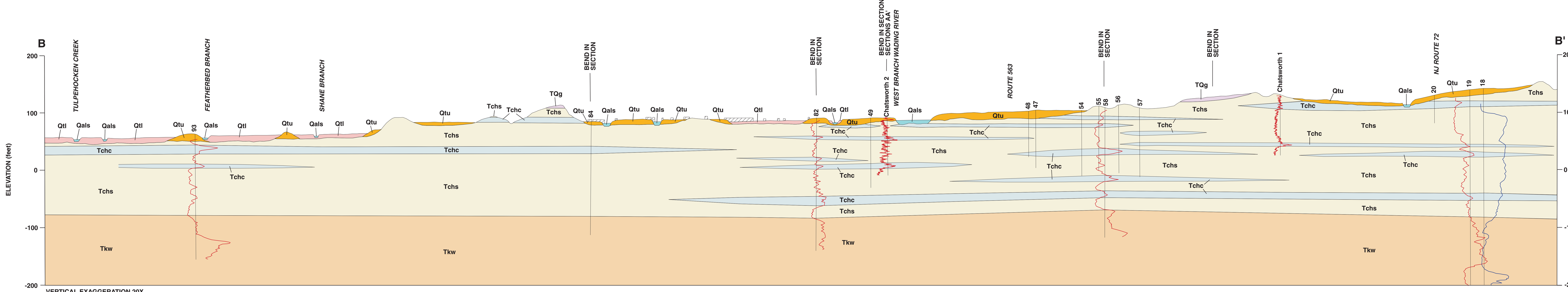
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

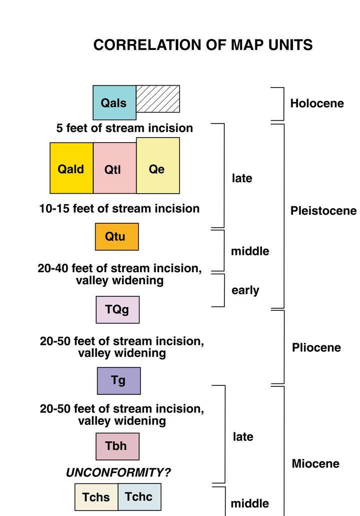
LOCATION IN NEW JERSEY

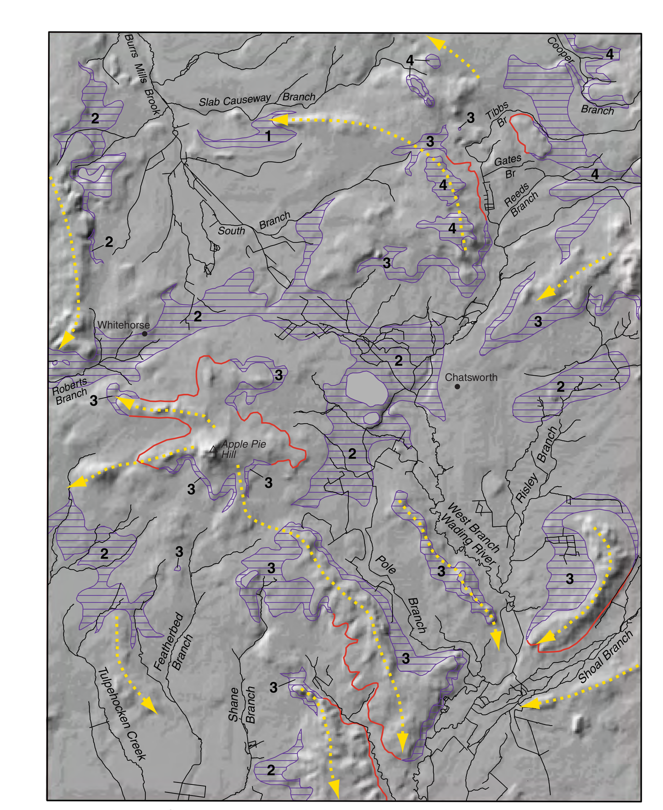
GEOLOGY OF THE CHATSWORTH QUADRANGLE
BURLINGTON COUNTY, NEW JERSEY

by
Scott D. Stanford
2012









2 outcrop of Cohansey clay-sand facies, number indicates stratigraphic position (1=lowest, 4=highest)
projected outcrop position, clay not observed in field
drainage during deposition of Upland Gravel, lower phase

Figure 1.—Outcrop areas of Cohansey Formation, clay-sand facies, in Chatsworth quadrangle, and general direction of stream drainage during deposition of the Upland Gravel, lower phase. Stratigraphic position of clays indicated by numbers.

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)
E201205568 Chatsworth 1	0-15	brownish-yellow fine-to-medium sand with a few subangular very fine quartz pebbles and a few subrounded fine quartz pebbles (Tchs)
	15-25	yellow to brownish-yellow fine sand, very fine-to-fine sand, slightly clayey (Tchc)
	25-55	yellow to brownish-yellow fine sand, fine-to-medium sand (Tchs)
	55-72	brownish-yellow fine-to-medium sand (Tchs)
	72-83	very pale brown, white, light gray clay (Tchc)
	83-103	light yellowish-brown to brownish-yellow medium sand, medium-to-coarse sand, minor fine sand, and a few subangular very fine quartz pebbles (Tchs)
E201205579 Chatsworth 2	0-10	yellowish-brown, brown fine-to-medium sand with some subangular fine quartz pebbles (Qtu over Tchs)
	10-30	brownish-yellow, pale brown medium sand, some fine sand, some coarse sand, a few subangular very fine quartz pebbles (Tchs)
	30-40	yellow fine-to-medium sand (Tchs)
	40-90	yellow fine sand (Tchs) with very pale brown to white clay to clayey fine sand beds from 35-43 (Tchc)
	90-103	yellow fine sand, fine-to-medium sand (Tchs) with yellow to very pale brown clay to clayey fine sand beds from 82-88 (Tchc)
E201205591 Chatsworth 3	0-20	brownish-yellow fine-to-medium sand with a few subangular very fine quartz pebbles (Tchs)
	20-30	yellow fine-to-medium sand (Tchs)
	30-50	yellow medium sand, some fine sand, minor coarse sand, with a few subangular very fine quartz pebbles (Tchs)
	50-70	light yellowish-brown to yellow fine sand (Tchs) with thin beds of white to very pale brown clay from 52-55 (Tchc)
	70-85	dark brown to dark grayish-brown medium sand, some fine sand and coarse sand, a few subangular very fine quartz pebbles (Tchs)
	85-103	white to very pale brown very-fine-to-fine sand (Tchs)
E201205598 Chatsworth 4	0-5	yellowish-brown fine-to-medium sand (Qtu)
	5-22	brownish-yellow to yellow fine sand (Tchs), clayey from 6-9 (Tchc)
	22-32	light gray clay with thin beds of dark brown lignitic clay and yellow fine sand (Tchc)
	32-50	light yellowish-brown fine-to-medium sand (Tchs)
	50-103	brownish-yellow to reddish-yellow medium-to-coarse sand, minor fine sand, a few subangular very fine quartz pebbles (Tchs)

Table 2. Selected well records.

Well Number	Identifier[1]	Formations Penetrated[2]
1	32-40, Transco 11	130 Tch 300 Tkw 954 TD
2	32-39, Transco 10, E	140? Tch 320 Tkw 928 TD
3	32-19692	14 Q 17 Tchc 30 Tchs 35 Tchc 54 Tchs 61 Tchc 82 Tchs
4	32-14935	5 Q 19 Tchs
5	32-14936	20 Tchs
6	32-14937	17 Tchs
7	32-15854	8 Q+Tchs 21 Tchc 29 Tchs 47 Tchc 59 Tchs 66 Tchc 97 Tchs
8	32-18218	14 Q 21 Tchc 29 Tchs 36 Tchc 41 Tchs 48 Tchc 70 Tchs 74 Tchc 105 Tchs
9	32-15856	2 Tchs 19 Tchc 24 Tchs 31 Tchc 60 Tchs 62 Tchc 88 Tchs
10	32-19700	10 Q 29 Thcs 43 Tchc 65 Tchs
11	32-19833	8 Q or Tchs 12 Tchc 19 Tchs 24 Tchc 33 Tchs 37 Tchc 42 Tchs 47 Tchc 68 Tchs 74 Tchc 85 Tchs
12	32-18036	9 Tchs+Tchc 18 Tchc 32 Tchs 39 Tchc 55 Tchs 60 Tchs+Tchc
13	32-22126	7 Tchs 15 Tchc 30 Tchs 35 Tchc 55 Tchs 72 Tchc 80 Tchs
14	32-18837	12 Q 14 Tchc 19 Tchs 23 Tchc 32 Tchs 36 Tchc 44 Tchs 49 Tchc 59 Thcs
15	32-471	35 Tchs 42 Tchc 69 Tchs
16	32-727	17 Tchs 40 Tchc 93 Tchs 97 Tchc
17	32-36, Transco 8, E	180 Tch 310 Tkw 902 TD
18	32-33, Transco 3, E	180 Tch 310 Tkw 1207 TD
19	32-468, Butler Place, G	180 Tch 300 Tkw 2297 TD
20	32-15681	3 Tchs 11 Tchc 50 Tchs
21	32-22950	5 Q+Tchs 9 Tchc 26 Tchc+Tchs 100 Tchs
22	32-13484	23 Tchc 27 Tchs 49 Tchc 57 Tchs 64 Tchc 82 Tchs
23	32-19446	14 Q 19 Tchs 21 Tchc 27 Tchs 32 Tchc 32 Tchc 36 Tchs 47 Tchc 60 Tchs 62 Tchc 82 Tchs
24	32-18501	14 Q 15 Tchc 32 Tchs 34 Tchc 46 Tchs 56 Tchc 64 Tchs 66 Tchc 89 Tchs
25	32-20132	12 Tchs 23 Tchs+Tchc 38 Tchs 49 Tchs+Tchc 58 Tchc 95 Tchs
26	32-12123	20 Q+Tchs 40 Tchc+Tchs 55 Tchc 106 Tchs
27	32-12282	30 Q+Tchs 32 Tchc 50 Tchs 75 Tchc 90 Tchs
28	32-14684	2 Tchs 17 Tchc 23 Tchs 28 Tchc 41 Tchs 47 Tchc 68 Tchs
29	32-14683	2 Tchs 17 Tchc 23 Tchs 28 Tchc 41 Tchs 47 Tchc 72 Tchs
30	32-13871	16 Q 31 Tchs 33 Tchc 41 Tchs 47 Tchc 54 Tchs 56 Tchc 73 Tchs
31	32-14263	3 Tchs 21 Tchc 25 Tchs 36 Tchc 43 Tchs 46 Tchc 57 Tchs 69 Tchc 80 Tchs
32	32-19565	3 Tchs 16 Tchc 67 Tchs 76 Tchc 100 Tchs
33	32-12151	30 Tchs 45 Tchc 80 Tchs
34	32-17504	12 Tchs 17 Tchc 23 Tchs 25 Tchc 29 Tchs 33 Tchc 39 Tchs 42 Tchc 58 Tchs 61 Tchc 70 Tchs 73 Tchc 92 Tchs
35	32-16555	10 Tchs 20 Tchc+Tchs 52 Tchs 70 Tchc 126 Tchs 132 Tchc
36	32-15205	42 Tchs 58 Tchc 61 Tchs 70 Tchc 100 Tchs
37	32-17433	15 Tchs 22 Tchc 65 Tchs 74 Tchc 85 Tchs+Tchc 115 Tchs
38	32-19984	10 Tchs 30 Tchc 70 Tchs 80 Tchc 105 Tchs
39	32-13065	10 Q+Tchc 20 Tchc 60 Tchs 75 Tchc 102 Tchs
40	32-12580	16 Q+Tchc 28 Tchs 35 Tchc 51 Tchs 59 Tchc 98 Tchs
41	32-12712	60 Tchs 68 Tchc 80 Tchs
42	32-19576	12 Tchs 31 Tchc+Tchs 42 Tchc 100 Tchs
43	32-19837	16 Tchs 22 Tchc 43 Tchs+Tchc 56 Tchs 67 Tchc 120 Tchs
44	32-15016	34 Tchs 41 Tchc 85 Tchs
45	32-23370	6 Tchs 13 Tchc 120 Tchs
46	32-92	8 Tchc 50 Tchs
47	32-22288	7 Q 22 Tchc 52 Tchs 57 Tchc 72 Tchs 83 Tchc 98 Tchs
48	32-21007	8 Q 20 Tchs 32 Tchc 40 Tchs 47 Tchc 75 Tchs
49	32-8991	15 Tchs 16 Tchc 122 Tchs
50	32-23346	32 Tchs 38 Tchc 52 Tchs 61 Tchc 97 Tchs+Tchc 100 Tchc+Tchs
51	32-17577	11 Tchc+Tchs 42 Tchs 48 Tchc 62 Tchs 78 Tchc+Tchs 85 Tchs 92 Tchc+Tchs
52	32-18019	42 Tchs+Tchc 47 Tchc 50 Tchs 54 Tchc 76 Tchs 79 Tchc 90 Tchs
53	32-9602	12 Tchs 15 Tchc 62 Tchs 79 Tchc 125 Tchs
54	32-17467	9 Tchs+Tchc 13 Tchc 50 Tchs 82 Tchs+Tchc 84 Tchc 112 Tchs
55	32-18303	11 Tchs+Tchc 18 Tchc 44 Tchs 52 Tchc 78 Tchs 84 Tchc 108 Tchs 110 Tchc
56	32-13931	14 Tchs+Tchc 16 Tchc 37 Tchs 43 Tchc 120 Tchs
57	32-21780	6 Q 14 Tchc 40 Tchs 48 Tchc 60 Tchs 66 Tchc 75 Tchs 80 Tchc 120 Tchs
58	5-678, G	35 Tchs+Tchc 70 Tchs 80 Tchc 115 Tchs 130 Tchc 170 Tchs 224 Tkw (from gamma log, no lithologic log)
59	32-29, Transco 1, E	144 Tch 334 Tkw 1140 TD
60	32-15879	5 Tchs 11 Tchc 74 Tchs 82 Tchc+Tchs 95 Tchc 112 Tchs
61	32-15877	9 Tchc+Tchs 14 Tchc 72 Tchs 77 Tchc 102 Tchs 114 Tchc 120 Tchs 124 Tchc 142 Tchs
62	32-15878	5 Tchs 11 Tchc 77 Tchs 82 Tchc 98 Tchs 111 Tchc 119 Tchs 124 Tchc 142 Tchs
63	5-679, G	12 Tchs 28 Tchc 131 Tchs (from gamma log, no lithologic log)
64	32-13764	60 Tchs+Tchc 70 Tchc 80 Tchs
65	32-12815	12 Tchs 14 Tchc 40 Tchs 46 Tchc 60 Tchs 63 Tchc 70 Tchs 72 Tchc 97 Tchs
66	32-15555	10 Q 25 Tchs 40 Tchc 100 Tchs
67	32-22409	9 Tchs+Tchc 17 Tchc 39 Tchs+Tchc 52 Tchs 56 Tchc 72 Tchs 76 Tchc 100 Tchs
68	32-23313	30 Tchs 75 Tchc 90 Tchs 125 Tchs+Tchc 150 Tchc
69	32-13478	55 Tchs+Tchc 63 Tchc 110 Tchs
70	32-20582	15 Q 38 Tchc+Tchs 62 Tchs 76 Tchc+Tchs 89 Tchs 93 Tchc 101 Tchs+Tchc 120 Tchs
71	32-12753	9 Q+Tchc 13 Tchc 28 Tchs+Tchc 33 Tchc 52 Tchs+Tchc 90 Tchs 93 Tchc 121 Tchs 123 Tchc 125 Tchs
72	32-18517	9 Tchs 11 Tchc 40 Tchs 54 Tchs+Tchc 58 Tchc 63 Tchs+Tchc 70 Tchc 132 Tchs
73	32-22234	9 Tchs 11 Tchc 40 Tchs 70 Tchc 112 Tchs 132 Tchc+Tchs 152 Tchs
74	32-17150	35 Tchs 54 Tchc+Tchs 83 Tchs 96 Tchc 120 Tchs
75	32-11350	30 Tchs 47 Tchc+Tchs 62 Tchs+Tchc 92 Tchs
76	32-14224, G	10 Tchs 57 Tchs+Tchc 58 Tchc 80 Tchs+Tchc 160 Tchs 200 Tkw
77	32-13974	14 Tchs 61 Tchs+Tchc 62 Tchc 84 Tchs+Tchc 164 Tchs
78	32-18328	10 Tchs 14 Tchc 45 Tchs
79	32-14521	22 Tchs 75 Tchs+Tchc 100 Tchs
80	32-18329	23 Tchs 39 Tchs+Tchc 46 Tchs
81	32-22158	49 Q+Tchs+Tchc 62 Tchc 139 Tchs+Tchc 165 Tchs 184 Tkw
82	32-8781, G	12 Q 34 Tchs+Tchc 39 Tchc 52 Tchs+Tchc 62 Tchs 88 Tchs+Tchc 139 Tchs 152 Tchs+Tchc 160 Tchs 202 Tkw
83	32-688	12 Q+Tchc 35 Tchc 65 Tchc+Tchs 80 Tchc 140 or 167 Tchs+Tchc 226 Tkw
84	32-22055	15 Tchs+Tchc 45 Tchs 60 Tchs+Tchc 165 Tchs 200 Tkw
85	32-15852	35 Tchs 49 Tchs+Tchc 72 Tchs
86	32-18330	23 Tchs 39 Tchs+Tchc 46 Tchs
87	32-22112	15 Tchs 22 Tchc 55 Tchs 64 Tchc 80 Tchs
88	32-15634	4 Q 37 Tchc 49 Tchs 52 Tchc 67 Tchs 69 Tchc 111 Tchs
89	32-13649	4 Q 23 Tchc 30 Tchs 34 Tchc 41 Tchs 46 Tchc 60 Tchs 63 Tchc 105 Tchs
90	32-23031	8 Q 35 Tchc 44 Tchs+Tchc 120 Tchs
91	32-44, Transco 14	180 Tch 366 Tkw 1519 TD
92	32-21331	9 Tchs+Tchc 18 Tchc 32 Tchs 35 Tchc 57 Tchs 59 Tchc 69 Tchs 73 Tchc 82 Tchs
93	5-451, G	16 Q+Tchs 28 Tchc 180 Tchs 216 Tkw (from gamma log, no lithologic log)
94	32-21329	20 Q 28 Tchs 48 Tchc 85 Tchs 94 Tchc 191 Tchs 207 Tkw
95	32-21455	10 Tchs 20 Tchs+Tchc 35 Tchs 40 Tchs+Tchs 100 Tchs
96	32-20216	39 Tchs 53 Tchc 70 Tchs+Tchc 95 Tchs

[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 Kirkwood in these wells are described in Johnson (1961) and Kasabach and Scudder (1961). The "Butler Place" well is a deep test well drilled by the U. S. Geological Survey in 1964. Formations below the Kirkwood in the Butler Place well are shown in Owens and others (1998). 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 are: Q=yellow and white sand, clayey sand, and gravel surficial deposits (map units Qals, Qtl, Qtu, TQg); 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, black) clay, silty clay, and sandy clay of the Cohansey Formation; Tkw=gray and brown clay, silt and fine sand of the Kirkwood Formation. A "+" sign indicates that units are mixed or interbedded. "TD" indicates total depth of deep wells for which units below Tkw are not listed. Units are inferred from drillers' lithologic descriptions on well records filed with the N. J. Department of Environmental Protection, or from geophysical well logs where lithologic descriptions are not available. Units shown for wells may not match the map and sections due to variability in drillers' descriptions and the thin, discontinuous geometry of many clay beds. In most well logs, surficial deposits cannot be distinguished from Cohansey sands; thus, the uppermost Tchs unit in well logs generally includes overlying surficial deposits.

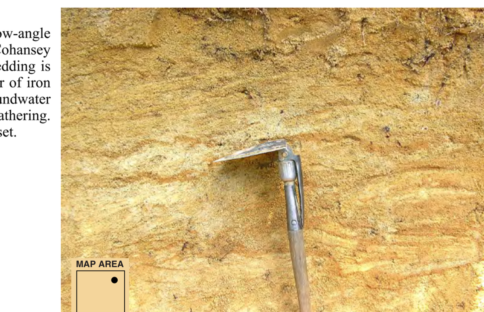


Figure 4. Plane-bedding to low-angle cross bedding in sand of the Cohansey Formation, sand facies. The bedding is highlighted by the orange color of iron compounds deposited by groundwater in coarser sand beds during weathering. Location shown on map and inset.

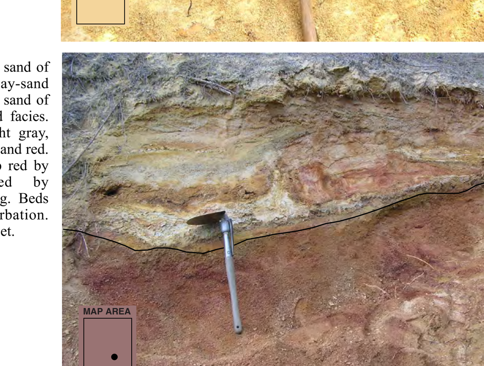


Figure 5. Interbedded clay and sand of the Cohansey Formation, clay-sand facies (above line) over coarse sand of the Cohansey Formation, sand facies. Clay beds are white and light gray, sand beds are yellowish-brown and red. Coarse sands are colored deep red by iron compounds deposited by groundwater during weathering. Beds are deformed by cryoturbation. Location shown on map and inset.