STRATIGRAPHY AND HYDROGEOLOGY OF THE UPPER CRETACEOUS RARITAN, MAGOTHY, AND CHEESEQUAKE FORMATIONS, NEW JERSEY COASTAL PLAIN

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INTRODUCTION

This field trip (Figure 1) examines some of the remaining pits exposing Cretaceous rocks in Middlesex County. Continuing rapid development of Middlesex County has led to the closure of many of the best geological exposures of the Cretaceous Raritan and Magothy Formations. Fortunately, many of these exposures have been documented and described in previous field guides including Owens and Sohl (1969), Owens et al. (1977), and Olsson (1987), and in geologic maps (Owens et al., 1995; Sugarman et al., 1995).

The stratigraphy of Cretaceous rocks in Middlesex County, New Jersey has been studied for well over a century. Early economic studies concentrated on the use of clay deposits for making earthen and stoneware pottery, and fire brick (e.g., Ries et al., 1904). Because small beds or lenses of clay were economically important, a stratigraphic terminology developed which often had local significance, but lacked criteria for regional correlation.

Later studies focused on the growing importance of these deposits as sources of ground-water (e.g., Barksdale et al., 1943). Ground-water supply and contamination studies continue to be the major focus of recent geologic and geohydrologic studies in the northern New Jersey Coastal Plain, in large part due to increasing ground-water withdrawals, declining water levels, and saltwater intrusion.

This trip will examine outcropping geology of the Cretaceous Raritan and Magothy Formations (Figure 2) to: 1) develop familiarity with the prominent members (or facies) within these formations; and 2) place these facies into a hydrostratigraphic framework. We will also examine the newly named Cheesequake Formation (Litwin et al., 1993).

STRATIGRAPHIC FRAMEWORK

The stratigraphic units listed below will be seen on this trip. Their distribution is shown on the South Amboy quadrangle (Sugarman et al., 1995).

Woodbury Formation

Dark-gray to olive black clayey silt with very fine quartz sand, finely micaceous, with occasional finely disseminated pyrite, lignite, and siderite. Bedding is massive to finely laminated, with alternating layers of very fine sand and clay-silt; typically burrowed. Glauconite sand makes up as much as 5 to 10 percent of the lower part of formation. Grades into the overlying Englishtown Formation. While the Woodbury is overall ~50 feet thick throughout its outcrop belt (Owens et al., 1995), it thins to less than 20 feet in the South Amboy quadrangle.

Wolfe (1976) used palynomorph assemblages, and Gohn (1992) ostracode assemblages, to assign an early Campanian age to the Woodbury. It was deposited in prodelta and inner-shelf environments.

Merchantville Formation

Highly bioturbated quartz-glauconite sand and clayey quartz silt; thick- to massive-bedded. Layers of fossiliferous siderite concretions are abundant. The Merchantville is the basal transgressive bed of the unconformity-bounded coarsening upward sequence which includes the overlying Woodbury and Englishtown Formations. The contact with the Woodbury is gradational, and is arbitrarily drawn where glauconite sand is no longer a major sand constituent. The unit is thinnest in the north (~20 feet), and thickest in the Trenton area (~70 feet; Owens et al., 1995).

The contact with the underlying Cheesequake Formation is an irregular, burrowed, reworked interval approximately 3 - 4 feet thick, with siderite concretions concentrated near the lower part of the reworked bed. A photo of this contact, from the Oschwald Pit in the adjacent Keyport quadrangle, is shown in Litwin et al. (1993).

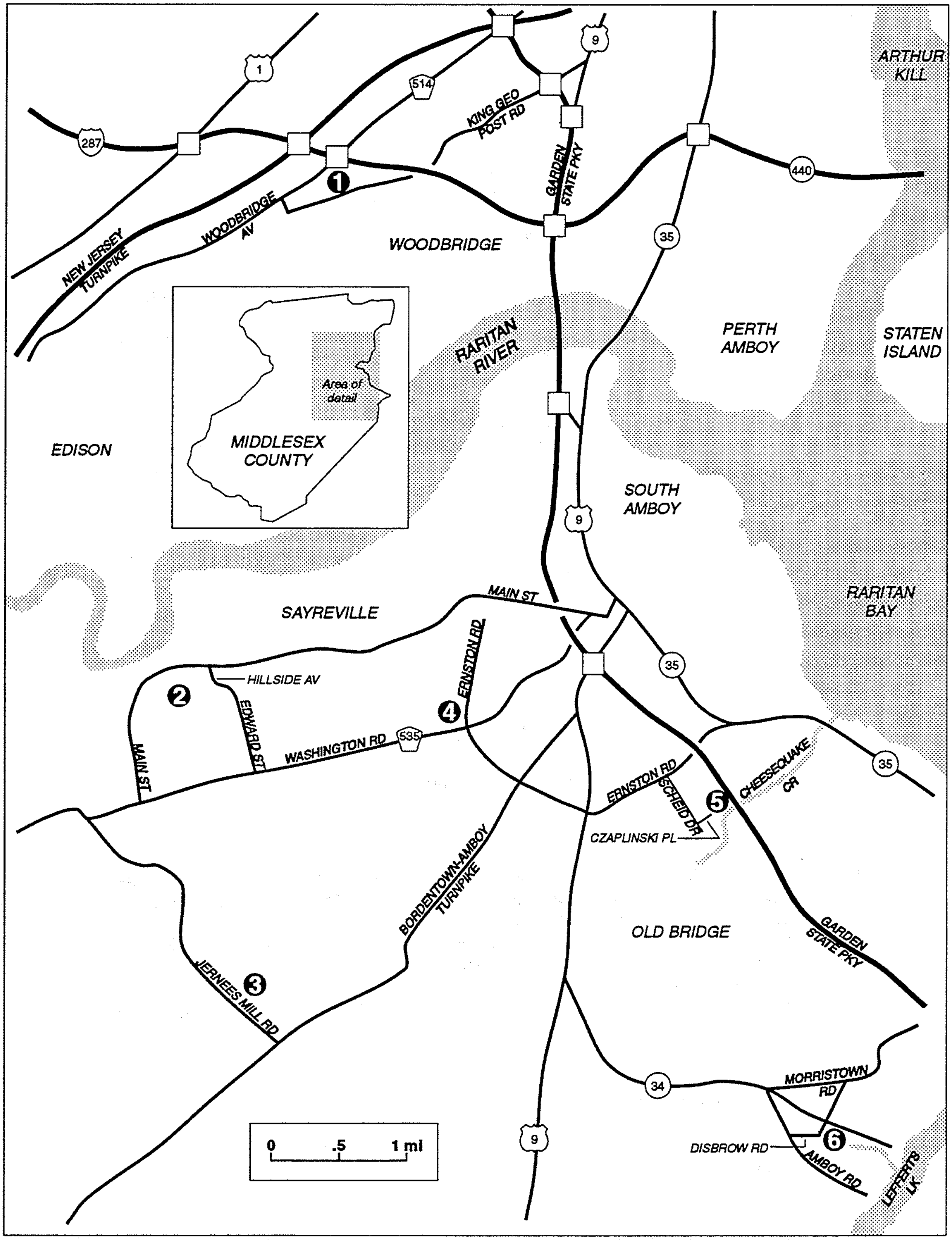

Figure 1. Sketch map showing field-trip route and stops.

The Merchantville is considered lower (but not lowermost) Campanian based on the ammonite *Scaphites hippocrepis* (DeKay) III and *Menabites (Delawarella) delawarensis* (Morton)(Cobban and Kennedy, 1992). It was deposited in a middle- to outer-shelf environment (Olsson, 1987).

Cheesequake Formation

Olive to dark-greenish-gray clay-silt, weathering to moderate brown; massive, burrowed (with lighter colored very fine to fine sand fillings), with mica (mostly clear, some green and brown) and lignite. Grades to olive-gray and dark yellowish-brown (moderate brown where weathered), silty, very fine to fine-quartz sand at top, generally laminated where not extensively burrowed. Very carbonaceous and micaceous, with glauconite (as much as 20%) typically in the basal few feet. Molds of gastropods and layers of large concretions (0.25-1 feet in diameter) are common in the base of the formation. The contact with the Magothy Formation is sharp and disconformable, and is marked by the change from cross-stratified sands and silts below to massive clays, occasionally laminated, with siderite concretions along the boundary.

The Cheesequake is well exposed south of Route 34 in the northwestern tributary of Lake Lefferts. Maximum exposures are 40 - 45 feet thick. Good exposures also occur just north of Route 34 in the southernmost tributaries of Cheesequake Creek. Because of a rapid change in facies in short distances, updip exposures (north of Route 34) generally lack glauconite sand, whereas downdip exposures (south of Route 34) typically contain glauconite sand in the clay-silt matrix. The Cheesequake has been previously placed in the upper Magothy (e.g., Owens et al., 1977; p. 98), and the lower Merchantville (e.g., Weller, 1907). In the subsurface, lack of recognition of the Cheesequake led some workers (e.g., Petters, 1976) to interpret the Magothy and Merchantville as interfingering in the subsurface.

The Cheesequake contains an uppermost Santonian to lowermost Campanian pollen assemblage in the outcrop and subsurface (Litwin et al., 1993). It is a marine unit, with the predominance of woody material and mica suggesting deposition in an inner shelf environment. Where bedding is not obliterated by burrowing, flasers also indicate a possible tidal flat environment.

Magothy Formation

Quartz sand, light colored, commonly interbedded with carbonaceous thin to thick, dark clays and silts. Sand is typically cross-stratified, although laminated sequences are also common. Heavy minerals are dominated by the zircon-tourmaline-rutile (ZTR) suite (Owens and Sohl, 1969). The Magothy contains many lithologies which have been mapped for their economic resources (for example Ries et al., 1904) and hydrologic properties (for example Barksdale et al., 1943). The application of deltaic facies models and palynostratigraphy by Wolfe and Pakiser (1971), Owens and Sohl (1969), Owens et al. (1977), and Christopher (1979) led to a more integrated chronostratigraphic framework for the Magothy and Raritan Formations. Usage follows that of Owens et al. (1977, 1995), and Sugarman et al. (1995) wherein the Magothy includes, from oldest to youngest, the following informal members: South Amboy Fire Clay, Old Bridge Sand, Amboy Stoneware Clay, Morgan beds, and Cliffwood beds. Pictures of the members can be found in Owens and Sohl (1969) and Owens et al. (1977). Although each of these members generally has some distinctive lithologic characteristics, rapid vertical and lateral facies changes complicates mapping; moreover, exposures are limited.

Overall, the Magothy Formation is interpreted as a series of delta-plain and delta-front deposits. This is supported by the abundance of lignite, and interbedded fossiliferous and nonfossiliferous strata (Owens and Gohn, 1985).

Cliffwood beds - quartz sand, light colored, fine to medium, some mica (clear and green), commonly cross-stratified; some horizontal bedding with local *Ophiomorpha* burrows; interbedded with thin dark micaceous and carbonaceous silt containing pyrite. Fossils, primarily crustaceans, in the siderite concretions at the base of the Cliffwood beds in Cliffwood Beach have been described by Weller (1907). The Cliffwood Beach type locality, described in Owens et al. (1977; p. 98), is no longer exposed. Best exposures are in gullies north of Route 34 in the southern section of Cheesequake Park. Maximum thickness of 25 feet. The Cliffwood beds represent delta-front deposits.

Morgan beds - laminated to thinly bedded clay, light to medium gray, typically carbonaceous, and interbedded light micaceous quartz sand. Sands massive or cross-bedded, yellowish-gray (weathered), and predominantly fine grained. Heavy minerals are dominated by ilmenite, leucoxene, and the mature ZTR suite; and to a lesser extent, the staurolite-sillimanite-kyanite (SSK) suite. Clay minerals are mostly kaolinite and illite. Excellent exposures are in the gullies and abandoned pits northwest of Melvins Creek

<table>
<tr><th>Series</th><th>Stage</th><th>Formation</th><th>Member</th><th>Hydrogeologic Units</th></tr>
<tr><td rowspan="11">Upper Cretaceous</td><td rowspan="3">Campanian</td><td>Woodbury</td><td rowspan="3"></td><td rowspan="6">Merchantville -Woodbury Confining Bed</td></tr>
<tr><td>Merchantville</td></tr>
<tr><td>Cheesequake</td></tr>
<tr><td rowspan="5">Santonian</td><td rowspan="5">Magothy</td><td>Cliffwood Beds</td></tr>
<tr><td>Morgan Beds</td></tr>
<tr><td>Amboy Stoneware Clay</td></tr>
<tr><td>Old Bridge Sand</td><td rowspan="2">Upper PRM Aquifer</td></tr>
<tr><td>South Amboy Fire Clay</td></tr>
<tr><td rowspan="3">Cenomanian</td><td rowspan="2">Raritan</td><td>Woodbridge Clay</td><td>Confining Bed</td></tr>
<tr><td>Farrington Sand</td><td rowspan="2">Middle PRM Aquifer</td></tr>
<tr><td>Potomac</td><td>Unit III</td></tr>
<tr><td>Jurassic</td><td>Hettangian</td><td>Diabase</td><td rowspan="2"></td><td rowspan="2">Bedrock ConfiningBed</td></tr>
<tr><td>Late Triassic</td><td>Rhaetian/ Norian</td><td>Passaic</td></tr>
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Figure 2. Stratigraphy (after Owens et al., 1995) and hydrogeologic units (after Zapecza, 1989) for the field trip.

and west of the Garden State Parkway. The Morgan beds are approximately 40 feet thick, and grade into an underlying clay. The Morgan beds are interpreted as tidal delta deposits (Olsson, 1987).

The Cliffwood and Morgan beds have been assigned to the *?Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zone by Christopher (1979), which is equivalent to the upper part of Zone VII of Sirkin (1974). This *?Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zone is considered Santonian to earliest Campanian.

Amboy Stoneware Clay Member - Clay-silt, dark gray to grayish-brown, weathering to white; carbonaceous and micaceous, with grayish-pink fine quartz sand laminas. Fine grained pyrite is commonly associated with the carbonaceous areas. Owens et al. (1977) note that certain beds had large pieces of lignitized logs, and small cylindrical burrows filled with light sand. The Amboy Stoneware is very variable in thickness along strike, in places massive, and appears to have been deposited in lensoidal channels. This unit is ~25 feet thick.

Christopher (1979) placed the South Amboy and upper part of the Old Bridge in his *Psuedoplicapollis longiannulata-Plicapollis incisa* zone, which he considered Coniacian (?) to early Santonian; this corresponds to the lower part of Sirkin's (1974) Zone VII. Sugarman et al. (1995) informally assigned Zone VI to the *Psuedoplicapollis longiannulata-Plicapollis incisa* zone, suggesting that the Amboy Stoneware disconformably overlies the Old Bridge Sand Member. Due to the presence of dinoflagellates in certain localities, the Amboy Stoneware is interpreted as a marginal marine deposit. It may represent an interdistributary bay deposit.

Old Bridge Sand Member- Quartz sand, light gray, weathered to shades of orange and pink, medium to coarse grained, rarely burrowed, with clear mica and sand sized lignite; extensively cross-bedded including trough and planar-tabular cross-bedding varying greatly in size; interbedded with thin-(laminas) to thick-bedded dark discontinuous carbonaceous clay beds as much as 3 feet thick. Heavy minerals include opaques (ilmenite and leucoxene) and nonopaques, dominated by the mature ZTR suite. Exposures of the Old Bridge are poor due to the loose, sandy nature of the beds. Barksdale et al. (1943) estimates a thickness of 80 - 110 feet for the Old Bridge sand, while Owens et al. (1995) gives its thickness in outcrop as 40 feet. This discrepancy may be due to the fact that Barksdale et al. (1943) uses both surface exposures and wells.

The Old Bridge Sand Member is interpreted as a lower delta-plain deposit. The cross-bedded sands are probably distributary channels; the lignitic fine-grained deposits are marsh, swamp, and flood-basin deposits (Owens and Gohn, 1985).

South Amboy Fire Clay - Clay, massive to finely laminated, locally dark gray, but typically oxidized to shades of white and red. Dominated by kaolinite and mixed layer clays (Owens et al., 1977). Contains lignitized, pyritic logs which commonly are flattened. Also contains small fragments of amber in places (Owens et al., 1977). The clay beds generally occur in channels, and are commonly adjacent to cross-bedded, fine to medium grained quartz sands with thin carbonaceous layers containing varisized lignitized material, including logs. Heavy minerals in the sands include opaques (ilmenite and leucoxene); nonopaques are dominated by the ZTR suite.

The South Amboy Fire Clay is the lowermost member of the Magothy. Maximum thickness is 35 feet (Owens et al., 1977). Christopher (1979) recognized a major break in the Normapolles and triporate pollen distribution at the base of this clay, whereas Wolfe and Pakiser (1971) regarded it as the upper member of the Raritan Formation. The South Amboy Fire Clay is assigned to pollen Zone V in this study. The paleoecology of the palynomorph assemblage suggests a coastal lowland swamp with nearby mesic coniferous stands and swampside angiosperms; some brackish water is suggested by a few species of *Baltispaeridium*. This supports the previous interpretation of deposition of the South Amboy clay in abandoned meandering river channels in a subaerial delta-plain (Owens and Sohl, 1969).

The South Amboy Fire Clay is assigned to the *Complexiopollis exigua-Santalacites minor* Zone (Christopher, 1979); this zone was formerly considered Turonian to Coniacian (Christopher, 1979) and later revised to post-Coniacian (Christopher, 1982).

Raritan Formation

The Raritan Formation includes two informal members : the Farrington Sand and the Woodbridge Clay. Owens et al. (1977) included (from oldest to youngest) the Raritan Fire Clay, Farrington Sand, Woodbridge Clay, and Sayreville Sand (of Barksdale et al., 1943) as informal members of the Raritan. The

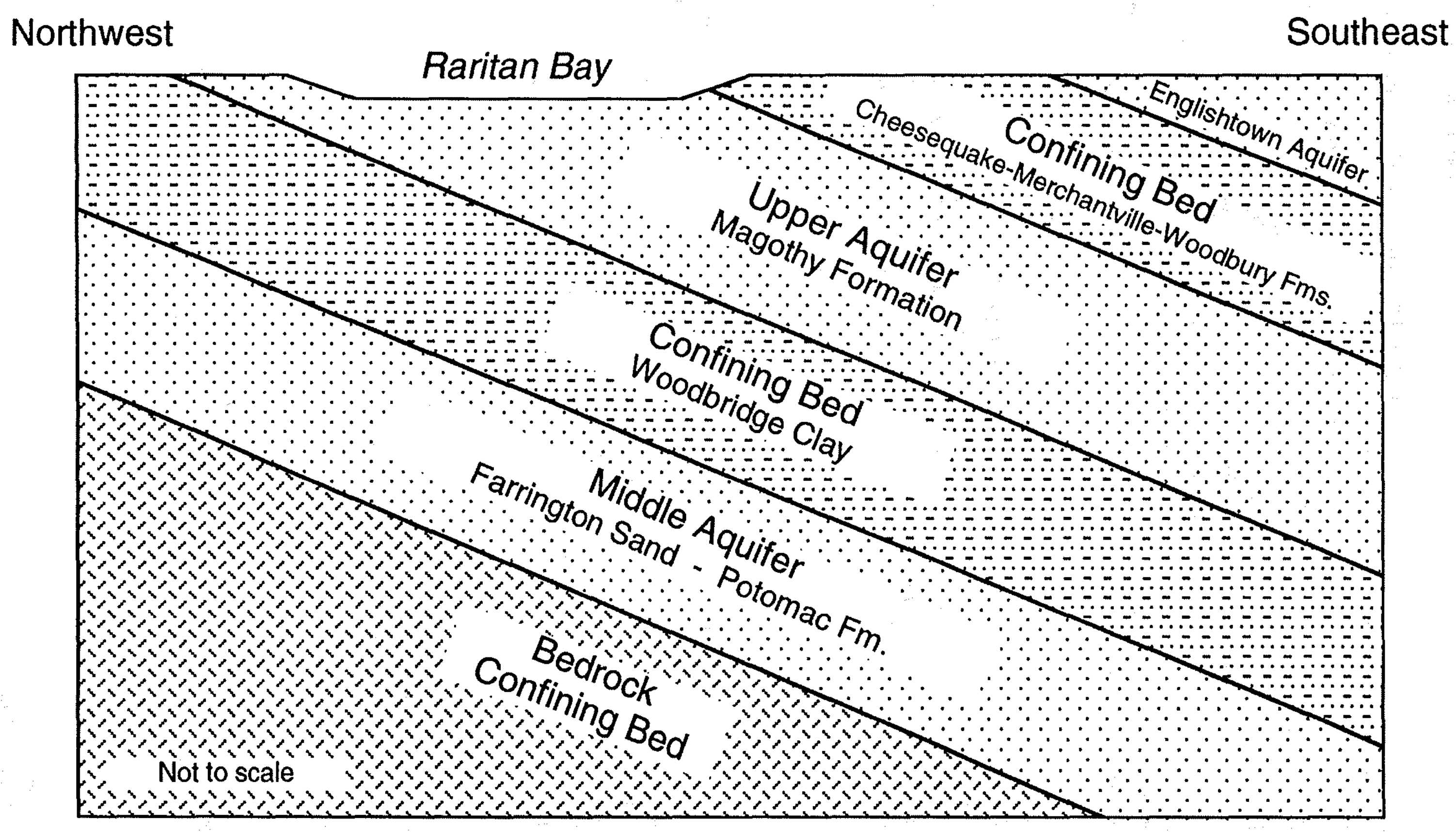

Figure 3. Generalized hydrostratigraphy of the Potomac-Raritan-Magothy aquifer system in the northern New Jersey Coastal Plain. The aquifer system is situated between the Bedrock confining bed and the Englishtown aquifer system. Hydrogeologic units are from Zapecza (1989). Geologic correlations are from Sugarman et al. (1995). Figure modified from Schaefer and Walker (1981).

Raritan Fire Clay, as described in Ries et al. (1904), may, in part, be a residuary clay formed from the decay of the shale, or the product of reworking and redeposition of material prior to the deposition of Cretaceous deposits. The Sayreville Sand was the "Feldspar"-"Kaolin" Sand Bed of Ries et al. (1904). Because the Sayreville is very discontinuous, irregular in thickness, and not recognizable over a large area, it is not mapped as a member of the Raritan anymore. The South Amboy Fire Clay includes a localized cross-bedded sand facies (see preceding discussion), and its limited exposures make it difficult to separate the Sayreville from the cross-bedded sand facies of the South Amboy. Consequently, all the beds above the Woodbridge Clay and below or immediately adjacent to the true clay in the South Amboy Fire Clay are included here in the South Amboy Fire Clay Member.

The contact of the South Amboy Fire Clay and the Woodbridge Clay is best exposed in the abandoned Sayre and Fisher Pit in Sayreville (Stop 2). There is ~25 feet of relief at the contact. The contact is marked by a thin (0.5-1 feet) bed of gravel and clay (white kaolinite) which consists of weathered ripup clasts. An ironstone layer typically overlies this bed.

Woodbridge Clay - Clay-silt, dark gray, massive, burrowed (*Callianassa* borings), with mica (clear, brown, and green), wood (typically fine grained), and pyrite. Occasionally interlaminated with light sand and dark clay-silt. Clay minerals are dominated by a kaolinite-illite assemblage (Owens et al., 1977). Small (less than 3 feet thick) beds and slabs of gray to brown siderite are common. Lignitized trees in growth position have been reported at the base of the Woodbridge in the Sayre and Fisher Pit (Owens and Sohl, 1969), where the best exposure of the Woodbridge remains (Stop 2). Fossil imprints occur near the middle and top of the formation in micaceous siderite sandstone concretions (Owens et al., 1977). Richards (1943) and Stephenson (1954) describe a diverse assemblage of mollusks from these concretions consisting predominantly of bivalves and gastropods. Stephenson (1954) correlates this fossiliferous layer with the Cenomanian Woodbine Formation of Texas. Recently, the upper Cenomanian ammonites *Metoicoceras bergquisti* and *Metengonoceras* sp. were collected from the Sayre and Fisher Pit (Cobban and Kennedy, 1990). The Woodbridge Clay is also the type for the Cenomanian Complexipollis-Atlantopollis assemblage Zone (Christopher, 1979), or Zone IV of Sirkin (1974). Dinoflagellate cysts, including *Cyclonephelium distinctum* and *Hystrichospheridium recurvatum*, occur in the Woodbridge (Sugarman et al., 1995).

The Woodbridge Clay deposit has been interpreted as a lowland swamp (for example, mangrove-type swamp, Owens and Sohl, 1969) with considerable marine influence; or an inner neritic shelf deposit (Sohl, in Owens et al., 1977), and the prodelta or inner neritic shelf deposits related to a delta system dominated by fine-grained sediment. It is 50 - 90 feet thick in outcrop (Owens et al., 1977).

Farrington Sand - Quartz sand, light, micaceous, commonly interbedded with thin gravel beds and thin to thick dark silt beds. It is interpreted as a meandering stream deposit. The Farrington rests unconformably on rocks of Mesozoic age. In the adjacent New Brunswick quadrangle, the Farrington overlies a weathered red clay, which grades downward into a red shale or siltstone of the Newark Group. Approximately 30-35 feet thick (Owens et al., 1995).

HYDROGEOLOGY

The Potomac-Raritan-Magothy aquifer system is the most productive ground-water resource in Middlesex County, accounting for 100 percent of ground-water withdrawals (Vowinkel, 1984). It has been extensively studied because of its importance to water supply. On this trip, we will focus on: 1) correlation of geologic formations and hydrogeologic units in the South Amboy quadrangle, and 2) physical characteristics and depositional environments of these hydrogeologic units.

Figure 3 is a generalized hydrostratigraphic framework for the northern New Jersey Coastal Plain and this trip. Hydrogeologic units are from Zapecza (1989), while geologic interpretations are based on the bedrock geologic map of the South Amboy quadrangle (Sugarman et al., 1995), the bedrock geologic map of the central New Jersey (Owens et al., 1995), and geologic relationships discussed in Barksdale et al. (1943).

Bedrock Confining Bed

The Middle aquifer of the Potomac-Raritan-Magothy aquifer system is confined in this area by the bedrock confining bed. The bedrock confining bed consists of several formations within the Newark Supergroup including the Stockton, Lockatong, and Passaic Formations, and diabase. In the subsurface to the southeast, the bedrock confining bed consists of undifferentiated pre-Mesozoic crystalline and metamorphic rocks. The transition from Newark Basin Rocks to pre-Mesozoic rocks occurs approximately at South River. A layer of saprolite is common along the contact of this unit with the Middle aquifer; it may be several feet to tens of feet thick. Formations composing the bedrock confining bed will not be seen on this trip.

Middle Aquifer of the Potomac-Raritan-Magothy Aquifer System

The middle aquifer of the Potomac-Raritan-Magothy aquifer system is correlative with the Farrington Sand Member of the Raritan Formation (Pucci et al., 1989). Barksdale et al. (1958) reports transmissivities of 2,300 - 13,440 (feet squared per day), and hydraulic conductivities of 79 - 2000 (feet per day), for the middle aquifer in Parlin and Old Bridge, Middlesex County. In outcrop (e.g., Stop 1 of this trip), the Farrington Sand is an interbedded crossbedded, medium micaceous sand and dark gray, very woody clay-silt. It is typically 30 - 35 feet thick (Owens et al., 1995). Barksdale et al. (1943) describes the Farrington Sand as medium to fine-grained in the upper part, and coarse, arkosic, and pebbly in the lower part. Barksdale et al. (1943) reports the thickness of the Farrington Sand as 80 feet.

While the correlation of the middle aquifer exclusively with the Farrington Sand is correct in the shallow subsurface (downdip from the outcrop of the Farrington Sand), it is problematic in the deeper subsurface. For example, at the Freehold borehole (40° 15' 16", 74° 13' 51", ~17 miles downdip from Sayreville), the Middle aquifer is correlated only with the Potomac Unit III (Pucci and Owens, 1989). Clearly, somewhere between its outcrop and the Freehold borehole, the Farrington Sand is replaced by the Potomac Unit III as the main component of the middle aquifer. The Potomac Unit III is approximately 200 feet thick at the Freehold borehole. It is interpreted as an upper delta plain deposit.

Confining Bed Between the Middle and Upper Aquifers

The confining bed between the middle and upper aquifers is composed predominantly of the Woodbridge Clay. The Woodbridge Clay is the thickest (50-90 feet in outcrop) and most persistent clay in either the Raritan or Magothy Formations (Owens et al., 1977). Zapecza (1989) reports a maximum thickness of 150 feet downdip for the Woodbridge Clay. Farlekas (1979) reports a vertical hydraulic conductivity of 3.6×10^{-2} to 8.6×10^{-6} feet per day for the Woodbridge Clay from model results in the field trip area.

The upper part of confining bed below the upper aquifer may also contain the finer grained (clay-silt) facies of the South Amboy Fire Clay. The South Amboy Fire Clay is thinner (maximum 35 feet) and less widespread (due to rapid facies changes) than the Woodbridge Clay. As discussed above, the Magothy has channeled into the Woodbridge Clay. As described at Stop 2, there is a thin bed of gravel and clay (white kaolinite) which consists of weathered ripup clasts. Water flows into the pit on top of the surface of this contact. So while in places the South Amboy Fire Clay and the Woodbridge Clay form the confining bed between the middle and upper aquifers, water may be channeled along the base of the stratigraphic contact within the confining bed. As seen on Stop 2, the rapid facies changes in the South Amboy Fire Clay makes it a poor confining unit by itself.

Upper Aquifer of the Potomac-Raritan-Magothy Aquifer System

The upper aquifer coincides with the Magothy Formation (Zapecza, 1989). In and near the outcrop belt, the Upper Aquifer is considered correlative with the Old Bridge Sand. In fact, the aquifer has been termed the "Old Bridge" aquifer (Schaefer and Walker, 1981), because of its equivalence with the Old Bridge Sand Member of the Magothy Formation (Zapecza, 1989). The transmissivity ranges from 1,760 - 19,400 feet squared per day, while the lateral hydraulic conductivities are from 4 - 483 feet per day in the upper aquifer (Pucci et al., 1989).

The hydrogeologic and geologic relationships in the upper part of the Magothy Formation (Amboy Stoneware, Morgan Beds, Cliffwood Beds) are complex due to rapid vertical and lateral facies changes. This is characteristic for sediments deposited in an upper delta plain and delta front environment. This complexity is not really addressed in simple hydrogeologic correlations (e.g., aquifer, confining unit). For example, by placing the Amboy Stoneware, Morgan Beds, and Cliffwood Beds within the Merchantville-Woodbury confining unit, it is implied that the Morgan and Cliffwood are relatively impermeable units. As will be seen on this field trip (Stop 5), considerable interbeds of fine-grained quartz sand are present in the Morgan Beds. The Cliffwood beds (not seen on this trip) are typically fine to medium grained horizontally bedded to crossbedded sand (Owens et al., 1995).

Of importance to this problem is the thickness and continuity of the Amboy Stoneware Clay Member. The Amboy Stoneware Clay is approximately 25 feet thick, but tends to pinch out along strike.

An excellent example of this relationship used to be visible in the former South River Sand & Gravel Pit where a thin lense of the Amboy Stoneware is channeled into the underlying Old Bridge Sand. Where the Amboy Stoneware is present, it should behave as a confining unit. Where it is absent or thinned due to either beveling, nondeposition, or facies changes, and the Morgan and Cliffwood beds are juxtaposed on the Old Bridge Sand, there exists the possibility that sand beds in the Morgan and Cliffwood may be capable of transmitting water to the Old Bridge Formation through these gaps. Although there is a large percentage of sand in the Cliffwood and Morgan beds, the uniformly fine grained nature of the sand precludes large yields for the wells tapping it. Therefore it does not have significance as an aquifer, except possibly for domestic supply (Barksdale et al., 1943).

Merchantville-Woodbury Confining Bed

The Merchantville-Woodbury confining bed includes the Cheesequake, the Merchantville, and Woodbury Formations. It may also include all or parts of the Amboy Stoneware Clay, Morgan beds, and Cliffwood beds in its lower part, and clays in the lower portion of the Englishtown Formation in its upper part. Vertical hydraulic conductivities of this confining unit were estimated from model results at 4.3×10^{-6} feet per day for the Northern New Jersey Coastal Plain (Nichols, 1977). This extensive confining bed functions between the upper aquifer of the Potomac-Raritan-Magothy aquifer system and the Englishtown aquifer system (Zapecza, 1989).

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Road Log

Road Log (Fig. 1) starts at the New Jersey side of the Outerbridge Crossing (Route 440S).

0.0	0.0	Continue westward on Route 440S
3.3	3.3	Route 514W exit sign
0.6	3.9	Exit onto Route 514W (left exit)
0.5	4.4	Exit right lane for Raritan Center
0.2	4.6	Turn left on King George Post Road
0.6	5.2	Park at the Business Center at Edison, and cross road to gully.

STOP 1: Raritan Center, Edison

Owner: Federal Business Centers.

In the drainage ditch on the Federal Business Centers, ~30 feet of the Raritan Formation are exposed. This formation is capped (at ~100 feet) by 5 feet of surficial material consisting of cross bedded sand and gravel. At this stop, the Raritan Formation consists of (from top down):

10 feet of interbedded black laminated to thin bedded clay.

10-15 feet of pale yellowish orange to grayish orange cross-bedded fine to coarse sand, occasionally micaceous.

10 feet massive black clay-silt; very lignitic, with pyrite, occasional 2 inch diameter siderite concretions, and interbedded fine sand.

1 foot of white, very clayey sand with possible burrows or roots. Contact of this white clayey sand and black clay above is irregular.

No marine fossils have been collected at this site. Pollen collected from black clays has been assigned to Pollen Zone IV of Sirkin (1974). This zone is equivalent with the Complexiopollis-Atlantopollis Assemblage Zone of Christopher (1979) which is predominantly middle to upper (?) Cenomanian.

Prior to recent industrial development, the Farrington Sand Member of the Raritan Formation was exposed across the road at lower elevations.

5-10 feet of an interbedded crossbedded, medium micaceous sand and dark gray, very woody clay-silt, which can be both massive and bedded. Interpreted as meandering stream deposit. Also assigned to Pollen Zone IV. At the base of the pit (~20-30 feet elevation), the Farrington was in contact with a red shale and clay.

0	5.2	Turn around on King George Post Road
0.7	5.9	Turn right at first light
0.1	6.0	Turn right onto Route 514E
0.2	6.2	Bear right onto Route 440N
1.5	7.7	Exit onto Route 9S
3.8	11.5	Bear right and continue on Route 9S
1.7	13.2	Exit onto Ernston Road
0.1	13.3	Turn right onto Ernston Road West
1.1	14.4	Turn left onto Washington Street (Route 535S)
2.8	17.2	Turn right onto MacArthur Avenue
1.1	18.3	Turn left onto Main Street
0.4	18.7	Turn off on right side of road.

STOP 2: Abandoned Pit of the Sayre & Fisher Brick Company

Owner: K-Land Corporation #5

The Sayre & Fischer brick pit offers the best exposure of the Woodbridge Clay Member in New Jersey. It also contains the contact of the Raritan and Magothy Formations in the southeastern part of the pit. This stop has been previously described by Owens and Sohl (1969), Owens et al. (1977) and Olsson (1987, 1980). The Woodbridge Clay at the pit contains:

30-40 feet of black laminated silts and clays containing many layers of siderite- and iron-oxide-cemented sand. Laminations destroyed by burrowing in the top section. Fossil imprints occur near the middle and top of the Woodbridge Clay in micaceous siderite sandstone concretions (Owens et al., 1977). Pyrite and lignite are scattered throughout the Woodbridge.

5-6 feet of sand and clay containing wood (often in an upright position) were previously exposed at the base of the pit and are now below the upper level of the pond.

Richards (1943) and Stephenson (1954) describe a diverse assemblage of bivalves and gastropods. Stephenson (1954) correlates this fossiliferous layer with the Cenomanian Woodbine Formation of Texas. Sohl (in Owens et al., 1977) interprets this fossil bed to be the result of a winnowed storm deposit, placing an infaunal-dominated molluscan assemblage into a marginal marine environment. Recently, the upper Cenomanian ammonites *Metoicoceras bergquisti* and *Metengonoceras* sp. were collected from the Woodbridge Clay at this pit (Cobban and Kennedy, 1990). The Woodbridge Clay is also the type for the Cenomanian Complexipollis-Atlantopollis assemblage Zone (Christopher, 1979).

0	18.7	Turn left back on Main Street
0.4	19.1	Turn right onto MacArthur Ave
0.1	19.2	Continue straight on Jernee Mill Road
2.4	21.6	Turn left onto Bordentown Avenue
0.3	21.9	Turn right into the Sayreville Recreational Complex.

STOP 3: Sayreville Recreational Complex.

Owner: The Borough of Sayreville

The closing of the South River Sand and Gravel Pit (see Owens et al. 1977 for a description) several years ago eliminated the finest exposure of the Old Bridge Sand in New Jersey. This exposure of the Old Bridge Sand member of the Magothy Formation is a good (but slumped) outcrop showing a major sand channel in the Old Bridge Sand. To the east of this exposure is a graded, seeded bank which offers a partial view of the very carbonaceous, laminated clay-silt and fine sand which was better exposed at the South River Sand and Gravel Pit, and is a common facies of the Old Bridge. The Old Bridge Sand (and thin surficial cap) at this site consist of:

0-5 feet of light brown surficial sand and gravel. At the contact of the surficial unit and the Old Bridge Sand (~90 feet elevation) is an ironstone layer.

25 feet of medium (occasionally coarse) micaceous cross bedded sand. Cross-beds consist of small 2-3 inch troughs, sometimes with thin clay stringers, and occasional thin lignitic cross-lamina.

0	21.9	Turn left onto Bordentown Avenue
1.9	23.8	Turn left onto Cheesequake Road
1.3	25.1	Turn right onto South Minisink Avenue
0.3	25.4	Turn right onto Washington Road (535N)
1.2	25.6	Turn left into John F. Kennedy Park

STOP 4: John F. Kennedy Park - Lunch

The park is the site of an old pit where there used to an excellent exposure of the South Amboy Fire Clay Member of the Magothy Formation. This member was described at this location by Owens et al. (1977; p. 96) as:

> "...a tough, white, light -blue to gray or red-mottled clay. Locally it may be quite dark and contain some lignite...". "Sulfur-balls" (round, ball-like aggregates of pyrite, 1 to 4 inches in diameter) are found in many places, and disseminated pyrite is common throughout the unit. At some localities, small pieces of amber occur near the base of the South Amboy".

On the other side of Washington Avenue we passed the DuPont plant on the way to Kennedy Park. A split spoon well from the site, described below, gives thickness and description of strata outcropping at the park, as well as in the shallow subsurface.

DuPont Parlin FW-5 (Ground Elevation 107 ft; depths reported below land surface).

Pennsauken Formation (~40 feet thick)
5-7': Yellowish red poorly sorted fine -very coarse sand, some rock fragments, trace granules and clear mica, 1% opaques.
10-12': Reddish yellow (7.5 YR 6/6) gravel (maximum 3/4"), gravely sand, some silt, poorly sorted, with rock fragments and feldspar, 2% opaques.
15-17': Light brown (7.5 YR 6/4) gravel (maximum 1.25"), gravely sand, and some rock fragments, with more large gravel.
20-22' Light gray (10YR 7/2) sand, well sorted, mixed with sandy gravel.
25-27': Very pale brown (10YR 7/3) moderately sorted sand, mostly fine with some medium, trace mica.
30-32': Light reddish brown (5YR 6/3) sand, poorly sorted, mostly medium, trace of clear and green mica.
35-37': Reddish yellow (5YR 6/6) clayey gravely sand; gravel to 1" maximum.

Magothy Formation - Old Bridge Sand (~55 feet thick)======================
40-42': Light gray (10YR 7/2) sand, well sorted, fine, clear quartz, trace medium, some fine opaques.
45-47': Same as above.
50-52': Light gray sand, medium.
60-62': Light gray sand, medium, some fine and coarse, minor mica and carbonaceous material..
65-67': As above, medium to coarse, trace gravel to 1/4".
70-72': Light gray to light brownish gray coarse to very coarse sand, trace mica.
75-77': Sand, clayey, medium to -very coarse, with some 1/2" gravel, becoming light yellowish brown.
80-82': Sand, light gray, coarse, with occasional gravel.
85-87': Yellowish gray (5Y 7/2) to light brown (5YR 5/6) interbedded clay and fine to medium sand.
90-92': Light gray sand, medium to coarse, poorly sorted, with some mica.

Magothy Formation - South Amboy Fire Clay (~32 feet thick)=================
95-97': White (N9) - pinkish gray (5YR 8/1) sand, very fine to fine, trace silt.
100-102': Yellow gray to light brown sand, very fine to fine, laminated, trace silt.
105-107': Yellowish gray (5Y 7/2) silty fine sand, with mica.
110-112': Sand, silty, fine to medium, with some coarse to very coarse.
115-117': As above, various shades of orange (10YR 8/2, 8/6, 7/4).
120-122': Light gray (N7) silty sand, very fine, well sorted, 1% clear mica, trace lignite.
125-127': Medium dark gray laminated clay-silt, 5% fine sand, 1% pyrite, mica, trace lignite.

Raritan Formation - Woodbridge Clay (~100 feet thick)====================

130-132': Light to medium light gray clay-silt, some very fine to fine sand, with some elongated lignite pieces.
135-137': Medium-dark (N6-N3) gray, as above, with more clay, carbonaceous material, and mica.
140-142': Light gray (N7) silt, 1-2% very fine sand, 2% mica (white).
145-147': Light olive gray (5Y 6/1) very fine to fine sand, some silt, white mica, and trace of fine carbonaceous matter.
150-152': Light olive gray (5Y 6/1) laminated silt, with abundant finely disseminated mica and carbonaceous material, some siderite.
155-157': As above.
160-162': Grayish orange (10YR 7/4) sand, very fine-fine, with white mica and some carbonaceous material.
165-167': Light gray silty fine sand, mica and trace wood.
170-172': Dusky yellowish brown (10YR 2/2) clay with some very fine sand laminae, trace mica, with occasional thin siderite lenses.
175-177': Moderate brown weathered siderite stained clay-silt.
180-182': Dark to moderate yellowish brown (10YR 4/2 to 5/4) laminated clay/silt with very fine sand, 2-3% finely disseminated mica and carbonaceous material.
185-187': Light gray (N7) clayey silt, laminated (?), with finely disseminated mica and carbonaceous material.
195-197': Light gray silt, as above, less mica.
205-207': Light olive gray to olive gray (5Y 6/1-4/1) clay, some silt, trace mica; massive.
215-217': Medium dark gray (N4) carbonaceous clay, slightly micaceous.
220-222': Medium dark gray (N4) silty clay with some very fine to fine sand, 2% clear mica, 1% fine carbonaceous material.

Raritan Formation - Farrington Sand (minimum 13 feet thick)================

227-240': Light gray sand, medium to very coarse, tr. lignite.

0	25.6	Turn left onto Washington Road
0.1	25.7	Turn right onto Ernston Road
1.1	26.8	Continue on Ernston Road past Route 9
0.8	27.6	Turn right onto Nathan Boulevard into La Mer.

STOP 5: Gully by Cheesequake Creek and Garden State Parkway

Owner: Kaplan Companies

The gully contains a complicated arrangement of facies generalized by Olsson (1987) as:

0-29 feet of "...dark gray sands and carbonaceous-rich clays, uniformly cross-bedded sands, intermixed flaser bedding, and layers of rip-up clasts." Sands are very micaceous.

16 feet of "...dark gray laminated clay, dark gray alternating sands and clays, and carbonaceous-rich layers".

0	27.6	Turn left onto Ernston Road
2.1	29.7	Turn right onto Route 9S
1.4	31.1	Exit left onto Route 34S
2.8	33.9	Pull over on right by creek.

STOP 6 Route 34 - Northwest tributary to Lake Leffert

Owner: Russ Weber

When initially entering the creek, the Merchantville and Woodbury Formations are exposed. They are gradational units, with no clear contact between them. Exposed in the northern part of the creek is:

0-5 feet of surficial gravel.

5 feet of massive to laminated slightly glauconitic clay-silt (Woodbury Formation).

2-3 feet of massive, burrowed clayey glauconite sand (Merchantville Formation).

Further down the creek, the contact of the Merchantville and Cheesequake Formations are exposed. The contact is irregular and burrowed with a 3 to 4 foot reworked zone, and siderite concretions along contact. Along the contact is a burrowed brown clay with dark green medium-to-course glauconite sand of the Merchantville Formation in the burrows.

The Cheesequake Formation is exposed in the southern part of the creek (tributary to Lake Leffert). Its total thickness is ~30 - 35 feet; descriptions are developed from composite sections. We will see the upper beds of the Cheesequake at this locality.

4 feet of pale to moderate to dark brown fine sand (lighter colors reflects more weathered sands), laminated with yellowish brown clay-silt, finely burrowed, with much fine dispersed mica (mostly clear) and lignite.

6 feet of massive olive-gray clay-silt with very fine sand, very micaceous and lignitic.

The lower beds down the creek and in gullys just to the north off Morristown Road are more fine grained and glauconitic:

10 feet of massive, dark greenish-gray clay-silt with very fine to fine sand, very lignitic and micaceous (clear, white, green, and brown - very fine to very coarse plates), and glauconitic (4-5%, mostly coarse and immature). Some delicate sand filled burrows are present.

1 foot of olive gray clay-silt, glauconitic (20%, fine to medium, botryoidal and accordion forms), with some very fine sand, very micaceous (mostly clear), and slightly lignitic. Contains 0.25-1 foot in diameter pale to grayish brown siderite concretions. At the base of the unit are clay filled burrows (0.5" diameter), occasional molds of gastropods, and siderite concretions (at basal contact with the Cliffwood Beds).

0	33.9	Turn onto 34N
2.8	36.7	Bear right onto Route 9N and return to Staten Island.

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