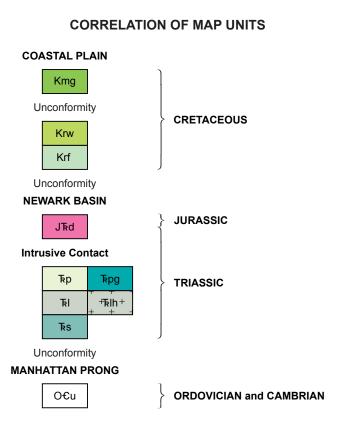


1,000 -

Cretaceous deposits not differentiated

SEA LEVEL



INTRODUCTION

The Perth Amboy and Arthur Kill quadrangles are located in the eastern part of the state, in Middlesex and Union Counties, in a mixed commercial, industrial and residential setting. They are characterized by subdued topography with elevations of 160 feet or less above sea level. The south-flowing Raritan River and Arthur Kill in the southern part of the area are the dominant drainages, and streams of smaller order, such as Robinsons Branch and Rahway River, drain the northern part of the area.

Bedrock is present in two physiographic provinces, the southeastern part of the Piedmont and the northern part of the New Jersey Coastal Plain. Rocks of the Piedmont include unmetamorphosed Jurassic and Triassic sedimentary rocks and metamorphosed pre-Mesozoic crystalline rocks of the Manhattan Prong. The latter do not crop out in the map area but are known to be present from logs of borings (Stanford, 1999) and previous geologic studies (Volkert and others, 1996). Coastal Plain bedrock units include unconsolidated sedimentary formations of Upper Cretaceous age. The Cretaceous formations, and pre-Cretaceous bedrock, are overlain in most of the map area by fluvial, glacial, and estuarine deposits of Pliocene and Quaternary age. These deposits are shown and described on a

separate surficial geologic map (Stanford, 1999).

STRATIGRAPHY

The youngest bedrock in the map area is Cretaceous and underlies the Coastal Plain. The Cretaceous sediments overlie Triassic and Jurassic bedrock in the southeastern part of the map area, generally to the south and east of the New Jersey Turnpike. They dip to the southeast at between 30 and 50 feet per mile and thicken from a feather edge at their northwest limit to about 250 feet thick in Perth Amboy. Incision of the Raritan River during the last glacial lowstand of sea level, to as much as 100 feet below modern sea level, completely eroded through the Cretaceous sediments in the valley bottom upstream from Perth Amboy. Borings show that surficial deposits directly overlie Triassic and Jurassic bedrock in this area.

The Cretaceous sediments include sand, silt, and clay laid down in fluvial and marginal marine settings between 100 and 85 million years ago on the North American margin of the Atlantic Ocean. The basal Cretaceous unit is the Farrington Sand member of the Raritan Formation. The Farrington is fluvial sand with minor clay interbeds laid down on a gently undulating erosion surface with as much as 50 feet of relief developed on weathered Mesozoic bedrock. It grades upwards into the Woodbridge Clay member of the Raritan Formation. The Woodbridge is gray, lignitic clay and silt with minor sand interbeds that was deposited in coastal swamp and shallow bay settings. A period of subaerial erosion and weathering followed deposition of the Woodbridge Clay. The Magothy Formation was laid down on this erosion surface, which has a gentle topography with less than 20 feet of relief. The Magothy in the map area includes clays and interbedded sand similar to the Woodbridge Clay (South Amboy Fire Clay member) overlain by sand with thin clay and silt interbeds (Old Bridge Sand member) deposited in tidal flats and tidal channels on a lower delta plain (Kulpecz and others, 2008).

Bedrock of Jurassic and Triassic age was deposited in the Newark basin, one of a series of northeast-trending rift basins that extend along the eastern North American margin. The Newark basin contains approximately 24,600 feet of interbedded sedimentary and igneous rocks that include Upper Triassic to Lower Jurassic conglomerate, sandstone, siltstone, and shale of fluvial and lacustrine origin, three Lower Jurassic tholeiitic basalt formations, and sills, dikes and bodies of Lower Jurassic diabase of igneous origin.

The majority of the map area is underlain by the Upper Triassic to Lower Jurassic Passaic Formation. The Upper Triassic Lockatong and Stockton formations are not exposed but are known to be present in the southeastern part of the area from drill-hole data. These formations are separated, and locally intruded, by the Lower Jurassic Palisades diabase sill and other thin sill-like bodies associated with the main sill.

The Passaic Formation is in conformable contact with, and underlain by, arkosic fa-

cies of the Lockatong Formation. The contact between them is placed within the Walls Island member, where predominantly reddish-brown siltstone and sandstone of the Passaic Formation gives way to tan or yellow arkosic beds, or gray bed sequences of the Lockatong (Olsen and others, 1996). Most of the Passaic Formation consists of reddish-brown, thin-bedded to fissile shale and silty shale. Thin gray bed sequences generally less than 6 feet thick were mapped nearly to the northern border of the mapped area.

The Lockatong Formation consists of arkosic beds that interfinger with cyclically deposited gray and black lacustrine siltstones averaging 15 feet thick that comprise the remainder of the formation (Van Houten, 1969). The contact between the Lockatong and underlying Stockton Formation is conformable and transitional. It is placed at the base of the Wilburtha member in the Lockatong, at the base of the lowest black or gray shale sequence, where tan to yellow arkosic sandstone and reddish-brown shale of the Stockton become more prominent (Van Houten, 1969; Olsen and others, 1996).

The Stockton Formation consists of yellowish-gray to reddish-brown arkosic sandstone and conglomerate that fine upward into siltstone and shale sequences (Van Houten, 1969). It was deposited directly on the eroded surface of the pre-Mesozoic crystalline rocks, but the contact between them is not exposed in the map area. Based on examination of core samples and boring logs from the Jersey City quadrangle (Volkert, 2016), the basal Stockton was noted to be mainly reddish-brown sandstone, pebbly sandstone and conglomerate, although a few of the borings encountered white to gray sandstone interbedded with reddish-brown lithologies.

Igneous rocks in the map area consist of Lower Jurassic diabase that comprises the southern extension of the Palisades diabase sheet. It intrudes the basal part of the Lockatong Formation and uppermost Stockton Formation, and the basal part of the Passaic Formation, as west-dipping sills. Other thin sill-like bodies also intrude these formations. Both above and below the Palisades diabase, the Lockatong has been thermally metamorphosed to a dark gray hornfels, and a few feet of arkosic sandstone of the Stockton have also been thermally metamorphosed beneath the base of the sill. The age of the Palisades diabase is well constrained by fairly recent geochronology. Zircon and baddeleyite U-Pb ages of 200.9 Ma were obtained by Dunning and Hodych (1990). Marzoli and others (2011) obtained 40Ar/39Ar plateau ages of 202.8 Ma from plagioclase and 201.7 Ma from biotite from the olivine zone, 30 feet above the base of the sill, and 195.1 Ma from plagioclase collected from 300 feet above the base of the sill.

exposed in the map area but are known to be present in the subsurface based on logs of borings and water-well records from Staten Island (Vincent Zambetti, written communication; Pagano, 1994; Cheryl Moss, written communication, 2013; R. A. Volkert, unpublished data). Pre-Mesozoic rocks include mainly micaceous schist of the Ordovician and Cambrian Hartland Formation and altered serpentinite. Other formations, such as Manhattan Schist Member C, or Ordovician Walloomsac Formation, may be present as well but insufficient information is available to identify them.

Metamorphosed crystalline rocks of pre-Mesozoic age of the Manhattan Prong are not

STRUCTURE Bedding

The overall trend of the bedrock units strikes uniformly at an average of N.53 $^{\circ}$ E. (fig. 1), nearly identical to the average strike of bedding of N.55 $^{\circ}$ E. in the Plainfield quadrangle to the west (Volkert and others, 2013). Beds in the map area dip northwest at 7 $^{\circ}$ to 16 $^{\circ}$ and average 10 $^{\circ}$.

A pair of brittle faults are known to deform the Passaic Formation in the central part of

the quadrangle, and they may extend into the northern part as well, but cannot be traced there because of the sparse bedrock exposure. The faults are characterized by closely-spaced fractures, thin zones of breccia and (or) clayey gouge and slickensides locally coated by chlorite or calcite. The westernmost fault, named the Farmhaven Brook Fault by Bond and others (2006), is not exposed and was recognized by the offset of marker beds in drill core. It strikes N.24°E. and dips vertically. It has a reverse movement sense with a maximum vertical offset of about 60 feet (Bond and others, 2006). Another fault about 2,000 feet southeast of the Farmhaven Brook Fault was recognized during mining at the Menlo Park copper mine in the 19th century. According to historical records, the fault zone was vertically-dipping, 6 inches to 2 feet wide and was composed of brecciated and slickensided shale into which most of the copper ore was concentrated (New Jersey Geological Survey, 1907). Apparently the fault doesn't reach the surface and ends beneath less deformed shale beds. Thus it is not shown on the map.

Joints

Joints are a common feature in all of the bedrock formations. Two main sets were measured in the Passaic Formation. They include a strike joint that averages N.42°E. and dips mainly southeast, and a cross joint that averages N.50°W. (fig. 2) and dips with equal abundance southwest and northeast. The dip of all joints ranges from 59° to 90° and averages 81°, but most joints dip between 75° to 90°. All joints are planar, moderately well formed, and spaced from less than 1 foot to several feet apart. Those formed near faults are spaced less than 1 foot apart. Surfaces are unmineralized, except near faults. Joints in sandstone are better developed and more continuous than those in fine-grained rocks, such as siltstone and shale, in which joints are commonly discontinuous over short distances.

Glacially Deformed Coastal Plain Formations

North of the limit of glaciation, which extends from Perth Amboy to Metuchen, the uppermost several feet of Cretaceous sediments are deformed by glacial overriding where they are overlain by till. The deformation, which is best developed in interbedded clay and sand, produced overturned, recumbent folds and, less commonly, thrust faults. Beds and lenses of till are folded or faulted into the Cretaceous sediments in places. Elsewhere, the clays are fractured and brecciated. Upsection, lenses of Cretaceous clay and sand as much as 20 or 30 feet in horizontal extent and 5 to 10 feet thick are thrust or folded into the overlying

ECONOMIC RESOURCES

Copper was mined during the 18th and 19th century at the Menlo Park mine, in the central part of the area, from workings that reached 120 feet below ground surface (Woodward, 1944). The host rock for the deposit was gray shale of the Passaic Formation. Ore consisted of native copper, chrysocolla and chalcopyrite that formed a mineralized zone as much as 4 feet wide (Lewis, 1907; Woodward, 1944).

Clay was mined from the early 1800's until the early 1900's (Cook, 1878; Ries and others, 1904) from numerous pits in Cretaceous deposits mainly south of Woodbridge, west of Perth Amboy, and southwest of Fords. Most of the clay was mined from the Woodbridge Clay member of the Raritan Formation, with some from weathered Triassic shale, and some from clay beds in the Farrington Sand member of the Raritan. These workings covered more than 1000 acres. Several small pits in Perth Amboy mined the South Amboy Fire Clay member of the Magothy Formation. The clay was used to make brick, terra cotta, tile, and

DESCRIPTION OF MAP UNITS

Coastal Plain

Magothy Formation (Upper Cretaceous) (Darton, 1893) - Quartz sand; fine-to-medium

grained, rarely coarse-grained; white, light gray, rarely pink, reddish yellow, yellow; micaceous; commonly interbedded with laminated to thin-bedded clay and silt, gray to white, rarely red and pink. Clay contains pyrite and lignite. Sand is typically cross-bedded or laminated. In the Perth Amboy quadrangle the Magothy (as redefined by Owens and others, 1977) includes, from oldest to youngest, two informal members: the South Amboy Fire Clay of Cook (1878) and Ries and others (1904), a basal unit of predominantly light gray, white, and red clay, as much as 30 feet thick; and the Old Bridge Sand of Barksdale and others (1943), a predominantly cross-bedded fine-to-medium quartz sand, here as much as 20 feet thick. These units were formerly exposed in several clay pits in Perth Amboy (Ries and others, 1904) and were observed during mapping in a gully near Sand Hills. Elsewhere, they are mapped from outcrop data in Ries and others (1904) and well and boring logs in Stanford (1999). The Magothy is Turonian-Coniacian (?) to Santonian in age (Christopher, 1979, 1982).

this quadrangle: the Farrington Sand of Barksdale and others (1943) and the Woodbridge Clay of Cook (1878) and Ries and others (1904). Another member, the "Raritan Fire and Potter's Clay" of Cook (1878) and Ries and others (1904) underlies the Farrington Sand and was mapped by them west of Keasbey. This unit, which may be as much as 20 feet thick, includes a lower red, olive, and gray clay (the "potter's clay") formed by weathering of shale and mudstone of the Passaic and Lockatong formations, and is included in those formations on this map; and an upper, discontinuous, gray sandy clay (the "fire clay") which is near the base of the Farrington Sand and is included in that member on this map. Another member, the "Feldspar-Kaolin Sand Bed" of Ries and others (1904), consisting of interbedded fine micaceous quartz sand, coarse clayey feldspathic sand, and thin clay lenses, lies between the Woodbridge Clay and the South Amboy Fire Clay in places, and was observed by Ries and others (1904) in pits in Perth Amboy. This sand interval, which is as much as 40 feet thick, is named the Sayreville Sand by Barksdale and others (1943) and is an aquifer in places south of the Raritan River. It is too discontinuous to map and included here in the Magothy Formation.

Raritan Formation (Upper Cretaceous) (Cook, 1868) - Includes two informal members in

Woodbridge Clay – Clay and silt; dark gray to black, locally oxidized to white, yellow, and red; massive to laminated; with mica, lignite, siderite concretions, and pyrite; interlaminated with white, yellow, pink, and reddish-yellow quartz sand. Clays are irregularly jointed in outcrop; joints are commonly coated or filled with ironstone. The Woodbridge Clay is as much as 140 feet thick in the map area. Contact with the underlying Farrington Sand is gradational. Northeast of Woodbridge Creek, the Woodbridge Clay is not separated from the Farrington Sand owing to insufficient outcrop and well data. Borings at Fresh Kills landfill on Staten Island, directly across the Arthur Kill from Carteret, show a basal gray Cretaceous sand with minor silt and clay interbeds grading upsection into a gray and black silt and clay with minor fine sand interbeds (Pagano, 1996), a sequence consistent with Farrington Sand overlain by Woodbridge Clay.

The Woodbridge contains pollen of the *Complexipollis-Atlantopolis* assemblage zone, or Pollen Zone IV, of Cenomanian age (Christopher, 1979; Sugarman, 1996). It also contains the ammonites *Metoioceras berquisti* and *Metengonoceras sp.*, indicating an upper Cenomanian age (Cobban and Kennedy, 1990).

Farrington Sand – Quartz sand; fine-to-coarse; white, yellow, reddish yellow, and pink; laminated to cross-bedded; micaceous; locally clayey; with thin interbeds of angular quartz granule gravel and dark gray to white silt and clay with lignite. Rests unconformably on weathered Jurassic and Triassic rocks; thins or pinches out where the rock surface rises, particularly on diabase rock. As much as 90 feet thick in the map area.

The Farrington is Cenomanian in age (Christopher, 1979). It is assigned to the upper part of Pollen Zone III by Christopher (1979). Samples of the Farrington near Sand Hills yielded Zone IV pollen assemblages (L. A. Sirkin, written communication, 1989; Sugarman, 1996). Cretaceous sediments at Fresh Kills landfill on Staten Island yielded Zone III to IV pollen assemblages (Pagano, 1996), consistent with the presence of both the Farrington and Woodbridge members.

Newark Basin Jurassic) – Dark-greenish-gray or blad

Diabase (Lower Jurassic) – Dark-greenish-gray or black, fine-grained, massive, hard diabase. Composed mainly of calcic plagioclase, clinopyroxene and opaque oxide minerals. Contacts are aphanitic and display chilled, sharp margins, and may be vesicular adjacent to enclosing sedimentary rocks. Not exposed in the map area and known from drill-hole data. Thickness of Palisades sill is as much as 1,300 feet.

Passaic Formation (Lower Jurassic and Upper Triassic) (Olsen, 1980a) – Interbedded sequence of reddish-brown and, less commonly, maroon or purple, fine- to coarse-grained sandstone, siltstone, shaly siltstone, silty mudstone, and mudstone (JTrp), separated by gray bed sequences composed of olive-gray, dark-gray, or black siltstone, silty mudstone, shale, and silty argillite (Trpg). Top of unit in the map area is marked by as much as 4 feet of massive, coarse-grained sandstone directly beneath Orange Mountain Basalt. Reddish-brown sandstone and siltstone are thin- to medium-bedded, planar to cross-bedded, micaceous, and locally mudcracked and ripple cross-laminated. Root casts and load casts are common. Shaly siltstone, silty mudstone, and mudstone are fine-grained, very-thin to thin-bedded, planar to ripple cross-laminated, locally fissile, bioturbated, and contain evaporite minerals. They form rhythmically fining-upward sequences as much as 15 feet thick. Thickness of gray bed sequences ranges from 1 foot to 40 feet. Maximum thickness of unit regionally is 11,480 feet.

Lockatong Formation (Upper Triassic) (Kümmel, 1897) – Cyclical sequences of mainly gray to greenish-gray and reddish-brown siltstone to silty argillite and dark-gray to black shale and mudstone. Siltstone is medium-to fine-grained, thin-bedded, planar to cross-bedded with mud cracks, ripple cross-laminations and locally abundant pyrite. Shale and mudstone are very-thin-bedded to thinly-laminated, platy, with local desiccation features. As much as 10 feet of unit have been thermally metamorphosed to hornfels (Trlh) along their contact with diabase. Maximum thickness regionally is as much as 3,500 feet.

Stockton Formation undifferentiated (Upper Triassic) (Kümmel, 1897) – Interbedded sequence of gray, grayish-brown, or slightly reddish-brown, medium- to fine-grained, thin- to thick-bedded, poorly sorted, to clast imbricated conglomerate, planar to trough cross-bedded, and ripple cross laminated arkosic sandstone, and reddish-brown clayey fine-grained, sandstone, siltstone and mudstone. Coarser units commonly occur as lenses and are locally graded. Finer units are bioturbated. Conglomerate and sandstone units are deeply weathered and more common in the lower half of the formation; siltstone and mudstone are generally less weathered and more common in upper half. Lower contact is an erosional unconformity. Thickness is approximately 4,500 feet.

Manhattan Prong Mesozoic crystalline rocks, undifferentiated (O

Ocu Pre-Mesozoic crystalline rocks, undifferentiated (Ordovician and Cambrian) (Volkert and others, 1996) – Schist and gneiss are gray, coarse- to medium-grained and composed of quartz, plagioclase, biotite, muscovite, and garnet. Serpentine is light yellow-ish-green to dark green, fine-grained, massive rock. Where fresh it contains olivine, orthopyroxene, and chromian spinel. More commonly altered to rock composed of various serpentine minerals that may be spatially associated with light green, medium-grained foliated rock composed of talc and magnesiohornblende.

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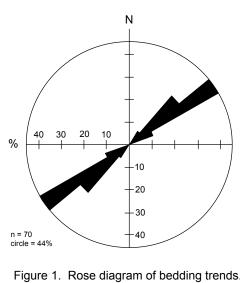
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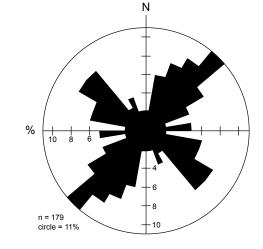


Figure 2. Rose diagram of joint trends.

