Environmental Geology of Central New Jersey

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Twenty-Eighth Annual Meeting
October 14-15, 2011

Edited by
Emma C. Rainforth
(Ramapo College of New Jersey)
***and* Alan Uminski**

Middlesex County College, Edison NJ

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Front Cover: Photograph of a geologist logging a soil core using a Munsell color chart and a photo ionization detector to measure volatile organic compounds.   Photograph: John Jengo

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Schedule

Friday, October 14th – Student Center, Middlesex County College

11:00-4:00 Registration

11:30-12:30 Teachers Workshop – Challenging Common Misconceptions in Earth and Environmental Science. *Jane Alexander*

Technical Program

1:00-1:20 Welcoming Remarks/Conference Overview – *Alan H. Uminski, GANJ President*

1:20-1:40 How laterally extensive are major conductive fractures in the Passaic Formation? *Richard Britton & Andrew Michalski*

1:40-2:00 Hydraulic diffusivity-based methodologies for characterization of fractured rock hydrogeologic regimes: examples from the Passaic Formation, New Jersey. *Robert D. Mutch*

2:00-2:20 Characterization of a previously unmapped subsurface fault zone in central New Jersey. *Robert Bond*

2:20-2:40 Earthquake loss estimation for Middlesex and Monmouth counties, New Jersey. *Scott Stanford*

2:40-3:00 Break

3:00-3:20 Direct-sensing tools for the evaluation of overburden geology and formation hydraulic properties in unconsolidated sedimentary deposits of New Jersey. *Jason C. Ruf & Matthew Ruf*

3:20-3:40 Stratigraphy and hydrogeology of the Cretaceous-age Raritan and Magothy formations in the Sayreville-Parlin area, Middlesex County, New Jersey. *John W Jengo*

3:40-4:00 Groundwater/surface water interaction at an EPA Superfund site on the coastline of New Jersey. *John Dougherty*

4:00-4:20 Correlation of outcrop to subsurface Magothy Formation sequences and members. *Peter Sugarman*

4:30-5:30 Keynote Presentation – Critical Area I: A success story. *Jeffrey L. Hoffman*

6:00 Dinner and Business Meeting

Saturday, October 15th – Field Trip

8:00 am – 5:00 pm. Meet at Parking Lot 2, Middlesex County College

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How laterally extensive are major conductive fractures in the Passaic Formation?

Richard Britton[1] & Andrew Michalski, Ph.D.[2]
[1]The Whitman Companies; [2]Michalski and Associates

Highly conductive/transmissive (T>7,000 gpd/ft) bedding fractures have been identified in the Passaic Formation during remedial investigations conducted at two contaminated sites located approximately 2.5 miles apart along the Watchung Syncline in central New Jersey. These fractures were characterized through the testing conducted in temporary test holes, including borehole geophysics, salt tracing, packer tests and short- term pumping tests conducted upon conversion of the test holes to short-screen wells. The testing has shown that the highly conductive fractures extend for a distance of at least 1,500 feet along the strike of bedding at each of these two sites.

Based on the acoustic and gamma logs, these transmissive bedding fractures occur within thin-bedded (deeper lake) portions of Van Houten depositional cycles, and are associated with sharp transitions from silt-rich to clay-rich beds apparent on the gamma logs. There is evidence that one of these transmissive bedding fractures is continuous between the two sites. This laterally extensive bedding fracture also acts as a geochemical boundary that receives fresh groundwater from the shallow zone and sulfate-rich regional flow from below. We suggest that the highly transmissive bedding fractures in the Passaic Formation can be mapped as aquifer units.

Hydraulic diffusivity-based methodologies for characterization of fractured rock hydrogeologic regimes: examples from the Passaic Formation, New Jersey

Robert D. Mutch, Jr., P.Hg., P.E.
Mutch Associates LLC; Columbia University; Manhattan College

Considerable advances have been made over the couple of decades in methodologies to characterize the "architecture" of complex fractured rock hydrogeologic regimes. Many of these newer methods measure directional hydraulic diffusivities, which can then be converted to directional hydraulic conductivities. Hydraulic diffusivity governs the rate of propagation of a wave of drawdown or recovery through geologic media and is defined as the ratio of hydraulic conductivity and specific storage, K/S_S, (or transmissivity and storativity, T/S). Diffusivity-based methods include the Hsieh cross-hole technique, the earlier Neuman and Witherspoon ratio method, and the tidal method. These technologies, particularly the Hsieh cross-hole method, permit better and more rapid characterization of complex hydrogeologic systems, allow for optimized design of both in situ groundwater treatment systems (i.e. in situ chemical reduction, in situ chemical oxidation, and enhanced in situ biotreatment) and conventional "pump and treat" remedies, and often produce significant cost savings.

The Hsieh "cross-hole" methodology typically involves a sequence of short-term extraction or injection tests in multiple wells while simultaneously monitoring water level responses in an array of monitoring wells. Where a sufficient three-dimensional array of monitoring wells exists, these tests allow detailed mapping of the architecture and the three-dimensional distribution of hydraulic conductivity in fractured rock aquifer systems. In some hydrogeologic settings, cross-hole testing can also be applied to complex, porous media, hydrogeologic regimes. In cases where an existing groundwater extraction system is operating, these tests can be done very inexpensively by conduct of "well shutdown tests" where each extraction well is sequentially shut off for a few hours and then restarted, while the three-dimensional propagation of the wave of water level rebound from each shutdown is monitored in the surrounding monitoring well network. Several case studies will be presented of hydraulic diffusivity-based aquifer testing in the Passaic formation in northern New Jersey.

Characterization of a previously unmapped subsurface fault zone in central New Jersey

Robert Bond, P.G.
Langan Engineering and Environmental Services, PO Bo 1569, Doylestown, PA 18901

The bedrock in the study area is the Passaic Formation of the Newark Supergroup consisting of interbedded shales, siltstones, mudstones and sandstones. According to the New Jersey Geologic Survey's Preliminary Geologic Map of the Perth Amboy Quadrangle (R. Volkert and D. Monteverde, 1994), the Livingston Member of the Passaic Formation forms the bedrock immediately beneath the study area. This fractured bedrock aquifer provides groundwater resources to domestic, commercial and industrial users. With the exception of Kilmer Member and Member T-U outcrops along nearby Coppermine Brook, bedrock in the study area is covered by till, outwash deposits, and the terminal moraine of the Wisconsinan glaciation; there is no surface expression of faulting. Initial evidence of a fault zone came from environmental studies of volatile organic contaminant plumes at this site and included plume geometry, bedrock topography, rock core stratigraphy, down-hole geophysical data and hydrogeology. The fault zone acts as a preferential pathway for impacted groundwater and different segments provide a source of groundwater recharge to and a sink for discharge from the overlying buried valley aquifer units. A portion of the fault zone has an estimated lateral offset of approximately 800-feet and a vertical offset of about 60-feet based on marker beds in cores. Investigators unofficially named the buried structure the Farmhaven Brook Fault Zone and presented it at the 2006 GSA conference (Bond et. al. 2006 http://gsa.confex.com/gsa/2006AM/finalprogram/abstract_115143.htm). Preliminary estimates of orientation and bedding offsets suggests this structure, together with the nearby faults documented in the Menlo Copper Mine, may be in the same category as intrabasinal-mapped faults such as the New Brunswick Fault and Westons Mill Pond Fault Systems. New work presented at this meeting includes the results of a shallow seismic refraction study performed in the summer of 2011. Two 1,200-foot transects were taken across the fault zone using a slide hammer to generate seismic waves. The resulting wave velocities were measured using an aligned array of geophones, spaced at 20-foot intervals and connected to a seismograph, and subsequently modeled.

Earthquake loss estimation for Middlesex and Monmouth counties, New Jersey

Scott D. Stanford, Ronald S. Pristas, David W. Hall, & Jeffrey S. Waldner
New Jersey Geological Survey, Mail Code 29-01, PO Box 420, Trenton, NJ 08625; scott.stanford@dep.state.nj.us

Introduction

Damaging earthquakes in and near New Jersey are rare but have occurred and will occur again. Earthquakes with estimated magnitudes (M) between 5 and 5.5 occurred in northern New Jersey and the New York City area in 1737, 1783, and 1884, and 12 events of M3.5 to 5 have been recorded in this area since 1846 (Sykes and others, 2008). Although this level of seismicity is low to moderate from a national perspective, the density, value, and vulnerability of buildings and infrastructure in the New York-New Jersey region place New York fourth and New Jersey fourteenth among all states on a national ranking of annualized potential earthquake loss (FEMA, 2008).

The causes of this seismicity are uncertain. New Jersey is on a passive margin in an intraplate setting that lacks obvious sources of tectonic stress. The crust here is affected by the residual adjustment to glacial unloading since retreat of the late Wisconsinan Laurentide ice sheet between 25,000 and 10,000 years ago, the ongoing effects of sediment and water loading on the adjacent continental shelf, and the continuous westward motion of the North American plate. The distribution of epicenters show no obvious relation to known faults, although there is some clustering of smaller events (M<3) along and to the west of the Ramapo Fault zone (Sykes and others, 2008). There is no proven faulting in Cretaceous or younger sediments in the New Jersey-New York region. The lack of obvious active faults and the scattered distribution of epicenters indicate that crustal stress is broadly distributed in this area and that no particular zone can be specified as having a high or low risk for earthquakes.

The uncertainty in identifying the driving forces of earthquakes and in predicting their location and timing does not mean that society cannot make preparations for them. The damage done by earthquakes depends not only on their magnitude and location but also on engineering and geologic factors. With these factors as inputs, models can be used to estimate the spatial distribution and degree of building, infrastructure, and economic damage from simulated earthquakes or probabilistic earthquake motions. The model outputs can be used to guide mitigation efforts and disaster planning. The geologic factors, as considered in the Hazards U. S. (HAZUS) model used by the Federal Emergency Management Agency (www.fema.gov/plan/hazus), include: 1) the amplification of earthquake waves passing through bedrock and surficial deposits to generate ground motion, 2) the susceptibility of soil to lose strength, or liquefy, when shaken, and

3) the susceptibility of slopes to sliding or slumping when shaken. This paper will describe how these factors were defined and mapped, and applied to the HAZUS model, to generate earthquake-loss estimates for Middlesex and Monmouth counties.

Geologic Setting

Middlesex and Monmouth counties include a variety of bedrock and surficial deposits that present a wide range of seismic amplification, liquefaction, and landslide hazards. Jurassic diabase and

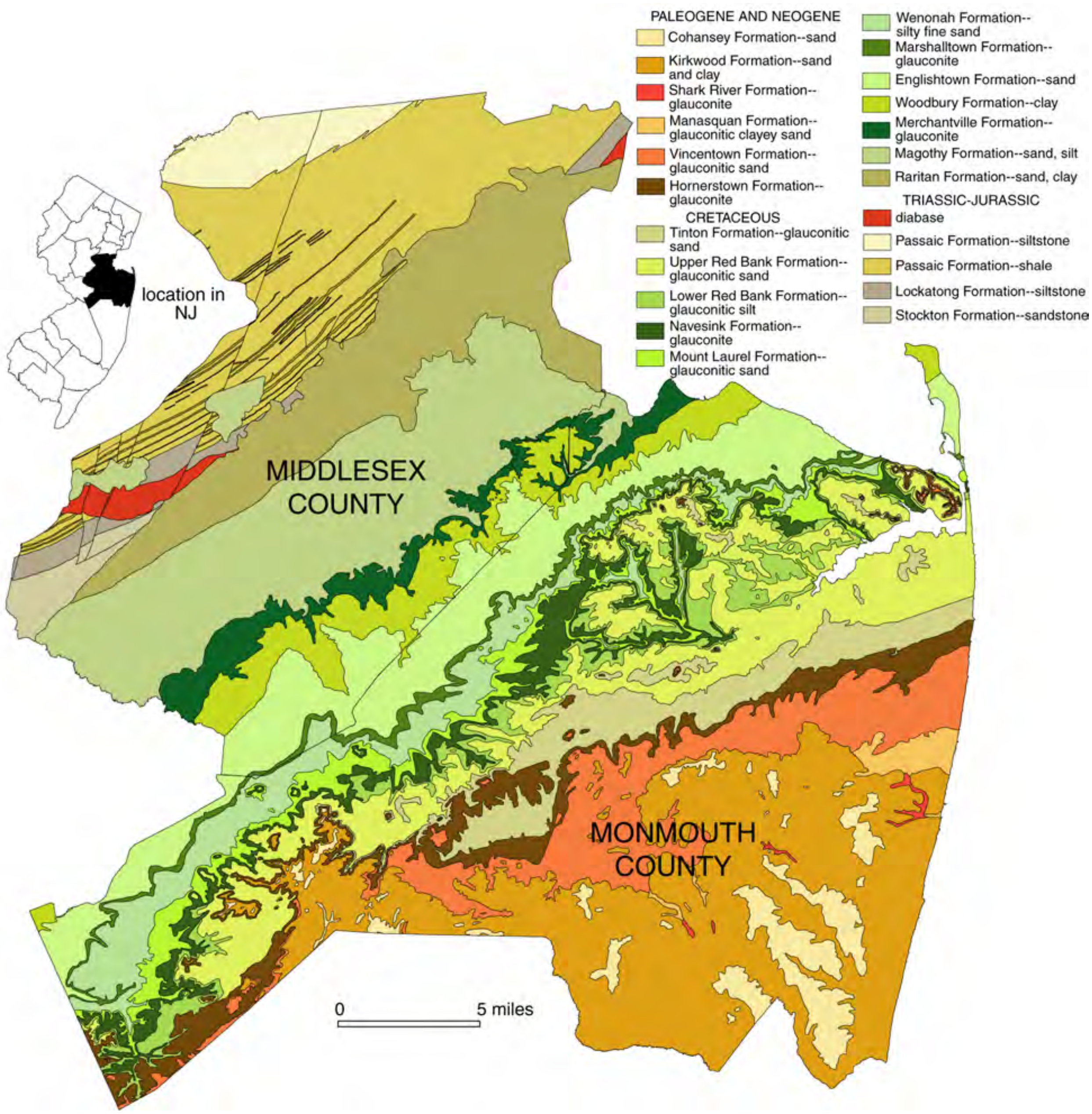


Figure 1. Bedrock geology of Middlesex and Monmouth counties. Geology from N. J. Geological Survey digital data (2004).

Triassic lacustrine and fluvial shale and siltstone of the Newark Basin crop out in northwestern Middlesex County and dip to the northwest at between 5 and 10 degrees. The rocks are onlapped to the southeast by unconsolidated Coastal Plain bedrock formations consisting of Cretaceous through Miocene sand, clay, and glauconite clay of marine and coastal origin (fig. 1). The Coastal Plain formations dip to the southeast at about 40 feet per mile and thicken to between 1500 and 2000 feet in southeastern Monmouth County.

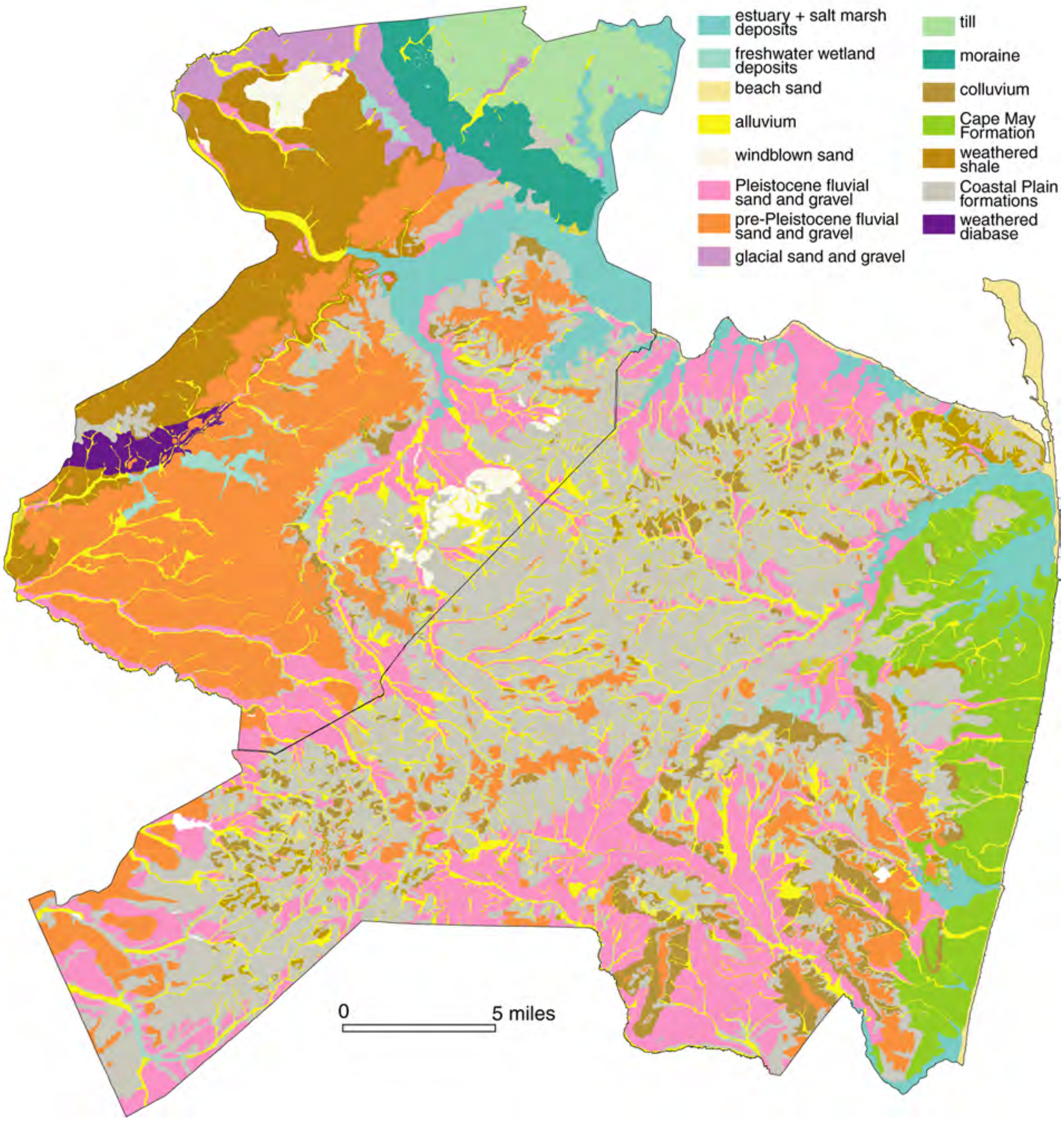


Figure 2. Surficial geology of Middlesex and Monmouth counties. Geology from N. J. Geological Survey digital data (2007).

Bedrock formations are overlain by surficial deposits that include glacial, fluvial, and marine deposits (fig. 2). The glacial deposits occur in northern Middlesex County and consist of till, glaciofluvial and glaciolacustrine sand and gravel, and glaciolacustrine silt and clay, of late Wisconsinan age. Fluvial sediments are chiefly sand, gravel, and silt. They occur throughout the two counties and range in age from late Miocene to Holocene. Beach sand, estuarine silt and clay, and salt-marsh peat of Holocene age occur at and below sea level in coastal areas and estuaries. Older beach deposits of Pleistocene age (the Cape May Formation) form coastal terraces up to 50 feet above sea level along the Atlantic shore in Monmouth County. Colluvium occurs in scattered locations at the foot of steep hillslopes, and windblown sand also occurs in scattered locations to the southeast of late Wisconsinan glaciofluvial and fluvial plains. Glacial, estuarine, and fluvial sediments are as much as 150 feet thick. The other surficial deposits are generally less than 30 feet thick.

Amplification Properties

Loose, soft geologic materials amplify seismic waves as they pass upward from hard, dense crustal rock at depth. The amplified waves will generate more ground motion at the land surface than waves traveling through hard rock, increasing building shaking and damage. Amplification increases as the shear-wave velocity of a formation or sediment decreases because as the seismic impulse slows more energy is dispersed into the host material. A procedure developed by the National Earthquake Hazards Reduction Program (NEHRP) classes the amplification properties of geologic materials based on their shear-wave velocity (FEMA, 1998). The NEHRP categories are known as *Site Classes*. From high to low shear-wave velocity, they are designated by the letters A, B, C, D, and E, and are defined by the following shear-wave velocity ranges (in feet/second, fps): A (hard rock, >5000 fps), B (rock, 2500 to 5000 fps), C (very dense soil and soft rock, 1200 to 2500 fps), D (stiff soil, 600-1200 fps), and E (soft soil, <600 fps). A sixth category (F) is for liquefiable or collapsible soils that require special evaluation.

Shear-wave velocities are often difficult to measure, particularly for deeply buried sediments. The NEHRP methodology includes an alternate means of classifying soils into classes C, D, and E using Standard Penetration Test (SPT) data. SPT values record the number of blows of a 140-pound hammer falling 30 inches that are required to advance a standard sampling tube (commonly known as a split-spoon) 1 foot into the test material. Blow counts are routinely measured in the course of drilling engineering test borings and, unlike shear-wave measurements, are widely available. The site classes correspond to the following depth-averaged mean SPT values (N): C (N>50), D (50>N>15), E (N<15).

To assign a site class, the shear-wave or SPT properties of the sediment and rock are summed to a depth of 100 feet, using a weighting formula to calculate a mean shear-wave velocity (v) or a mean SPT value (N) for the column of material. The formula divides the total thickness of the column (100 ft) by the sum of the thickness of the individual layers of soil or rock in the column (d_i) divided by the shear-wave velocity or SPT value of that layer (v_i or N_i): v or N = $100/\Sigma(d_i/ v_i$ or $N_i)$. Any column with more than 10 feet of soft clay is classed as E regardless of the mean shear-wave velocity. Also, the rock classes A and B are used only if unweathered rock is within 10 feet of the surface. Thus, mapping site class requires detailed knowledge of the thickness and stratigraphy of both surficial deposits and bedrock formations over the map area, and data on their shear-wave or SPT properties.

The N. J. Geological Survey uses shear-wave velocity measurements made on outcropping surficial deposits, and SPT data compiled from records of test borings, to establish mean velocities and SPT values for geologic materials on a county-by-county basis. Tables 1 through 4 show measured shear-wave velocities and compiled SPT data for geologic materials in Middlesex and Monmouth counties. These data were collected as part of geotechnical mapping and HAZUS simulations completed for Middlesex and Monmouth counties by the NJGS with funding from the NJ State Police Office of Emergency Management (Stanford and others, 2003, 2009). Shear-wave velocities for diabase (7000 fps) and shale (2300 fps) were assigned based on measurements on the same formations in Somerset County.

Table 1. Standard Penetration Test (SPT) data for surficial materials in Middlesex County.

Material	Number of Borings	Number of Tests	Range of SPT Values	Mean ± Standard Deviation	Percentage of Zero Values	Percentage of Refusals (SPT>200)
fill	92	245	2-200	18±24	0%	1%
salt-marsh deposits	173	656	0-33	3±5	48%	0%
alluvial silt, sand, and clay	20	53	0-69	13±14	24%	0%
nonglacial stream-terrace sand and gravel	125	471	2-200	32±29	0%	1%
glaciofluvial sand and gravel	41	170	2-200	20±17	0%	0.6%
till	75	342	2-200	41±41	0%	3%
glaciolacustrine silt and clay	4	14	5-26	16±5	0%	0%
weathered shale	100	179	2-200	70±51	0%	3%
weathered diabase	57	119	16-200	75±45	0%	2%
Cretaceous clay	90	608	4-240	51±45	0%	3%
Cretaceous sand	95	465	4-316	57±51	0%	4%
Pensauken Formation sand and gravel	49	206	4-51	20±9	0%	0%

Table 2. Shear-wave velocity measurements for Middlesex County.

Site	Location (latitude; longitude)	Material	Measured shear-wave velocity (feet/second)	Shear-wave velocity range predicted from SPT data (feet/second)	Comments
New Road	40°21'46"; 74°33'02"	Pensauken Formation	1507	600-1200	faster than predicted due to clay hardening
Thompson Park	40°19'49"; 74°25'54"	Pensauken Formation	1998	600-1200	faster than predicted due to clay hardening
Pigeon Swamp	40°23'14"; 74°28'20"	Pensauken Formation	974	600-1200	agrees
Helmetta Boulevard	40°23'05"; 74°25'42"	Cretaceous sand	723 (layer 1) 2087 (layer 2)	1200-2500	agrees (layer 2)
Crescent Ave.	40°23'47"; 74°24'20"	Cretaceous sand	674 (layer 1) 1172 (layer 2)	1200-2500	slightly lower than predicted (layer 2)
Marlboro Road	40°21'51"; 74°19'19"	Cretaceous sand	638 (layer 1) 1799 (layer 2)	1200-2500	agrees (layer 2)
Texas Road	40°21'22"; 74°21'04"	Cretaceous clay	1252	1200-2500	agrees
Pension Road	40°20'10"; 74°21'22"	Cretaceous clay	768 (layer 1) 2122 (layer 2)	1200-2500	agrees (layer 2)
Old Bridge Golf Course	40°25'06"; 74°16'06"	Cretaceous clay	838 (layer 1) 1315 (layer 2)	1200-2500	agrees (layer 2)
Phillips Park	40°23'10"; 74°21'15"	stream-terrace sand	778 (layer 1) 1179 (layer 2)	600-1200	agrees
Jernee Mill Road	40°26'07"; 74°21'01"	stream-terrace sand	448 (layer 1) 632 (layer 2)	600-1200	agrees (layer 2)
River Road	40°32'12"; 74°29'59"	stream-terrace sand	771 (layer 1) 2857 (layer 2)	600-1200	agrees (layer 1; layer 2 is shale bedrock)

Table 3. Standard Penetration Test (SPT) data for Monmouth County.

Material	Number of Tests	Number of Borings	Mean±Standard Deviation	Range	Percent Refused (SPT>100)[1]	Percent of Zero Values[2]
fill	114	37	28±21	2-85	0%	0%
Cape May Formation	287	71	31±30	1-198	3%	0%

estuary and salt-marsh deposits	89	20	8±6	0-22	0%	8%
stream-terrace deposits	181	57	18±15	0-88	0%	1%
Woodbury Formation	138	21	40±24	9-122	4%	0%
Cohansey Formation	132	21	44±33	2-166	10%	0%
Kirkwood Formation	534	98	31±31	2-212	0.6%	0%
glauconitic sand bedrock[3]	590	104	44±37	2-295	11%	0%
Vincentown Formation	347	62	21±16	2-115	1%	0%
glauconite clay bedrock[4]	63	11	28±18	1-86	0%	0%

[1]For these tests, the sampling tube failed to advance 6 inches after 100 blows of the hammer. In some tests, hammering continued past 100 blows until the tube was advanced 6 inches. In these cases, the full blow count was included in the data set even if it exceeded 100 blows per 6 inches.

[2]For these tests, the sampling tube was advanced 12 inches by the weight of the hammer or the weight of the drill rods alone, with no blows on the hammer.

[3]Includes Wenonah, Mount Laurel, Navesink, Red Bank, and Tinton formations.

[4]Includes Manasquan and Shark River formations.

Table 4. Shear-wave velocity measurements for Monmouth County.

Site	Location (latitude; longitude)	Material	Measured shear-wave velocity (feet/second)	Shear-wave velocity range predicted from SPT data (feet/second)	Comments
Monmouth Park	40º18’06”; 74º01’31”	Cape May Formation	636	600-1200	agrees
Palaia Park	40º15’41”; 74º01’55”	Cape May Formation	1141 (layer 1) 3158 (layer 2)	600-1200	agrees (layer 1), layer 2 is iron-cemented Vincentown or Manasquan Formation
Wreck Pond	40º08’23”; 74º02’35”	Cape May Formation	729	600-1200	agrees
Allaire	40º08’04”; 74º08’50”	Cohansey Formation	1364 (layer 1) 1818 (layer 2)	600-1200	faster than predicted, possible iron cementation at contact with Kirkwood Formation

Francis Mill	40º10'58"; 74º23'09"	Cohansey Formation	752	600-1200	agrees
Manasquan	40º07'55"; 74º07'03"	Cohansey Formation	1282	600-1200	slightly faster than predicted
Nomoco	40º10'44"; 74º18'58"	Kirkwood Formation	1094 (layer 1) 2927 (layer 2)	600-1200	agrees (layer 1), layer 2 is iron cementation at contact with Vincentown Formation
Peskin	40º11'09"; 74º13'19"	Kirkwood Formation	759 (layer 1) 2123 (layer 2)	600-1200	agrees (layer 1), layer 2 is iron cementation?
Route 537	40º10'39"; 74º13'19"	Kirkwood Formation	624	600-1200	agrees
Iron Ore	40º16'55"; 74º13'27"	sand bedrock (Englishtown Formation)	690 (layer 1) 1227 (layer 2) 3125 (layer 3)	600-1200	agrees (layer 1), layer 2 is slightly faster than predicted, layer 3 is iron cementation?
Rising Sun	40º12'20"; 74º27'32"	sand bedrock (upper Red Bank Formation)	928	600-1200	agrees
Witches Hollow	40º13'14"; 74º27'32"	sand bedrock (upper Red Bank Formation)	1279	600-1200	slightly faster than predicted
Boundary	40º19'27"; 74º13'27"	clay bedrock (lower Red Bank Formation)	641 (layer 1) 1120 (layer 2)	600-1200	agrees
Burke	40º13'03"; 74º19'44"	clay bedrock (Hornerstown Formation)	916 (layer 1) 2295 (layer 2)	600-1200	agrees (layer 1), layer 2 is iron cementation
Elton	40º13'08"; 74º18'32"	clay bedrock (Hornerstown Formation)	1463 (layer 1) 2979 (layer 2)	600-1200	faster than predicted due to iron cementation

The softest, slowest soils are estuarine and salt-marsh deposits, which yield a mean SPT of 3±5 in Middlesex County and 8±6 in Monmouth County. These deposits are organic silts and clays, and peats, laid down during Holocene sea-level rise. They have never been exposed to desiccation or weathering, and have never experienced sediment or water loads greater than at present, and so have never been consolidated. Modern floodplain alluvium is soft for similar reasons (mean SPT of 13±14 in Middlesex County, not sampled in Monmouth County), although it is generally sandier, contains less organic matter, and has experienced more drying and soil development than estuarine sediments and so is a bit

Older fluvial and beach deposits, including glaciofluvial sand and gravel, nonglacial stream-terrace sediments, the Pensauken Formation (a fluvial sand of Pliocene age), and the Cape May Formation, have been exposed and weathered for periods of thousands to hundreds of thousands of years, and are more sandy and gravelly than modern floodplain and estuarine sediments. For these reasons, they yield higher mean SPT values (in the 15 to 35 range) than the younger, finer, wetter sediments. Till, weathered shale and diabase, and Coastal Plain bedrock formations in Middlesex County

("Cretaceous clay" and "Cretaceous sand" in table 1) all have mean SPT values of >40 because they have been consolidated by the weight of glacial ice (in the case of till) or of recently eroded Coastal Plain sediment (in the case of Cretaceous formations, which were buried under a minimum of several hundred feet of younger formations until they were eroded in the late Miocene and early Pliocene), or include embedded fragments of unweathered or partly weathered rock (weathered shale and diabase). Younger Coastal Plain formations in Monmouth (the Woodbury, Cohansey, Kirkwood, and Vincentown formations, and "glauconite sand' and "glauconite clay" in table 3) are higher in the section and so experienced less sediment loading than the older Cretaceous formations in Middlesex County. Thus, they have slightly lower mean SPT values (20-40) than the older formations.

The wide range and standard deviations of SPT data for fluvial sand and gravel and till in Middlesex County reflect the presence of gravel and scattered boulders, which result in some blow counts being much higher than in the sand and silty sand that comprise the bulk of these sediments. Shear-wave measurements (table 2) in the stream-terrace deposits confirm that the mean SPT value is representative of the deposit as a whole. Two of the three shear-wave velocities measured for the Pensauken Formation in Middlesex County were faster than the range predicted by the SPT data (table 2). The Pensauken has undergone a long period of weathering and soil development. These processes have created a compact clayey matrix in the upper 5 to 10 feet of the formation that yields high shear-wave velocities, especially under dry conditions. This "clay hardening" does not affect the formation below the surface horizon, so the SPT data more accurately represent the bulk of the Pensauken.

Wide ranges and standard deviations are also evident in the SPT data for Coastal Plain bedrock formations in both counties (tables 1 and 3). Wide ranges are also observed in shear-wave velocity at different depths in these formations (tables 2 and 4). These variations are likely due to iron cementation within the formations, and at contacts between formations. Deposition of iron oxides and iron hydroxides along clay-sand boundaries, or within permeable sands, is common in Coastal Plain formations. The iron compounds cement or harden the sediment into rock-like masses which increase shear-wave velocity and resist penetration tests. These masses are patchy and, in outcrop, rarely exceed more than 10 to 15 feet in horizontal dimension and 1 to 2 feet in vertical dimension, so they do not impart any overall strengthening to the formations. For this reason, the uncemented velocities are used to establish site class.

The site-class maps (fig. 3) show soft E-class soils in estuaries, salt marshes, and a couple of freshwater wetlands that accumulated peat and organic mud. Some of these areas have been filled over and built on, particularly along the Arthur Kill and Raritan River in Middlesex County, and parts of the Raritan Bay shore and its tributary tidal creeks, and the Shrewsbury River estuary in Monmouth County. In these filled areas, marsh sediments remain beneath the fill in most places and still classify as E even though they may be more compact than in unfilled areas. The fill itself is quite variable, ranging from soft, loose, uncompacted trash to compact engineered fills. Sandy Hook is also E-class because the beach sand there overlies thick Holocene estuarine sediment. In Middlesex County, class D soils are mapped where till is more than 80 feet thick over shale, where fluvial sediment is more than 40 feet thick over shale, and where fluvial sediment is more than 10 feet thick over Coastal Plain formations. These cutoff thicknesses were determined with the NEHRP weighting formula described above, using mean SPT and shear-wave values for the sediment and rock types. The remainder of the county, where Coastal Plain formations and shale are at shallow depth, is class C. The belt of outcropping diabase in the county is covered by sandy-clayey weathered material, which classes as C because it is generally more than 10 feet thick, even though the unweathered diabase beneath is hard rock of class A. All of Monmouth County, except for the estuaries and marshes, and the northwest edge of the county, where the older, more deeply buried Coastal Plain formations of class C crop out, falls into class D.

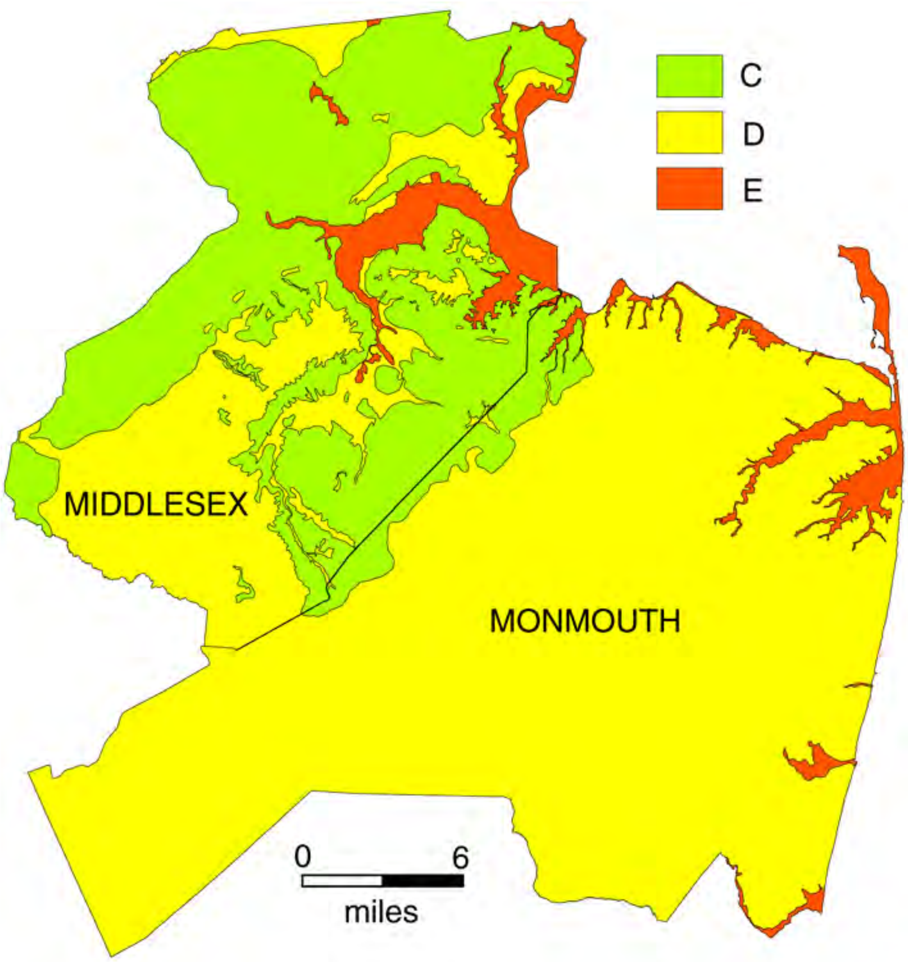


Figure 3. Site classes for Middlesex and Monmouth counties.

Liquefaction Susceptibility

Loose, saturated fine sand and silt will lose strength and flow as liquids at earthquake magnitudes as low as 5 to 5.5, which is within the range of the largest known earthquakes in the New York City area. Thus, liquefaction is a potential hazard in New Jersey, although it is not as important a cause of damage as site class in most places. Empirical methods using SPT data, grain size, density, pore pressure, and depth below land surface to predict liquefaction for given seismic accelerations have been proposed (for example, Seed and others, 1983) but require specialized data and are difficult to apply over large areas. The HAZUS model uses a simpler scheme based on geologic factors, including the distribution of cohesionless sediments in a deposit, age of the deposit, and depth to water table, to classify liquefaction hazard into six categories. They are: very high susceptibility (25% of map unit susceptible to liquefaction), high (20%), moderate (10%), low (5%), very low (2%), and none (0%). The categories of deposits and ages used in the HAZUS model are based on classifications developed in the Los Angeles area (Youd and Perkins, 1978). Some of these classifications are not applicable to New Jersey, but the scheme is easily adapted. In Middlesex and Monmouth counties, alluvial, estuarine, and beach deposits of Holocene age are assigned a high susceptibility because they contain a high proportion of loose, saturated sand and silt (fig. 4). Low-lying stream-terrace deposits (with surfaces 5 to 10 feet above modern floodplains) are assigned a moderate susceptibility because the water table is generally at shallow depth in these deposits. Higher, older fluvial, glaciofluvial, and marine terrace deposits are assigned a low susceptibility because the water table is at greater depth and the sediments are somewhat more compact. Coastal Plain formations, weathered rock material, till, colluvium, and pre-middle Pleistocene fluvial deposits are assigned a very low susceptibility because they are compact.

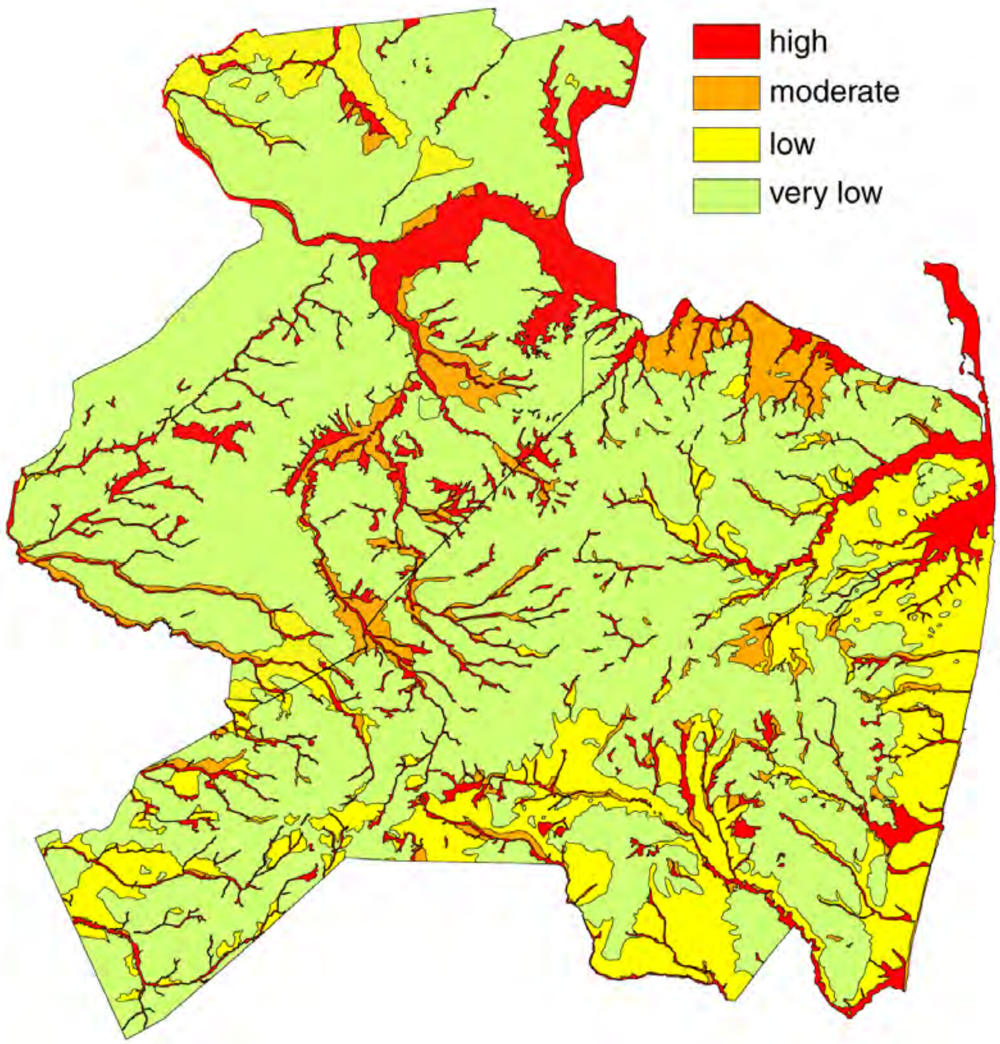


Figure 4. Liquefaction susceptibility of Middlesex and Monmouth counties.

Landslide Susceptibility

Seismically induced ground motion can trigger landslides. The susceptibility of a slope to failure depends on its steepness, geologic material, and depth to groundwater. Wet clays will fail at much gentler slope angles than dry hard rock. The HAZUS model uses a ten-class scheme to capture these variables. The scheme uses three geologic classes: strongly cemented rocks, weakly cemented rocks and sandy soils, and shales and clayey soils; six slope classes (1-10°, 10-15°, 15-20°, 20-30°, 30-40°, and >40°); and two groundwater classes (groundwater below depth of sliding, groundwater at and above depth of sliding).

Only small areas in Middlesex and Monmouth counties have slopes steep enough to be susceptible to landslides (fig. 5). Most are streambanks, coastal bluffs, and a few deep roadcuts and former sandpit and claypit walls, in clay and sand Coastal Plain formations. Bluffs in shale along the Raritan

River and Lawrence Brook near New Brunswick, and a few hillslopes in Coastal Plain formations in upland areas of the Coastal Plain, are also steep enough to classify.

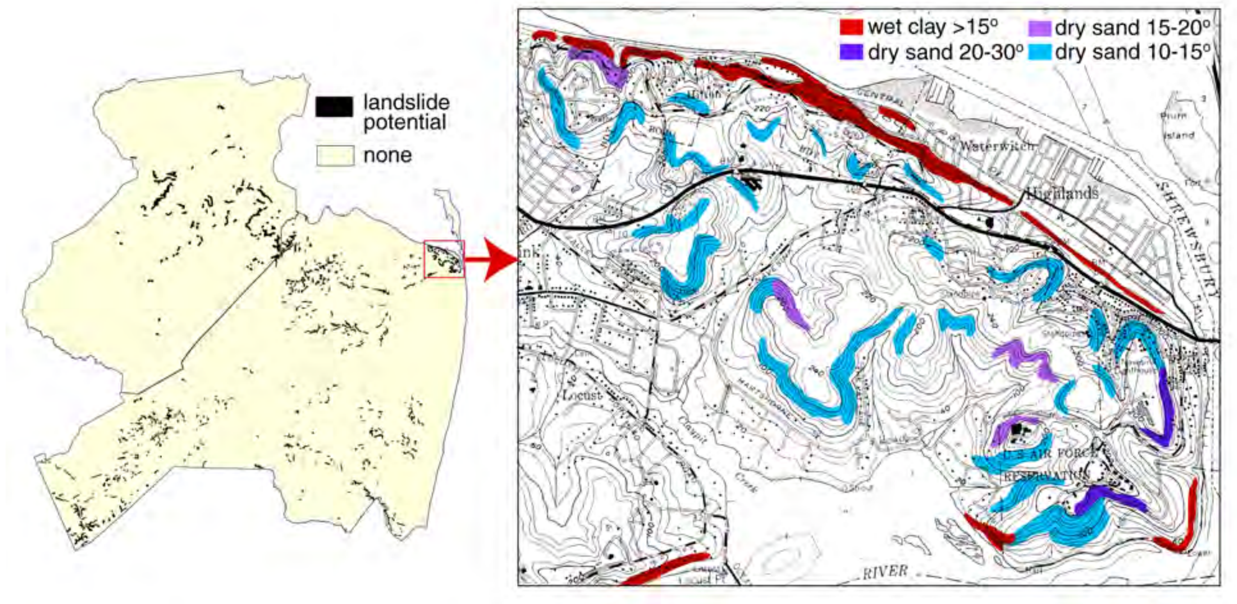


Figure 5. Areas of landslide potential in Middlesex and Monmouth counties (left) and enlargement of Atlantic Highlands area (right).

Of these areas, the most prone to landslides are the coastal bluffs along Sandy Hook Bay in the boroughs of Atlantic Highlands and Highlands in Monmouth County (fig. 5, right panel). Here, very steep and tall slopes (30-35°, rising to 150-200 feet) are developed on a fine-sandy silt formation (lower Red Bank Formation) overlain about halfway up the bluff by a sand (upper Red Bank Formation). Groundwater pools at the contact and discharges onto the lower half of the bluff. This saturated state places these bluffs in the highest susceptibility category (red on fig. 5), requiring a seismic acceleration of only 0.05 g (5% of gravity) to initiate slides. This acceleration is close to the peak ground acceleration with a 10% chance of being exceeded in a 50-year period mapped by the USGS for this area from analysis of historic seismicity and crustal properties (Peterson and others, 2008). There is a long historical record of landslides and slumps here, usually triggered by heavy rains. Slump blocks at the base of the tallest bluff record pre-historic instability (Minard, 1974). Despite this history, residential development over the years has spread on and at the top and the foot of the bluff. The added danger of earthquakes should be considered when assessing the safety of continued development.

Damage Estimates

The HAZUS model uses demographic, economic, infrastructure, and building data, from governmental and commercial sources, aggregated by census tract, in combination with the geotechnical data described above, to calculate damage and economic loss from earthquakes. The earthquake can either be deterministic, that is, a specific event with magnitude, depth, and location selected by the user, or probabilistic, that is, the seismic ground motions expected for the modeled area within a selected return period, based on the historic earthquake catalog for the region.

For Middlesex and Monmouth counties, and for the seven other counties in northeastern New Jersey for which the NJGS has completed geotechnical mapping and HAZUS simulations (complete studies for each county are available at www.njgeology.org/enviroed/hazus.htm), census tract maps were overlaid on the site class, liquefaction susceptibility, and landslide susceptibility maps. Site class and liquefaction and landslide susceptibility classes were assigned to each census tract by determining the dominant class for the built portion of the tract. In rural and suburban areas, census tracts are large; some include entire municipalities. Discretizing the geotechnical classes for such tracts is thus imprecise. In the case of landslide susceptibility, only small areas of steep slopes within a tract are hazardous. The HAZUS model assigns a percentage of total area susceptible to landslides for each tract, based on the geotechnical class (1% for lowest susceptibilities, 30% for highest susceptibilities) to address this issue. A similar approach is used for liquefaction susceptibility, since only specific sites within a susceptible deposit will liquefy during an earthquake.

Figures 6 and 7 show the percentage of buildings with moderate or greater damage by census tract for M5.5 earthquakes placed at the county centroid for Middlesex and Monmouth counties. Buildings with moderate damage must be evacuated and inspected before reoccupancy, and so the moderate damage level is a good index to social disruption. Both simulations show that damage decreases in a rough bulls-eye pattern away from the epicenter, but with variations related to geotechnical class or, in some cases, to differences in building age and stock between tracts (not studied by NJGS). In Middlesex County, the change of site class from C to D or D to E increases building damage by 10 to 20%. An increase in liquefaction hazard also increases damage by as much as 10% in susceptible tracts. In Monmouth County the variation between tracts is due largely to landslide susceptibility, and to a lesser extent, liquefaction class, since site class is D for almost all of the tracts. The extraordinary predicted damage in Highlands and Atlantic Highlands (90-100% of buildings with moderate or greater damage) is the result of the extremely high landslide susceptibility (HAZUS class 10, the most hazardous) resulting from the steep bluffs in saturated,

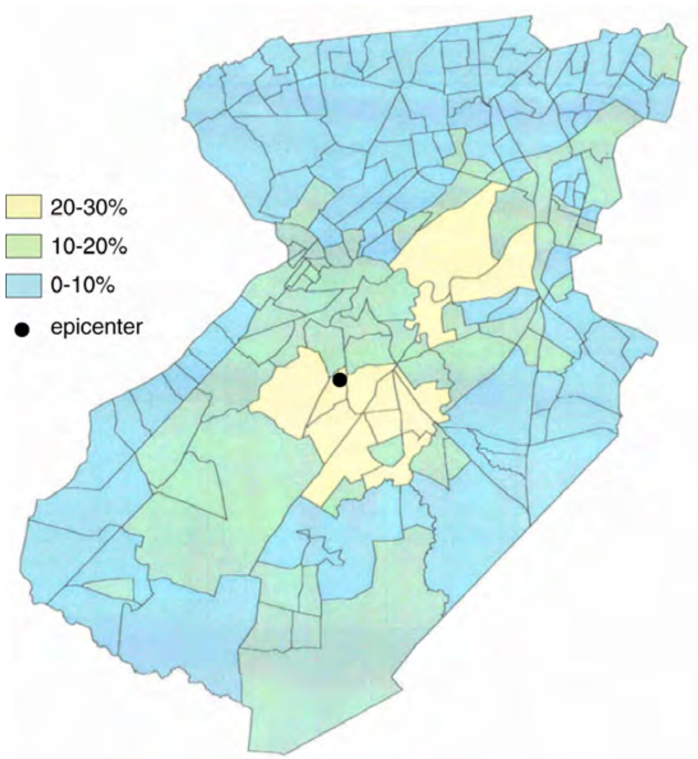
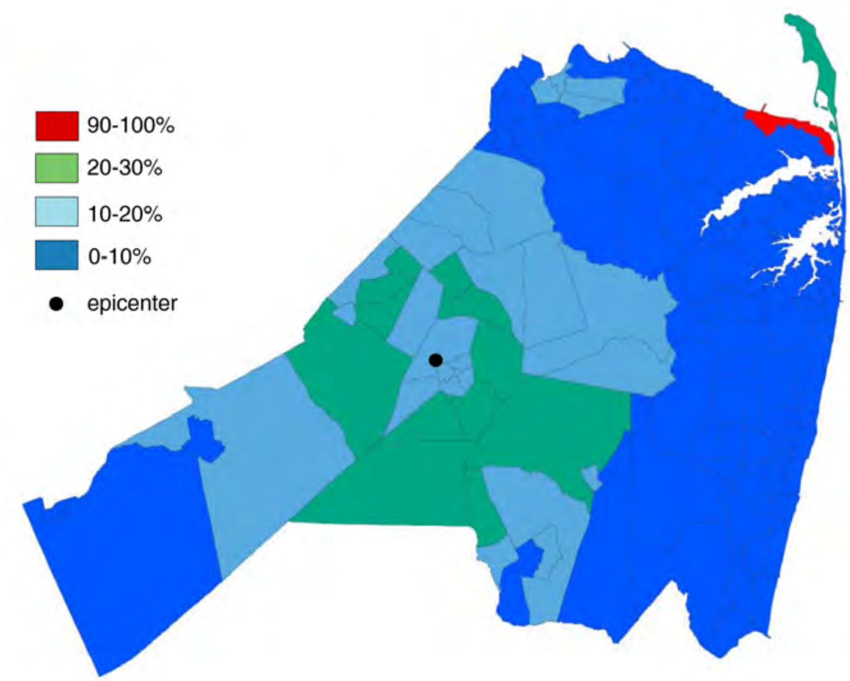


Figure 6. Percentage of buildings damaged to a moderate or greater degree for an M5.5 earthquake at the centroid of Middlesex County.

Figure 7. Percentage of buildings damaged to a moderate or greater degree for an M5.5 earthquake at the centroid of Monmouth County.



clayey material. For this class, the HAZUS model considers 30% of the tract susceptible to slides. This proportion is excessive in this case, because the vulnerable bluffs occupy perhaps 10% of the tracts in question, so the damage is likely overestimated.

Economic loss, building damage, and displaced households, calculated by the HAZUS model for various deterministic and probabilistic earthquakes, are provided in table 5. Deterministic simulations were run for each county separately, with epicenters at the county centroid, and damage values are for the county only. Probabilistic simulations were run for Monmouth County only. The magnitudes listed for the probabilistic runs are driving magnitudes needed to simulate liquefaction, they do not represent a scenario earthquake. The simulations indicate that an M5 to M5.5 earthquake, in the range of known events in the area, would cause several billion dollars of

Table 5. Total economic loss (TEL, in billions of dollars), major building damage (MBD, in thousands of buildings), and displaced households (DH, actual number of households requiring shelter) for the HAZUS runs for Middlesex and Monmouth counties (D=deterministic run, number is earthquake magnitude; P=probabilistic run, number is return period in years, M=driving magnitude for liquefaction). Total economic loss includes building damage plus loss of building contents plus loss due to business interruption. Major building damage includes buildings of any type damaged to the “extensive” and “complete” state.

Magnitude	Middlesex County			Monmouth County		
	TEL	MBD	DH	TEL	MBD	DH
D 5.0	0.5-1.9	<1	140-500	0.6-2.3	0-2	400-1800
D 5.5	1.3-5.2	1-6	1200-5000	1.9-7.5	3-14	2000-9000
D 6.0	2.9-11.5	5-20	5000-19,000	4.7-18.9	10-40	7000-27,000
D 6.5	5.1-20.3	11-50	10,000-40,000	8.8-35.2	19-80	13,000-52,000
D 7.0	7.7-30.6	20-80	17,000-68,000	13.4-53.4	30-120	20,000-81,000
P500 M5.5	-	-	-	0.1-0.4	<1	60-300
P500 M6	-	-	-	0.1-0.6	0-1	170-700
P500 M6.5	-	-	-	0.2-0.6	0-1	200-900
P1000 M5.5	-	-	-	0.6-2.3	1-5	800-3000
P1000 M6	-	-	-	0.6-2.5	1-6	1100-4000
P1000 M6.5	-	-	-	0.7-2.7	1-6	1200-5000
P2500 M5.5	-	-	-	2-8.1	4-17	3000-12,000
P2500 M6	-	-	-	2.1-8.4	4-17	3000-14,000
P2500 M6.5	-	-	-	2.2-8.8	4-18	4000-15,000

economic loss, would significantly damage several hundred to several thousand buildings, and would displace several hundred to several thousand households. In Monmouth County, the damage from the M5.5 deterministic earthquake is similar to the damage from the 2500-year probabilistic ground motion, indicating that an M5.5 event within the county has a return period of about 2500 years, or a 2% chance in 50 years.

It is difficult to judge the accuracy of these simulations. The HAZUS model has not been tested predictively or retrodictively for eastern US earthquakes, which differ in their attenuation and propagation behavior from those in the western US. While these differences are incorporated in the model, it is not known if they have been accurately captured. The wide ranges of the loss estimates probably encompass the potential actual damage for the events, and the spatial distribution of damage reflects actual geologic vulnerabilities from amplification, liquefaction, and landsliding, even if the predicted amount and degree of damage is unproven at present.

Acknowledgements

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Direct-sensing tools for the evaluation of overburden geology and formation hydraulic properties in unconsolidated sedimentary deposits of New Jersey

Jason C. Ruf & Matthew Ruf
S_2C_2, Inc., 5 Johnson Drive, Suite 12, Raritan, NJ 08869; jruf@s2c2inc.com

In New Jersey, most overburden consists of post-Cretaceous clastic wedge deposits, glacial deposits (i.e., till, glacial lake bottom deposits, terrace deposits, deltaic deposits, etc.), and post-glacial deposits (marsh deposits, alluvial deposits, fill, coastal plain deposits, etc.). Evaluating these deposits is typically limited to sub-surface investigations historically completed by advancing soil borings and logging soil cores. With the advancement of direct-push technologies combined with direct-sensing tools, more specifically electrical conductivity (EC), hydraulic profiling tool (HPT) as well as cone penetrometers (CPT), a more detailed data set for evaluating both geologic depositional environments as well as for evaluation of hydrogeologic properties is possible. These data can be compared to published surficial geologic maps that can provide better conceptual models for subsurface conditions and aid in environmental, geotechnical and engineering design.

Stratigraphy and hydrogeology of the Cretaceous-age Raritan and Magothy formations in the Sayreville-Parlin area, Middlesex County, New Jersey

John W. Jengo, P.G.
MWH Americas, Inc., 200 Lindenwood Drive, Suite 100, Malvern, PA 19355;
John.Jengo@mwhglobal.com

Purpose of Study

A detailed stratigraphic study utilizing borehole geophysics, in conjunction with palynological analyses and outcrop observations, was conducted over a 350-acre (1.42 sq. Km) industrial site in the Sayreville-Parlin area, Middlesex County, New Jersey (Figure 1). The study was performed to develop a site-specific stratigraphic framework more precise than that which could be extrapolated from regional stratigraphic frameworks developed by previous workers (Owens and Sohl, 1969; Owens et al., 1977; Olsson, 1975, 1978, 1980, 1988, 1991; Owens and Gohn, 1985; Zapecza, 1984, 1989; Gronberg et al., 1989, 1991), particularly because the work preceded the proficient New Jersey Geological Survey (NJGS) mapping of the South Amboy quadrangle (Sugarman et al., 2005).

Geologic and Stratigraphic Overview

The study area, located within the Atlantic Coastal Plain Physiographic Province, is characterized by a wedge of unconsolidated sediment, striking approximately northeast-southwest and dipping southeast from 10 to 60 ft/mile (1.9 to 11.4 m/Km) (Zapecza, 1984). The unconsolidated Coastal Plain strata range in age from Cretaceous to Quaternary and unconformably overlie Precambrian and lower Paleozoic crystalline bedrock or Triassic age siliciclastic rocks (Owens and Sohl, 1969).

The study area is directly underlain by the Cretaceous age Raritan and Magothy formations which consist of interbedded gravels, sands, and silt/clays that reach a thickness of approximately 300 to 400 ft (91 to 122 m) in this area (Zapecza, 1984). In ascending order, these unconsolidated deposits include the informal members Farrington Sand and Woodbridge Clay of the Raritan Formation, and the informal members Sayreville Sand, South Amboy Fire Clay (which were formerly included in the Raritan Formation), and the Old Bridge Sand of the Magothy Formation (Owens and Sohl, 1969; Owens et al. 1977; Zapecza, 1984).

The description in Reis et al. (1904) of the complexity of these deposits scarcely needs refinement more than a century later: the units were “characterized by the rapid alternation of strata, the

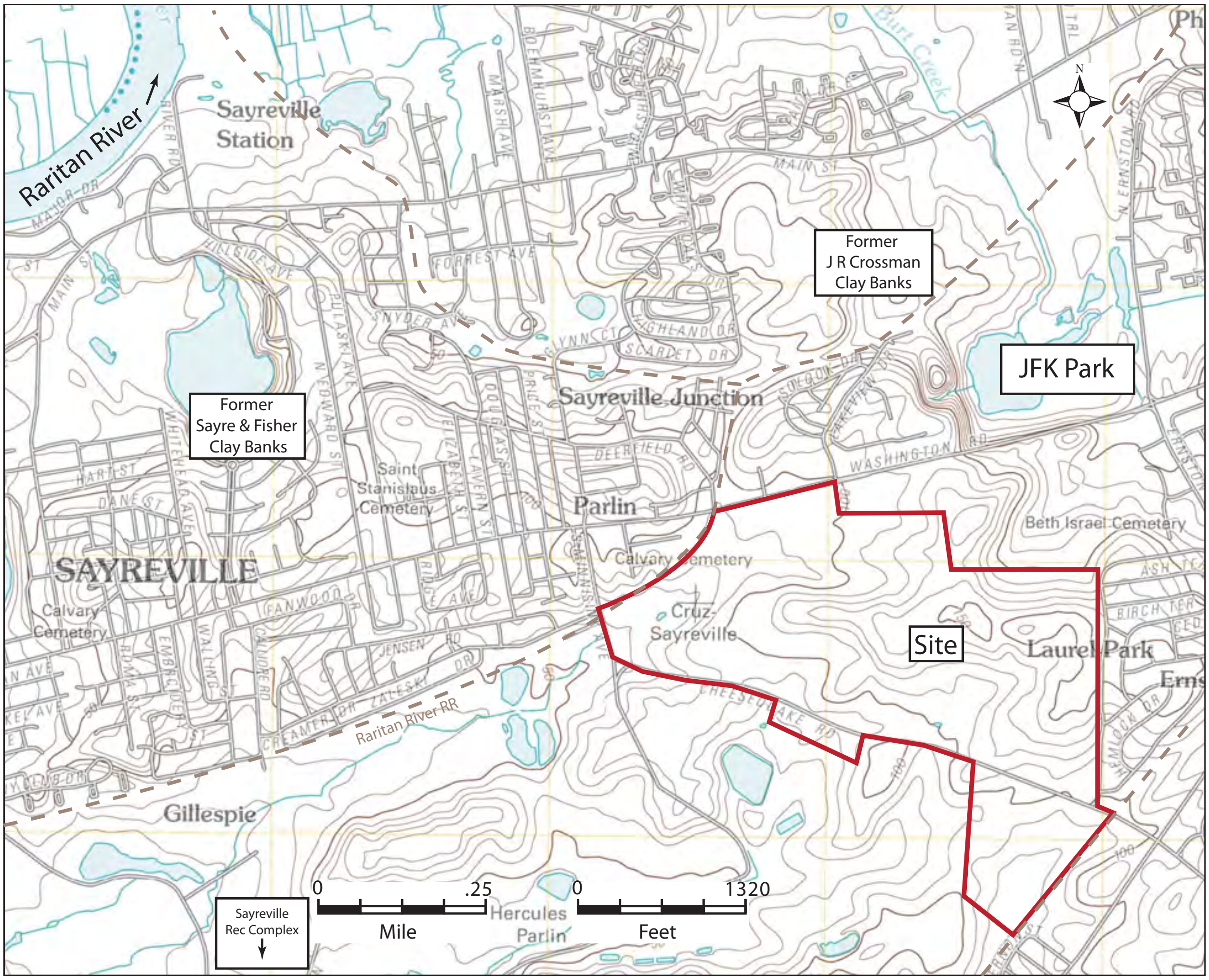

Figure 1: Location map of study area, including the site of the former Sayre & Fisher Company clay banks and the former J.R. Crossman clay banks.

absence of any definite and orderly arrangement over extended areas. Individual beds of clay thin out rapidly or grade bodily into beds of sand within short distances. In not a few instances data have been observed, which indicate that beds after deposition were partially swept away by shifting currents, before the overlying layers were formed. Within comparatively short distances, also, sand and clay were being deposited simultaneously, so that rapid changes in the character of the deposits have resulted."

Introduction

Interesting papers could be written on the various aspects of the 19th and early 20th century economic development of clay deposits in Middlesex County. Reflecting their importance, names for individual clays were established by 1878, and two full NJGS reports were written within the span of 26 years (Cook and Smock, 1878; Ries et al., 1904) that were entirely dedicated to the composition, extent, and economics of this resource and its wide-ranging uses (pottery, common brick, fire brick, tiles, piping, ceramics, paint fillers, among many other applications). The growing importance of the sand units as industrial and public water supply aquifers during and after World War I, as described concisely by Barksdale (1937), prompted the initiation of aquifer studies in 1923, which lead to detailed hydrologic evaluations and the naming the sand unit members two decades later (Barksdale, et al., 1943). It was these informal member names that were brought to the fore in influential United States Geological Survey (USGS) publications (Zapecza, 1984, 1989) that formed the basis of the stratigraphic and hydrogeologic framework of this area when the author assumed responsibility for characterizing the geology of the subject site in 1990. As such, much of the author's work focused on trying to identify the presence (or absence) of these Magothy and Raritan Formation informal members, prior to characterizing the overall hydrogeologic and groundwater flow regime. The presence of former clay banks (i.e., quarries) so near the subject site allowed these same informal member units to be examined in outcrops, as they rarely can be when working in the New Jersey Coastal Plain, in the hopes that the facies relationships observed there could facilitate the understanding of the stratigraphic units underlying the site.[1]

Investigative Methodology

Development of a site-specific stratigraphic framework of deltaic, fluvial or non-marine deposits of the Potomac-Raritan-Magothy (PRM)[2] section utilizing commonly used methods, such as continuous split-spoon or Geoprobe® Macrocore sampling, can be successful when data acquisition can be closely-spaced to account for the inherent lithologic variability and small-scale facies changes of the deposits. However, when assuming responsibility of a site from prior consultants, the variability in previous sample descriptions and the subjective interpretations and classifications of lithologies by different geologists can complicate or vanquish altogether attempts at cross-sectional correlations that are so crucial to characterizing a site's hydrogeology.

Given the limits of traditional investigative methods at the time the study was conducted (mud rotary drilling and split spoon sampling, which often resulted in no sample recovery, loss of drilling fluids when attempting to sample, and collapsing boreholes)[3] and the desire of the site owner not to repeat drilling and sampling work accomplished previously, this site was well suited for the application of borehole geophysics. Such a methodology can facilitate retroactively developing a stratigraphic framework, specifically the delineation of the sand and clay units, and to document whether the screened intervals of existing wells were monitoring consistent hydrostratigraphic

[1] To reduce the cumbersome formational names throughout this paper, the lithostratigraphic units will be referred to without their informal member designation (e.g., Woodbridge Clay Member = Woodbridge Clay).
[2] Despite the absence of the Potomac Formation in this region, the aquifer designation of "PRM" will still be used herein although only the Magothy and Raritan Formations comprise the upper and middle PRM aquifers, respectively.
[3] Mud rotary was the only drilling technique available for installing wells in these unconsolidated deposits; the work was conducted before the availability of the Rotosonic method that can economically produce nearly undisturbed continuous core samples while maintaining a stable borehole.

intervals.[4] This methodology would also reveal a new perspective on the relationships between the stratigraphic units, which will be discussed herein.

Investigative Approach

A total of 88 monitoring wells were present on-site at the start of the borehole geophysical investigation; these wells had been installed during a series of previous site investigations conducted during the 1970s through the late 1980s. Although these wells were not evenly distributed across the site, they offered a cost-effective way to assess the site stratigraphy in the absence of continuous core data and help focus subsequent drilling to only those locations where stratigraphic data gaps existed.

The borehole geophysical investigation began with the natural gamma ray logging of 30 selected boreholes and wells at the site; the deepest wells were logged because they penetrated the greatest thickness of sediments and thus would reveal more of the site stratigraphy (Jengo, 1992, 1995; Jengo and Parr, 1993). Because cased wells were being logged, the most appropriate geophysical tool was natural gamma ray because it did not require physical or fluid contact with the formation; further details on the equipment specifications and explanations on why the emission of naturally occurring radiation is much higher in clayey sediments and in sediments rich in weathered feldspar and/or phyllosilicate minerals than in quartz sand deposits can be found in Jengo (1995).[5]

Outcrop exposures of the Woodbridge Clay and Sayreville Sand were also thoroughly examined in the former Sayre & Fisher Company clay banks in Sayreville, which has now been lost to the TowneLake housing development (1.5 miles or 2.4 Km to the west-northwest from the center of the study area). Exposures of the South Amboy Fire Clay and Old Bridge Sand in former George Such Clay Banks, which is more commonly known as the Burt Creek – J.R. Crossman clay banks (north of Kennedy Park, 0.75 mile or 1.2 Km to the north from the center of the study area) were also studied and sampled (Figure 1). These well-known exposures have been described in detail by many previous workers, most notably by Owens and Sohl (1969) and Owens et al. (1977), and have served as the principal type sections for the characterization of these informal members. Comparisons of data obtained from site wells to the aforementioned clay bank exposures were essential in establishing the presence of each of these informal members beneath the site.

[4] Screening wells in consistent hydrostratigraphic intervals is particularly critical if aquifers are contaminated with Dense Non-Aqueous Phase Liquids (DNAPLs). Due to the nature and behavior of DNAPLs in the saturated zone, screening wells in the same stratigraphic unit across the site will not adequately monitor DNAPL migration if the base of the aquifer consists of different sand facies. In other words, if various sand facies are onlapping a confining unit, the DNAPLs will move downslope across those facies; therefore, it is necessary to screen wells in the sand facies directly overlying the confining unit (in a consistent hydrostratigraphic interval) rather than in the same stratigraphic interval across the site.

[5] It is important to note that geophysical well logs in this study were not interpreted without some supporting lithologic data because log responses are a relative, not an absolute, indicator of lithology. Examination of archived lithologic samples from representative boreholes was conducted whenever possible so that the log responses could be calibrated to a definitive lithology. The author's experience has been that borehole geophysics can be used quite successfully in characterizing and correlating Cretaceous-age deposits (Jengo, 1995; 1999) but is much less useful in the stratigraphic correlation of Quaternary-age sediments (Jengo, 2006).

Representative Stratigraphic Cross Sections

A total of eight stratigraphic cross-sections were originally developed and most were included in Jengo (1995); two representative cross-sections are included here to illustrate significant stratigraphic relationships that became evident following the geophysical logging (Figure 2).

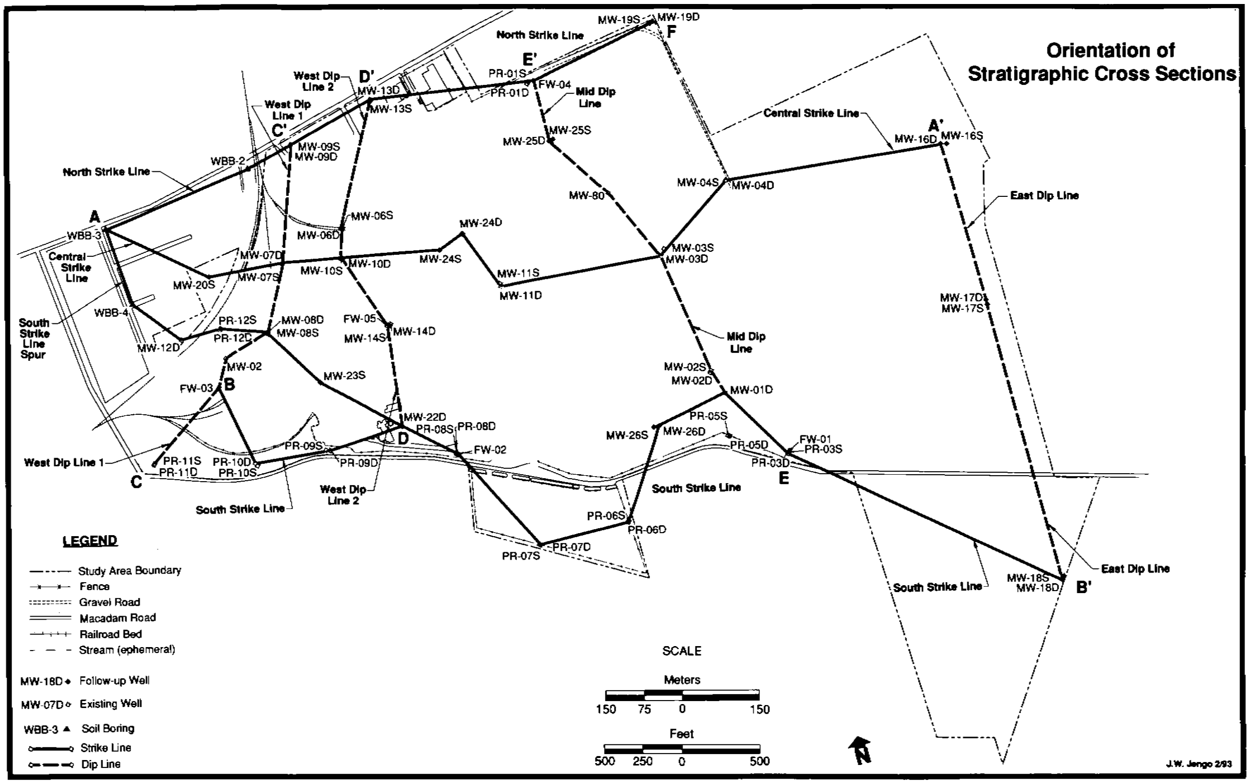

Figure 2: Orientation of the eight primary stratigraphic cross-sections developed for the site. The Central Strike Line (A-A') and the West Dip Line 2 (D'-D) are presented herein.

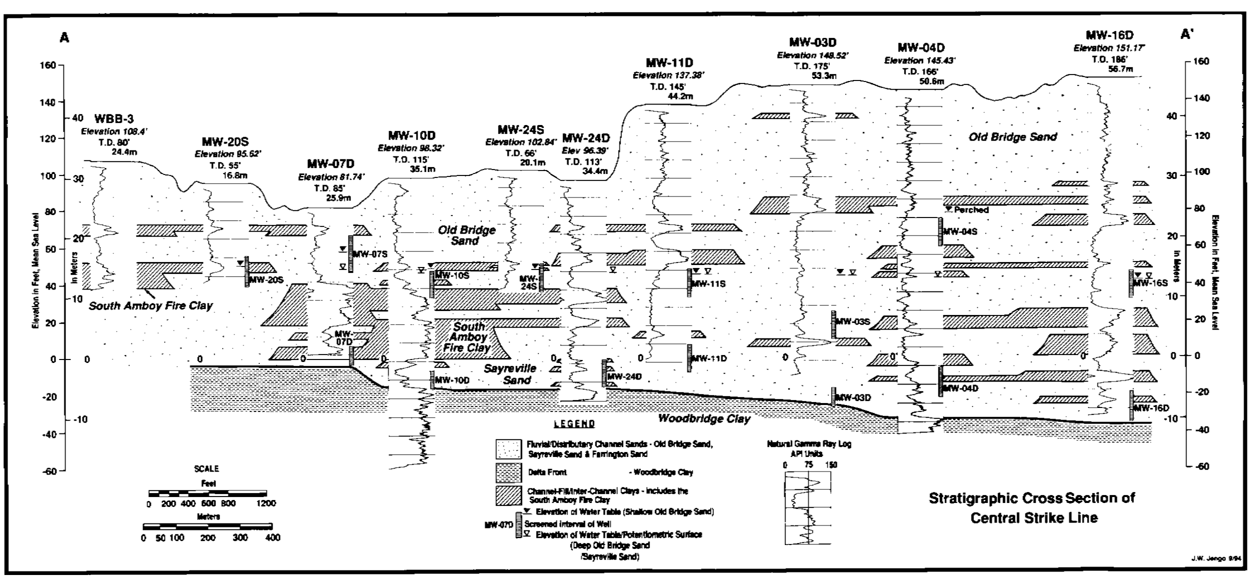

Figure 3: Central Strike Line stratigraphic cross-section.

Figure 3 presents the Central Strike Line cross-section along the approximate strike of the stratigraphic units through the central portion of the site. The cross-section illustrates the discontinuous character of what was identified by the author as the South Amboy Fire Clay and other clay beds within the Old Bridge Sand, and the wide variability of the thickness of the Old Bridge Sand. The maximum thickness of the South Amboy Fire Clay (40 ft or 12.2 m) within the site was encountered in well MW-10D, although this also included an intercalated sand bed. The planar view of this occurrence of the South Amboy Fire Clay revealed that it had a curved geometry, indicating a possible abandoned channel (oxbow lake) depositional paleoenvironment (see Jengo and Parr, 1993). The manner in which the South Amboy Fire Clay was interbedded with the Old Bridge Sand and Sayreville Sand[6] (particularly in wells MW-07D, MW-10D, and MW-24D) prompted

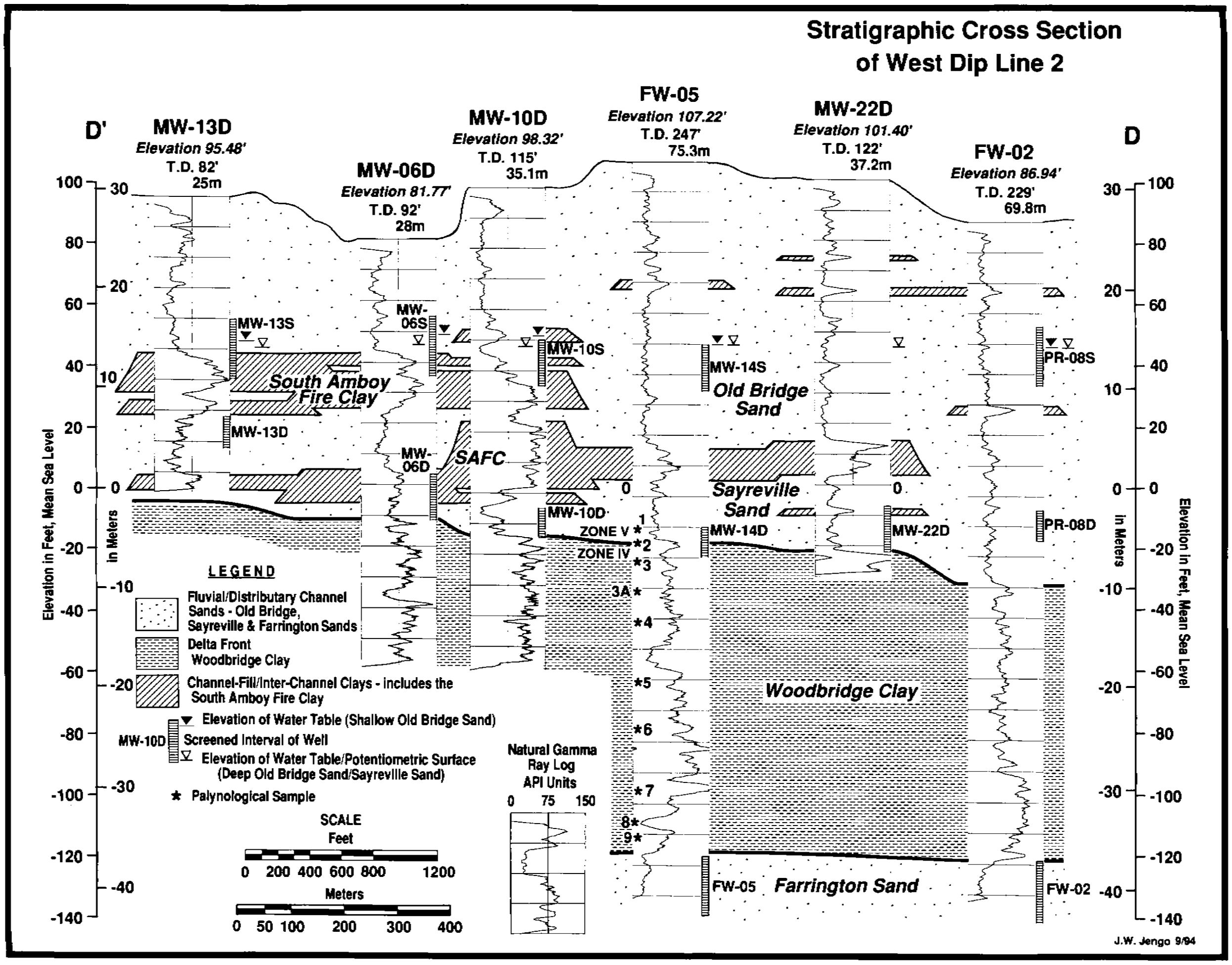

Figure 4: West Dip Line 2 stratigraphic cross-section.

[6] The NJGS did not map the Sayreville Sand in their South Amboy quadrangle bedrock geology map (Sugarman et al., 2005) because this unit was not considered to be a "mappable continuous sand" (S.D. Stanford, pers. comm., June 22, 2009) but because this paper wants to remain consistent with historic stratigraphic descriptions from the adjacent clay quarries, the "Sayreville Sand" nomenclature will be used herein.

an evaluation of their paleodepositional relationship, which will be discussed below. Also evident on this cross-section was the discontinuous character of hydraulically insignificant clay beds within the Old Bridge Sand in the central and eastern portion of the site.[7]

Figure 4 presents the West Dip Line 2 cross-section along the approximate dip of the stratigraphic units in the western portion of the site. The cross-section also illustrates the occurrence of thick, discontinuous clay intervals interpreted to be the South Amboy Fire Clay and the apparent interbedded relationship between the Old Bridge Sand, the South Amboy Fire Clay, and Sayreville Sand, suggesting a greater stratigraphic complexity than the traditional layer-cake representation of these units that has been presented in some reports of this region. The dip and undulating paleotopography surface of the Woodbridge Clay was evident between wells MW-06D and FW-02. The Woodbridge Clay was found to have a very consistent thickness and continuity across the site and, therefore, was considered to be a major impediment to vertical ground water flow, effectively isolating the Old Bridge Sand/Sayreville Sand aquifer from another important regional aquifer, the underlying Farrington Sand.

A Brief Synopsis of Study Area Stratigraphic Units

The following discussion summarizes the lithologic descriptions and paleoenvironmental interpretations of the Raritan and Magothy Formation units in the vicinity of the study area from previous authoritative work by the NJGS and USGS, and new data obtained by the author from outcrop observations, lithologic samples obtained from site wells, and interpretation of natural gamma ray log responses. The chart shown in Figure 5 summarizes the author's revised correlation of the lithostratigraphic units discussed in Jengo (1995; 1999) to the established pollen zonation and also presents a refinement of the equivalency correlations between the lithostratigraphic units and the regional USGS hydrogeologic units of Zapecza (1989), based on geographic region.[8]

Farrington Sand

The Farrington Sand of the Raritan Formation has been described as white, light to dark gray to yellowish red, quartz sand with thin gravel beds and dark gray silt beds (Sugarman et al., 2005). Study area lithologic samples of the Farrington Sand indicated a predominantly light to dark gray, micaceous fine- to coarse-grained angular sand with gravel, clayey silt, and silt beds. The Farrington Sand is equivalent to the middle PRM aquifer in this area (Figure 5) (Zapecza, 1984). In the vicinity of South River, Sayreville, and Old Bridge, the thickness of the Farrington Sand ranges from 44 to

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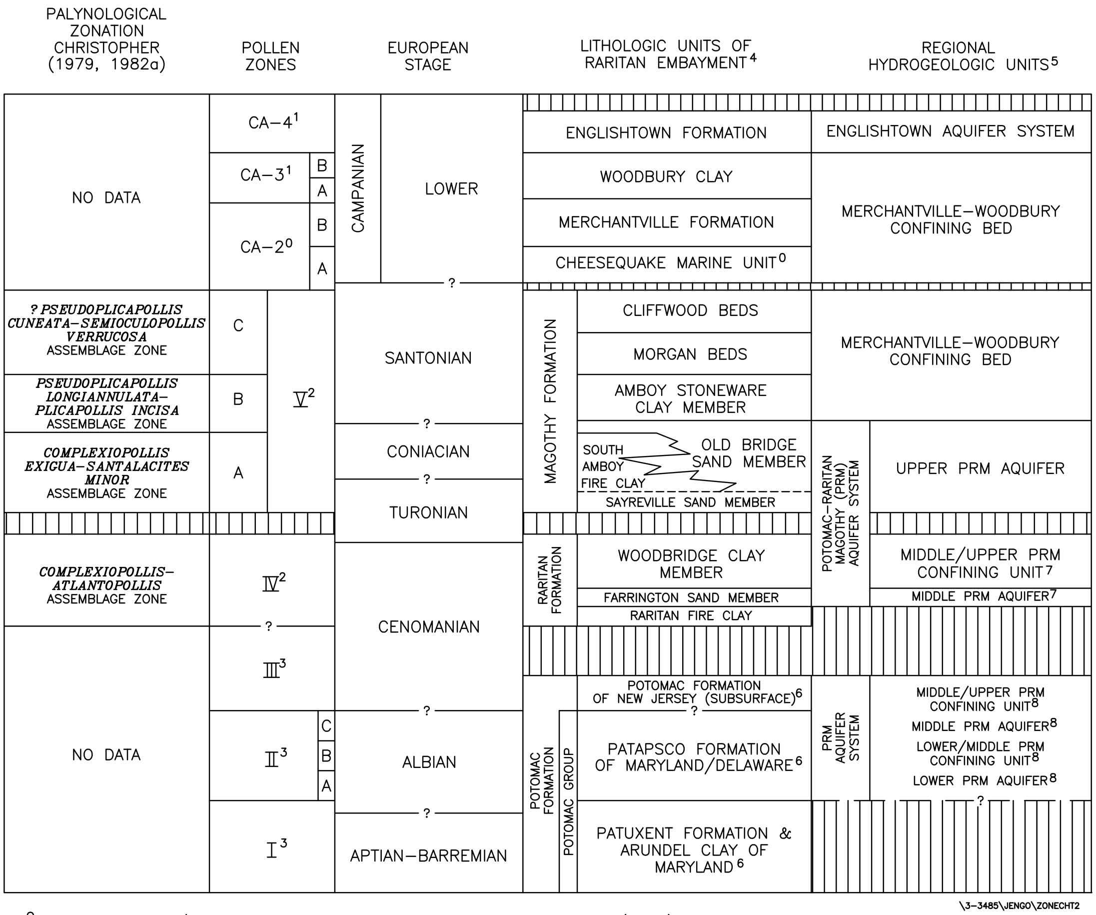
[7] The author designated only thick and relatively prominent clay beds within the study area as the South Amboy Fire Clay to facilitate an association with the historic (and economic) identification of this unit, and allow thin and sporadic (and hydrogeologically unimportant) clay beds to remain within the Old Bridge Sand nomenclature.

[8] The author recognizes the long tradition of study of the Late Cretaceous-age section in New Jersey. Detailed columnar sections of the entire interval of "clays" that were eventually to be assigned to the Raritan and Magothy Formations were described by Cook (1868) and illustrated and described in exceptional detail by Cook and Smock (1878) and Ries, et al. (1904); the Magothy/Raritan Formation sands were assigned informal member names by Barksdale et al. (1943). However, to simplify the following analyses, the author utilized the fine lithostratigraphic synthesis developed by Owens and Sohl (1969) and the hydrostratigraphic framework of Zapecza (1989) with the realization that this work benefited from more than 150 years of research by the aforementioned pioneering geologists, other early 20th century geologists, in addition to the seminal pollen zonation work conducted by various palynologists.



0 EUROPEAN STAGE/POLLEN ZONE CORRELATIONS FOLLOW LITWIN ET AL. (1993).

1 EUROPEAN STAGE/POLLEN ZONE CORRELATIONS FOLLOW WOLFE (1976).

2 EUROPEAN STAGE/POLLEN ZONE CORRELATIONS FOLLOW CHRISTOPHER (1977b).

3 EUROPEAN STAGE/POLLEN ZONE CORRELATIONS FOLLOW DOYLE AND ROBBINS (1977).

4 EUROPEAN STAGE/LITHOLOGIC UNIT & CORRELATIONS FOLLOW OWENS AND OTHERS (1977), JENGO (1995), AND THIS PAPER.

5 HYDROGEOLOGIC UNIT/LITHOLOGIC UNIT CORRELATIONS FOLLOW ZAPECZA (1989), SUNDSTROM ET AL. (1967) AND THIS PAPER.

6 LOWER CRETACEOUS SEDIMENT CORRELATIONS TO EUROPEAN STAGE/POLLEN ZONES FOLLOW BRENNER (1963), DOYLE (1969a), WOLFE ET AL. (1975), AND DOYLE AND ROBBINS (1977). THE "RARITAN FORMATION" OF MARYLAND AND DELAWARE CONSIDERED TO BE ZONE III BY DOYLE (1969a) AND WOLFE ET AL. (1975) AND UPPERMOST PATAPSCO FORMATION BY WOLFE AND PAKISER (1971).

7 COASTAL PLAIN NORTHEAST OF BURLINGTON COUNTY, NEW JERSEY.

8 COASTAL PLAIN SOUTHWEST OF BURLINGTON COUNTY, NEW JERSEY.

NOTE: ZONE VII OF SIRKIN (1974) HAS BEEN MODIFIED TO ZONES VB & VC OF CHRISTOPHER (1979, 1982a).
ZONE V OF SIRKIN (1974) HAS BEEN MODIFIED TO ZONE VA OF CHRISTOPHER (1979, 1982a).

Figure 5: Modified geologic, hydrogeologic, and pollen zonation chart of the Cretaceous-age section discussed in this paper and in Jengo (1995, 1999).

104 ft (13.4 to 31.7 m) (Farlekas, 1979). Interpretation of isopach maps provided by Gronberg et al. (1991) indicated the Farrington Sand to be between 50 ft (15.2 m) and 75 ft (22.9 m) thick in this vicinity.

The elevation of the top of the Farrington Sand, determined by lithologic and natural gamma ray logs from the five FW-series wells, ranged from -84 to -129 ft (-25.6 to -39.3) mean sea level (msl). These elevations were consistent with the interpretations in Gronberg et al. (1991) for neighboring wells 23-386 and 23-1016 and the author's interpretation of the descriptive logs of wells 23-399, 23-386, and 23-1016 in Gronberg et al. (1989). Available study area data indicated a southeastward dip from about 27 to 122 ft/mile (5.1 to 23.1 m/Km) for the Farrington Sand, which was consistent with the regional dip of the unit as determined by Zapecza (1984).

Owens and Sohl (1969) interpreted the large scale cross stratified sands comprising the Farrington Sand as fluvial point bar or channel bar deposits.

Woodbridge Clay

The Woodbridge Clay of the Raritan Formation has been described as a massive, dark gray to grayish black, micaceous, thin- to thick-bedded succession of lignitic and siderite-rich silt and clay, with alternating micaceous white to light gray sand layers (Owens and Sohl, 1969; Owens et al., 1977; Sugarman et al., 2005). Study area lithologic and grain size analyses samples of the Woodbridge Clay indicated predominantly dark gray micaceous silty clay (Figure 6). Well-preserved lignitic woody trunks, root systems, and branches on the order of 2 to 4 ft (0.6 to 1.2 m) long were commonly observed in the Sayre & Fisher Company clay banks. The Woodbridge Clay overlies the Farrington Sand and is equivalent to the Middle/Upper Confining Unit in this area (Figure 5) (Zapecza, 1984).

Figure 6: Exposure of the Woodbridge Clay overlain by the Sayreville Sand in the former Sayre & Fisher Company clay banks in Sayreville, NJ, now lost to the TowneLake housing development. Note the undulating contact between the two units. The measured section from the top of photograph to the end of the tape measure is 10.5 ft (3.2 m).

In the vicinity of its outcrop area, the Woodbridge Clay ranges in thickness from 50 to 90 ft (15.2 to 27.4 m) (Barksdale et al., 1943). The Woodbridge Clay ranged in thickness from 89 to 103 ft (27.1 to 31.4 m) beneath the site, a range that was consistent with the approximate 100 ft (30.5 m) thickness contour around the study area indicated in Gronberg et al. (1991). The elevation of the top of the Woodbridge Clay, interpreted using lithologic and natural gamma ray logs, ranged from +11 ft (+3.4 m) msl along the western margin of the site to -35 ft (-10.7 m) msl in the eastern part of the site. The natural gamma ray logs indicated the contact between the Woodbridge Clay and the overlying Sayreville Sand was generally very sharp. Rip-up clasts and scoured surfaces marked this undulating contact in the Sayre & Fisher Company clay banks (see following *Sayreville Sand* discussion). Structure contour mapping utilizing site well data indicated an overall east-southeast to southeast dip for the Woodbridge Clay ranging between 14 ft/mile (2.7 m/Km) in the eastern portion of the site to 127 ft/mile (24.1 m/Km) in the western portion of the site.

A detailed discussion of the likely paleoenvironments of the lower and upper Woodbridge Clay can be found in Jengo (1995). In summary, the Woodbridge Clay is interpreted as a lowland swamp with marine influences transitional to prodelta (delta front slope) and/or marine inner shelf (Owens and Sohl, 1969; Sugarman et al., 2005). Evidence of the proximity to marine waters was found in sideritic nodules that contained a fully marine, transported, disarticulated molluscan fauna (Owens et al., 1977; Sohl, 1977a); Sirkin (1989) reported marine influences in the paleoecology of the palynomorphs recovered from the lower portion of the Woodbridge Clay in well FW-05 (samples nos. 5, 6, 7, and 8) (Figure 4). The lowland swamp paleoenvironment was evident by the lignitic trees exposed in the Sayre & Fisher Company clay banks and the observation of dinosaur footprints in the upper part of the Woodbridge Clay (Barksdale et al., 1943). Sirkin (1989) reported no marine influences in the paleoecology of the palynomorphs recovered from the upper portion of the Woodbridge Clay in well FW-05 (samples nos. 3 and 4).

Sayreville Sand

The Sayreville Sand has been described as a white, micaceous fine- to medium-grained quartz sand (Owens et al., 1977). Study area lithologic and grain size analyses samples of the Sayreville Sand indicated a predominantly white, gray, pale brown, and reddish yellow silty and clayey silty fine- to medium-grained sand that contained lignite and siderite concretions; there were also coarse-grained sand intervals at the contact with the underlying Woodbridge Clay. The predominant sedimentary feature of the Sayreville Sand were extensive large-scale trough cross-stratified sands containing clay intraclasts (Owens and Gohn, 1985) that were once nicely exposed in the Sayre & Fisher Company clay banks (Figure 7). Intercalated beds of light- to dark-colored clayey silt were also observed (Owens et al., 1977) (Figure 8). Regionally, the Sayreville Sand reaches a maximum thickness of 35 to 40 ft (10.7 to 12.2 m) (Barksdale et al., 1943). In the study of the PRM stratigraphy in Middlesex County, Gronberg et al. (1989, 1991) did not delineate between the Sayreville Sand and the Old Bridge Sand.

The contact between the Sayreville Sand and the underlying Woodbridge Clay was described in early geological reports to be “irregular or wavy” (Ries et al., 1904). The elevation of the base of the Sayreville Sand varied approximately 46 ft (14 m) across the site because of the dip and undulating paleotopography of the underlying Woodbridge Clay. In those wells where the South Amboy Fire

Clay was absent, the sands present from the near subsurface to the Woodbridge Clay had such similar natural gamma ray log responses that without facies descriptions, it was not possible to define a clear separation between the Sayreville and Old Bridge Sands.

Figure 7: Stacked trough cross-beds with pronounced internal lamination of the Sayreville Sand in the former Sayre & Fisher Company clay banks in Sayreville, NJ. The measured section from the top of photograph to the spade is 4 feet (1.2 m).

Figure 8: Silty fine- to medium-grained sand with intercalated beds of light- to dark-colored clayey silt of the Sayreville Sand in the former Sayre & Fisher Company clay banks in Sayreville, NJ. The measured section from the top of the tape measure to the spade is 3.75 feet (1.1 m).

Owens and Sohl (1969) interpreted the unfossiliferous, unidirectional cross-bedded sands comprising the Sayreville Sand as fluvial point bar or channel bar deposits. Owens and Gohn (1985) also recognized locally derived clay intraclasts and channel geometries in the Sayreville Sand. In this study area, the blocky or cylindrical pattern of the natural gamma ray logs that characterized the Sayreville Sand section most likely represent channel fills, typical of either fluvial channels or marginal marine distributary-channels (Fisher, 1969; Cant, 1984). Sirkin (1989) reported no marine influences in the paleoecology of the palynomorphs recovered from the Sayreville Sand section in well FW-05 (samples nos. 1 and 2) (Figure 4).

Sayreville Sand & Woodbridge Clay Chronostratigraphic Clarification

Christopher (1979) grouped the Sayreville Sand with the Woodbridge Clay in the *Complexiopollis-Atlantopollis* Zone (equivalent to Zone IV of Doyle and Robbins, 1977) and because the Sayreville Sand was grouped with the Woodbridge Clay in numerous other publications (Christopher, 1977a, 1982a; Owens and Gohn, 1985; Olsson, 1988), the stratigraphic assignment of the Sayreville Sand was evaluated and discussed in great detail in Jengo (1995). It is briefly reviewed as follows:

Christopher (1979) stated that the samples from the Woodbridge Clay and Sayreville Sand comprised a tightly packed, relatively homogeneous subset of samples (p. 92) and that “only one productive sample” from the Sayreville Sand was recovered (p. 83). According to the diagrams provided in Christopher (1979), the single Sayreville Sand sample (R1184B) was very near the contact between the Sayreville Sand and the Woodbridge Clay. Jengo (1995) theorized that sample R1184B may have extracted from an intraclast originating from the Woodbridge Clay and thus, did not truly represent the Sayreville Sand because Christopher (1979) stated that “palynological characteristics of sand units were based on samples obtained from clay stringers…contained within the sands” (p. 83). Although no description of sample R1184B was given, in 1991 when the Sayre & Fisher Company clay banks were still accessible, the author excavated exposures of the Sayreville Sand/Woodbridge Clay contact. As shown in Figure 9, numerous Woodbridge Clay intraclasts and clay stringers can be found within the Sayreville Sand immediately above the contact with the Woodbridge Clay. Although Owens and Gohn (1985) also reported clay intraclasts within the Sayreville Sand and Olsson (1991) noted rip-up clay clasts at the contact between the Woodbridge Clay and Sayreville Sand, the representativeness of the R1184B sample apparently wasn’t questioned until Jengo (1995).[9] Thus, the single “Sayreville Sand” clay sample analyzed by Christopher (1979) and then used to group the Sayreville Sand and Woodbridge Clay together in the *Complexiopollis-Atlantopollis* Zone probably originated from, and was thereby representative of, the Woodbridge Clay.

Fortunately, the biostratigraphic separation of the Woodbridge Clay and the Sayreville Sand could be independently verified because palynological pollen data results from on-site well FW-05 were made available courtesy of Peter Sugarman of NJGS. This pollen zonation data generated by Sirkin

[9] The juxtaposition of these sediments was noted by previous workers. For example, in the Sayre & Fisher Company clay banks, Owens et al. (1977) identified a Sayreville Sand cut and fill channel that truncated Woodbridge Clay sediments; however, Owens and Sohl (1969), Owens et al. (1977), and Owens and Gohn (1985) interpreted this relationship as contemporaneous sedimentological facies rather than the Woodbridge Clay being subsequently truncated by the fluvial channel/distributary-channels and interdistributary deposits of the Sayreville Sand, South Amboy Fire Clay, and the Old Bridge Sand sequence.

(1989) indicated that an unconformity was present between -20 and -23 ft (-6.1 to -7 m) msl or according to the stratigraphy outlined in Jengo (1995) and this paper, between the Sayreville Sand and Woodbridge Clay (Figure 4). This interpretation was based on the occurrence of pollen such as *Atlantopollis*, restricted to late Cenomanian-early Turonian? age *Complexiopollis-Atlantopollis* Zone (or Zone IV) found below -23 ft (-7 m) msl in the Woodbridge Clay in well FW-05 (in sample nos. 3 through 9) with no occurrences of *Complexiopollis exigua-Santalacites minor* Zone pollen (or Zone V) index pollen at or below this sample depth. The occurrence of *Complexiopollis* sp. V, restricted to the late Turonian to Coniacian? age *Complexiopollis exigua-Santalacites minor* Zone (Zone V) in the Sayreville Sand above -20 ft (-6.1 m) msl in well FW-05 (in sample nos. 1 and 2) would indicate an unconformity exists between the Woodbridge Clay and Sayreville Sand (Figure 5).

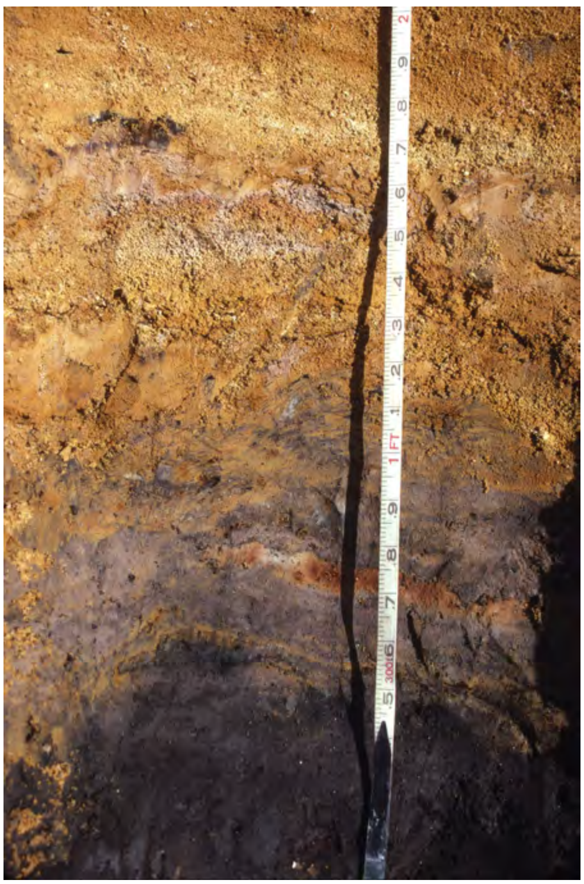


Figure 9: Woodbridge Clay intraclasts and clay stringers within the basal Sayreville Sand immediately above the undulating contact with the Woodbridge Clay in the former Sayre & Fisher Company clay banks in Sayreville, NJ. See narrative for an explanation of how the inclusion of Woodbridge Clay clasts may have affected the representativeness of the “Sayreville Sand” palynological sample of Christopher (1979). The measured section depicted in the photograph is 2 feet (0.6 m).

South Amboy Fire Clay

The South Amboy Fire Clay has been described as a “tough” (presumably meaning geotechnically stiff to hard) massive to laminated, white, light-blue to gray and red-mottled, somewhat lignitic clay, with occurrences of disseminated pyrite, pyritic logs, and pieces of amber (Owens et al., 1977; Sugarman et al., 2005). Study area lithologic and grain size analyses samples of the South Amboy Fire Clay indicated a predominantly gray to pale brown, micaceous plastic clayey silt, sandy clayey silt, silty clay, and sandy silty clay that contained lignite and marcasite, with intervals of silty fine-grained sand. Farlekas (1979) reported the South Amboy Fire Clay reached a maximum thickness of 35 ft (10.7 m); South Amboy Fire Clay beds ranged in thickness from less than a meter to 40 ft (12.2 m) beneath the site. The South Amboy Fire Clay was described by Owens and Sohl (1969) and

Owens et al., (1977) as lensing rapidly and being less widespread and persistent than the Woodbridge Clay. As observed in outcrop, and often mentioned in historical reports such as Ries et al. (1904), the upper surface of the South Amboy Fire Clay is irregular, perhaps reflecting the channel scouring deposition of the overlying Old Bridge Sand (Figure 10).

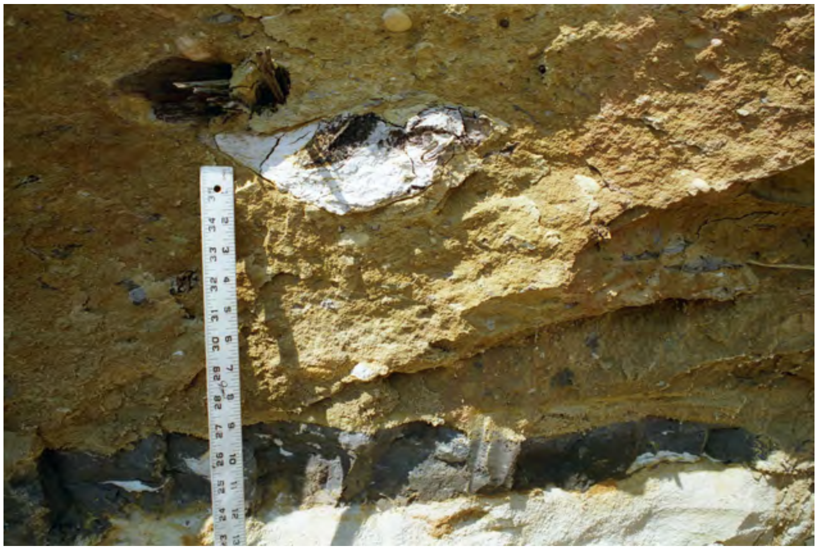


Figure 10: Exposure of the Old Bridge Sand in the former J.R. Crossman clay banks north of John F. Kennedy Memorial Park in Parlin, NJ, which is now been graded over and covered with vegetation. The South Amboy Fire Clay, including beds of white fine-grained sand and carbonized plant remains resembling coal seams, are overlain by poorly sorted, basal gravelly sand containing carbonized plant and clay rip-up clasts. The measured section depicted in the photograph is 1.6 feet (0.5 m).

The palynoassemblage obtained from the South Amboy Fire Clay suggested a coastal lowland swamp paleoenvironment (Sugarman et al., 2005). The South Amboy Fire Clay has been previously interpreted as an oxbow lake deposit (Owens and Sohl, 1969). Although there was some evidence of this latter interpretation in the geometries of certain clay bodies delineated in this study (see Jengo and Parr, 1993), the paleoenvironment was likely more varied and may have included quiet-water deposition in an embayment.

Old Bridge Sand

The Old Bridge Sand has been described as a light gray to weathered white, light yellow, orange and pink, micaceous fine- to medium-grained quartz sand with lignite and intercalated white to dark gray carbonaceous clayey silts and clays (Owens and Sohl, 1969; Owens et al, 1977; Sugarman et al., 2005). Study area lithologic and grain size analyses samples of the Old Bridge Sand indicated a predominantly white, gray, pale brown, yellowish-brown to reddish yellow, well-sorted, micaceous fine- to medium-grained angular to subangular quartz sand. The unit contains lignite and can have a "sugary" textural appearance, with alternating layers of thinly-bedded clayey silt, silt, and fine silty sand. Thin coarser-grained sand and gravel beds at the base of thick sand intervals have also been observed. Large-scale trough and planar-tabular cross beds (greater than 2 inches or 5.1 cm per set) were most common within the sands, with the scale of planar beds ranging from a few centimeters to a meter (Figure 11) (Owens and Sohl, 1969). Owens and Sohl (1969) reported that locally continuous, white to dark gray, stiff clay beds were also very common within the Old Bridge Sand, reaching a thickness of 25 ft (7.6 m) in some areas; Owens et al. (1977) also reported that the Old Bridge Sand contained thin clay stringers and clay beds, which are quite evident in outcrop exposures (Figure 12). Study area lithologic and grain size analyses samples of these thicker clay beds indicated a predominantly white, gray, pale brown, and reddish yellow, micaceous plastic fine sandy clayey silt to silty clay with trace medium sand.

Figure 11: Exposure of the Old Bridge Sand at the Sayreville Recreational Complex immediately south of the Sayreville Cogeneration Facility in Sayreville, NJ. The Old Bridge Sand has extensive large-scale trough and planar-tabular cross beds. The measured section depicted in the photograph is 25.5 inches (2.1 feet or 0.65 m).

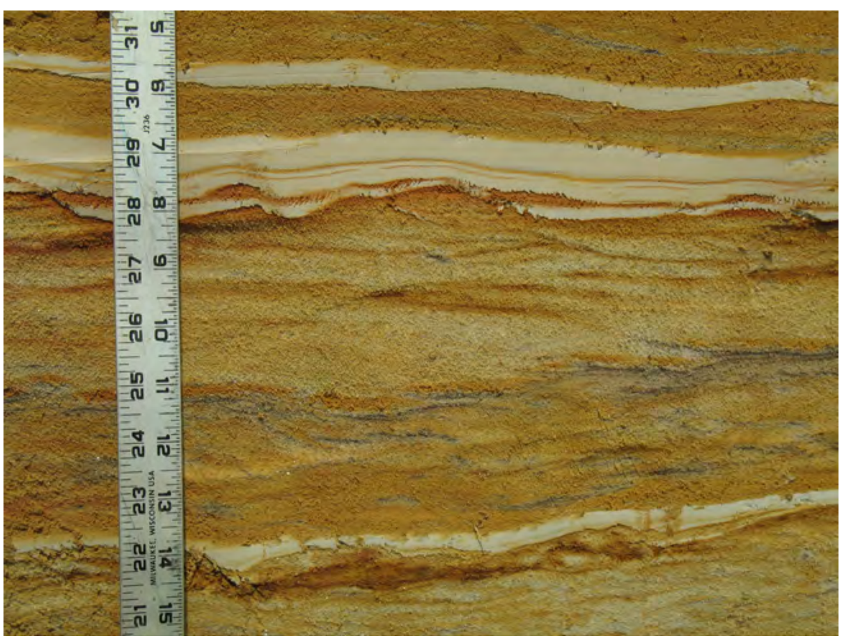


Figure 12: Exposure of the Old Bridge Sand at the Sayreville Recreational Complex immediately south of the Sayreville Cogeneration Facility in Sayreville, NJ, which is stratigraphically several feet higher than the exposure depicted in Figure 11. The Old Bridge Sand also contains numerous thin clay stringers and clay beds that are particularly evident in outcrop exposures but can also be recognized in natural gamma ray logs. The measured section depicted in the photograph is 11 inches (0.92 feet or 0.28 m).

The Old Bridge Sand comprises a significant portion of the upper PRM aquifer in this area (Zapecza, 1984). According to Barksdale et al., (1943), the Old Bridge Sand ranges in thickness from 80 to 110 ft (24.4 to 33.5 m). Because younger deposits such as the Tertiary age Bridgeton Formation were not mapped separately in this study, site-specific thickness estimates for the Old Bridge Sand were not developed. In topographically low areas, such as in the southwestern corner of the site, the Old

Bridge Sand and overlying deposits were approximately 60 ft (18.3 m) thick; however, at the extreme eastern portion of the site, the Old Bridge Sand and overlying deposits increased in thickness to over 100 ft (30.5 m). Interpretation of the base elevation of the upper PRM aquifer in Gronberg et al. (1991) for neighboring wells 23-386, 23-590, and 23-1016 and the author's interpretation of the descriptive log of well 23-399 in Gronberg et al. (1989) were consistent with the study area stratigraphic framework.

A detailed discussion of the likely paleoenvironments of the Old Bridge Sand can be found in Jengo (1995), but bears some reiteration herein. The Old Bridge Sand has been interpreted to be a series of channel deposits formed in a deltaic distributary-channel system (Owens and Gohn, 1985; Olsson, 1991). The blocky or cylindrical pattern of the natural gamma ray logs throughout the Old Bridge Sand most likely represent a series of stacked channel fills (Fisher, 1969; Cant, 1984). In this study area, the natural gamma ray log patterns also show many planar erosive bases or flat-based sands, which may be representative of the level of migration of the scour pool (Reading, 1978). Crevasse splay and delta foreset deposits within the Old Bridge Sand were characterized by horizontally stratified interbedded intervals of thin dark silts and light colored sands, typically much finer grained and more poorly stratified than sandy channel fill deposits and field studies have shown these thin bedded intervals in the Old Bridge Sand grade into cross bedded channel sands suggesting a near-channel deposition (Owens and Sohl, 1969).[10]

The author recalls in the summer of 1993 in the former J.R. Crossman clay banks that a series of pits had been dug into the South Amboy Fire Clay and there were some superb cliff exposures of the overlying Old Bridge Sand (these areas are now graded and covered with thick vegetation). The author examined numerous exposures of South Amboy Fire Clay-Old Bridge Sand contact, including beds of white, fine-grained sand and carbonized plant remains resembling coal seams overlain by poorly sorted, basal gravelly sands containing carbonized plant and clay rip-up clasts, nicely illustrating the erosive nature of the channel deposits (Figure 10). The clay rip-up clast in the sand depicted in Figure 10 was submitted to Les Sirkin in 1997 for palynological analyses and it contained assemblages indicative of the South Amboy Fire Clay.[11]

<u>Old Bridge Sand & South Amboy Fire Clay Chronostratigraphic Clarification</u>

As recently as 1969, the Old Bridge Sand and the underlying Cretaceous section down to the Raritan Fire Clay were assigned to the Raritan Formation (Owens and Sohl, 1969). Wolfe and Pakiser (1971) reassigned the Old Bridge Sand to the Magothy Formation using pollen zonation, however, they continued to group the South Amboy Fire Clay and Woodbridge Clay together based on

[10] The author acknowledges that geologist Dr. Bruce Cornet, who was conducting fossil leaf collections in the summer of 1993 at the same time as the author's clay banks reconnaissance work, recognized on the southern end of the J.R. Crossman's Clay Banks (just north of the Raritan River Railroad tracks) a remarkably complete cross-section of a distributary channel, and interdistributary features including levee and open-water lagoon or bay deposits. The author benefited enormously from these outcrop exposures and observations, but has not been able to find a publication by Dr. Cornet on his excellent interpretative work, but did find a website that interested readers should definitively consult: www.sunstar-solutions.com/sunstar/Sayreville/Kfacies.htm.

[11] Sirkin, in an unpublished May 1, 1997 report to the author, stated that the sample had "abundant spores, gymnosperms and several specimens of angiosperm pollen including tricolpate and tricolporate taxa such as *Porocolpopollenites*, and the triporates *Complexiopollis sp. V, sp. I,* and *C. cf. exigua*, as well as *Triatriopollenites* (with specimens similar to New Genus *D sp. B* of Christopher [19]78). In age this sample compares with the…South Amboy Fire Clay Member, and the *C. exigua-S. minor* zone."

perceived similarities in pollen assemblages. However, Christopher (1977a, 1979) identified a close microfloral relationship between the South Amboy Fire Clay and basal Old Bridge Sand based on pollen assemblages and suggested the differences between these assemblages identified by earlier workers were due to relative abundance changes rather than species composition. Therefore, Christopher (1977a, 1979) grouped the South Amboy Fire Clay and the Old Bridge Sand together in the *Complexiopollis exigua-Santalacites minor* Zone (equivalent to Zone V of Sirkin, 1974) but did not advocate a formal transfer of the South Amboy Fire Clay to the Magothy Formation (see Figure 12 in Jengo, 1995). He also recognized that the microfloral assemblages in the South Amboy Fire Clay and Woodbridge Clay were distinctly different, as did Sirkin (1974), and suggested that a hiatus separated these stratigraphic units.

Paleodepositional vs. Hydrogeologic Relationship Between Sayreville Sand, South Amboy Fire Clay, and Old Bridge Sand

The NJGS has proposed that all the beds above the Woodbridge Clay and below or immediately adjacent to the true clay in the South Amboy Fire Clay should be included in the South Amboy Fire Clay (Sugarman et al., 2005). The data presented in Jengo (1995) supported the inclusion of the Sayreville Sand with the Old Bridge Sand in comprising the upper PRM aquifer in this area, with the South Amboy Fire Clay considered to be an intrafacies within this hydrogeologic section because it was evident in the site cross-section development that this clay facies had a more limited extent than the Sayreville Sand. It was beyond the scope of this study to determine whether the Sayreville Sand-South Amboy Fire Clay-Old Bridge Sand represent a relatively integrated stacked series of fluvial channel/distributary channel deposits that were part of the prograding and aggrading deltaic sequence or whether the Old Bridge Sand was deposited later in time, justifying a separation of that deposit from the Sayreville Sand-South Amboy Fire Clay. Based on the natural gamma ray log correlations performed in this study, the South Amboy Fire Clay appears complexly interbedded with both the Old Bridge Sand and the Sayreville Sand at multiple horizons, with little indication of an interruption in the continuity of the depositional sequence of these three informal members.

Tertiary or Quaternary Age Sediments

In some undeveloped areas of the site, up to 20 ft (6.1 m) or more of a brownish-yellow, yellowish-brown and yellowish red, poorly-sorted very coarse to fine-grained sand with well-rounded quartz and quartzite granules, pebbles, and cobbles, along with iron-banded clayey silts and ironstone, was encountered. No effort was made by the prior consultants to map the occurrence of Tertiary units such as the Bridgeton Formation (Stanford, 1993) or Quaternary age units at the site because when these deposits were encountered, it was typically above the water table and thus, was considered to have no influence on the hydrogeologic mapping of the site. As such, on Figure 3 and Figure 4, the depiction of the upper Old Bridge Sand also can include these undifferentiated deposits. It is recommended; however, that all surficial deposits, including those encountered in the unsaturated zone, be recognized and delineated in site investigations because their possible effect in the vertical migration of contaminant releases.

Achieving a Complete Site Environmental Characterization

Screening Monitoring Wells in Consistent Hydrostratigraphic Intervals

As shown on Figure 4, a number of existing wells such PR-08D previously installed at the site were not screened at the base of the Old Bridge Sand/Sayreville Sand aquifer. The consultant who installed these wells apparently did not determine the depth of the contact between the base of the Old Bridge Sand/Sayreville Sand aquifer and the top of the Woodbridge Clay at these locations (e.g., the placement of the well screen in well PR-8D was well above the top of the Woodbridge Clay). The consultant may have identified clay in the drill cuttings or split-spoon sample, but without a stratigraphic framework, they did not recognize that there was an additional 15 ft (4.6 m) of section before reaching the base of the Old Bridge Sand/Sayreville Sand aquifer. Developing a site-specific hydrostratigraphic framework using borehole geophysics along with detailed lithologic and facies descriptions prior to installing critical monitoring wells can achieve the objective of screening both shallow and deep wells in consistent hydrostratigraphic intervals.[12]

More Efficient Monitoring Well Installations

The installation procedure followed for well MW-22D can illustrate how knowledge of the site hydrostratigraphy was successfully applied during the subsequent installation of 20 new ground water monitoring wells by the author across the site. The top of the Woodbridge Clay was correlated between wells FW-05 and FW-02 (which were geophysically logged in the initial investigation) and estimated to be approximately 120 to 125 ft (36.6 to 38.1 m) below the MW-22D location (Figure 4). The well was then drilled as an 8-inch diameter borehole to 130 ft (39.6 m) in approximately 4 hours (with no split-spoon sampling to interrupt the mud rotary drilling process). Logging of the well took approximately one hour, including setup and breakdown of the geophysical equipment. The gamma ray log showed a major deflection at 120 ft (36.6 m) that was interpreted to be the top of the Woodbridge Clay, and that depth was selected as the base of the Old Bridge Sand/Sayreville Sand aquifer and the well was constructed.[13] This one-day well installation guided by borehole geophysical logging resulted in a superior well,[14] and was less costly than if the well had been drilled over a three to five day period to accommodate split spoon sampling. In addition, the data collected from the deep well was interpreted and used to determine the depth and screened interval of the adjacent shallow well, allowing that well to be installed without the need for sampling. Such location-specific screening of individual wells was absolutely necessary because of the relatively extreme topographic relief at this site, (e.g., the depths of wells completed at the

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[12] Although screening the shallow wells across the water table ensures that they are installed in a consistent hydrostratigraphic interval, the placement of the deep well screens in the study area was dependent on locating the contact between the base of the Sayreville Sand and the top of the Woodbridge Clay.

[13] It was expected that the gamma ray response of the Woodbridge Clay would be more pronounced in the MW-22D borehole than the response obtained from logging the existing wells FW-05 and FW-02. This is because the FW wells were logged through double-cased (steel) construction, which resulted in a reduced gamma ray penetration to the logging tool, whereas MW-22D was logged as an open hole without casing.

[14] This is because in order to hold the borehole open during the time intervals to collect spilt spoon samples, a heavier drilling mud needed to be circulated. This increase in mud circulation and weight resulted in greater mud cake aquifer penetration, which became harder to remove during well development, reducing the well's productivity.

base of the Old Bridge Sand/Sayreville Sand aquifer ranged from 55 to 198 ft (16.8 to 60.4 m) below ground surface).

More Accurate Hydrogeologic Characterizations

The primary benefit from the aforementioned stratigraphic investigation was the recognition that the Old Bridge Sand/Sayreville Sand aquifer section could have different hydrogeologic properties throughout its vertical profile because of variations in paleodepositional setting, including the effect of the intercalated South Amboy Fire Clay and other clay beds. Such differences would then have very consequential effects on vertical and horizontal dissolved phase groundwater migration. As such, subsequent evaluations of potentiometric elevations, hydraulic conductivity, groundwater flow velocities, and fate and transport effects were always conducted in both aquifer sections, the upper and unconfined Old Bridge Sand and the lower, and very often confined, Sayreville Sand section. These studies did, in fact, reveal hydraulic gradient differentials greater than 10 feet between the Old Bridge Sand and the Sayreville Sand in the presence of the South Amboy Fire Clay (note the potentiometric head difference between the shallow MW-07S and deep MW-07D wells on Figure 3) with very insignificant differentials where the South Amboy Fire Clay and other clays were absent or thin/discontinuous. Further, the hydraulic conductivity of the Sayreville Sand was very often lower by one or two orders of magnitude than the upper Old Bridge Sand (e.g., 1.06×10^{-2} cm/sec or 30 ft/day in MW-13S vs. 1.76×10^{-5} cm/sec or 0.05 ft/day in MW-13D, included on Figure 4), which had a significant effect on groundwater flow velocities. These data were critical parameters in determining and predicting the fate and transport of dissolved phase constituents.[15] In summary, the effort to ascertain the site stratigraphy, determine the paleodepositional settings and relationships between the various deposits, and establish accurate correlations to the regional geologic setting facilitated the accurate characterization of the hydraulic flow properties of the aquifers and confining units at this site.

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[15] For example, a relatively silt and clay free section of the Old Bridge Sand with hydraulic conductivities in the 10^{-2} cm/sec range would be expected to transmit dissolved phase constituents farther and wider than a silty sand section of the Sayreville Sand with hydraulic conductivities in the 10^{-3} to 10^{-4} cm/sec range. Determining the areal extent and distribution of different types of aquifer transmissivities is a key element in delineating groundwater contamination.

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Groundwater/surface water interaction at an EPA Superfund site on the coastline of New Jersey

John Dougherty
CDM, Inc.

Background/Objectives

This paper will present the results of the evaluation of groundwater/surface water interaction and groundwater contamination at an EPA Superfund site on the coastline of New Jersey. At the site, slag from a former smelting operation had been deposited to form a seawall and to armor a jetty along a 1.5-mile long section of a bay. Over time, the slag has weathered and has contaminated sediment in the near-shore environment. The site is underlain by Quaternary age beach deposits (Qbs) which are up to 15 feet thick. Offshore, the site is underlain by Quaternary age estuarine deposits (Qmm) consisting of organic clay and silt, peat, and sand and gravel. These same estuarine deposits underlie two nearby creeks and their associated wetlands. Developed areas, where houses and business are located, are underlain by weathered coastal plain sediments (Qwcp), consisting of sand, silt, and clay, or by Upper Terrace Deposits (Qtu) up to 20 feet thick, consisting of sand, gravel, and minor silt. Regional mapping shows that the Quaternary deposits are underlain by the Cretaceous age Magothy Formation.

Approach/Activities

A series of monitoring wells were installed along and perpendicular to the shore to provide lithologic, water level, and water quality data. Continuous water level data were collected for one month, January to February 2011, from some of the monitoring wells installed at the site. Synoptic water level data were collected at high and low tide on one day for six months, January to June 2011, from all wells at the site. Tide data were obtained from a nearby gauging station. In January 2011, one complete set of groundwater samples was collected from all wells installed at the site. Salinity data were collected from surface water and groundwater samples. The water level data were graphed to evaluate water level changes over time and horizontal and vertical hydraulic gradients. Water level data were also graphed with rainfall, barometric, and tidal data to evaluate recharge at the site and the influence of tides on groundwater levels. Salinity data were evaluated to estimate the mixing of surface and groundwater.

Results/Lessons Learned

The water level data showed that, although shallow groundwater at the site flows toward surface water, the groundwater flow direction may be temporarily reversed close to shore at high tide. Water level and precipitation data showed generally rapid recharge to the shallow water bearing zones at most, but not all, wells at the site. Comparison of water level data at high and low tide showed that the tidal influence was greatest on wells closest to the shore and dissipated rapidly in wells further inland. Salinity data showed that most groundwater samples were brackish, with some salinity levels close to those found in bay water samples. However, some shallow groundwater samples close to the shore were not brackish. Groundwater sampling results for key parameters showed that arsenic concentrations in 5 of 23 samples, including the background location, exceeded the screening level criterion of 3 micrograms per liter (μg/L). Lead exceeded the screening criterion (5 μg/L) in 12 of the 23 samples, including the upgradient well. Copper and antimony did not exceed their respective screening criteria in any samples. Chromium was detected in all but two samples and exceeded its criterion in only one sample. Hexavalent chromium was not detected in any groundwater samples.

Correlation of outcrop to subsurface Magothy Formation sequences and members

Peter Sugarman[1], James Browning[2], Kenneth Miller[2] & Andrew Kulpecz[3]
[1]New Jersey Geological Survey, PO Box 420, Mail Code 29-01, Trenton, NJ 08625; [2]Rutgers University Department of Earth and Planetary Sciences, Wright Labs, 610 Taylor Road, Piscataway, NJ 08854-8066; [3]Chevron Energy Technology Company, Reservoir Characterization Unit, 1500 Louisiana St., Houston, TX 77002

The Cretaceous Magothy Formation in the Raritan Bay area is a thick, complex assemblage of marginal marine, predominantly deltaic sediments. It is dominated by fine- to course quartz sand and interbedded thin to thick beds of clay that are often carbonaceous. In outcrop, five informal members have been mapped from oldest to youngest: South Amboy Fire Clay, Old Bridge Sand, Amboy Stoneware Clay, Cliffwood beds, and Morgan beds. Regional mapping of these members has been difficult because local vertical and lateral facies changes are common (as is common in a delta), age dating is difficult due to limited pollen preservation in weathered silts and clays, and exposures are poor due to its sandy nature and widespread cover by younger sediments. The ODP 174AX Sea Girt borehole, drilled in 2003 approximately 28 miles downdip from the South Amboy quadrangle Magothy outcrops, recovered a complete section of the Magothy Formation, allowing for a detailed analysis of the facies relationships within the Magothy Formation using core samples and geophysical logs. Five Turoniam-Coniacian sequences were identified that we correlate with outcropping members: Magothy I (Sayreville Sand member of the Raritan Formation), II (South Amboy Fire Clay and Old Bridge Sand), III (Amboy Stoneware Clay), IVA (Cliffwood beds) and IVB (Morgan beds). Although Magothy sequences consist of a diverse system of deltaic facies, they maintain fairly consistent well-log signatures across the New Jersey Coastal Plain, suggesting sea-level control is a major influence on the development and preservation of these sequences.

Keynote Presentation: Critical Area I: A success story

Jeffrey L. Hoffman
New Jersey Geological Survey, PO Box 420, Mail Code 29-01, Trenton, NJ 08625;
JeffreyLHoffman@dep.state.nj.us

Abstract

The New Jersey Department of Environmental Protection (NJDEP) may establish a Water Supply Critical Area where overpumpage or pollution has depleted water resources and the remaining resource is threatened. Two such areas are now in effect in New Jersey. Critical Area No. 1 is in New Jersey's northeast coastal plain and applies to the Wenonah-Mt. Laurel, Englishtown, Old Bridge and Farrington aquifers underlying parts of Monmouth, Middlesex, and Ocean Counties. NJDEP ordered pumpage reductions from these aquifers beginning in 1990 as water from alternate sources became available. Pumping reductions of about 25% from the area have created water-levels recoveries of as much as 150 feet. This has preserved the resource by lessening the threat of saltwater intrusion

Introduction

All aquifer pumpage must be balanced by a combination of releases of water from storage, increased recharge to the aquifer, or decreased discharge from the aquifer (Bredehoeft, Papadopulos and Cooper, 1982). Excessive withdrawals can increase pumping costs, force users to deepen wells to follow falling water levels, and pull in recharge from areas of lower water quality. These impacts were all evident in the northeast coastal plain of New Jersey where pumpage from confined aquifers created regional cones of depression.

NJDEP is charged with protecting the water resources of the State for current and future users. This includes the wise stewardship of groundwater so as not to permanently degrade the resource. NJDEP regulations (N.J.A.C. 7:19-8) allow the creation of "areas of critical water supply concerns." if these criteria apply:

(1) Shortage of surface water due to previous diversions in an area >10 mi^2.
(2) Shortage of groundwater due to diversions exceeding dependable yield in an area >10 mi^2 as shown by:
   a. A lowering of groundwater levels that threatens the supply to existing wells, or
   b. Lowering of groundwater levels in a confined aquifer so that the -30' elevation contour is within five miles of salt water or intersects the 250 ppm chloride isochlor, or

c. Lowering of groundwater levels in an unconfined or semi-confined aquifer so that the 0' elevation contour is within five miles of salt water or intersects the 250 ppm chloride isochlor.

(3) Significant groundwater contamination may reasonably be expected to affect a significant portion of the aquifer.

A key component to this approach is that before ordering any pumping reductions NJDEP must prepare alternate-water-supply strategies that identify how to compensate for reductions in groundwater withdrawals. This may include water conservation measures to reduce demand, alternate water sources in the area, or regional water-supply projects.

Location & Geology

NJDEP has created two water supply critical areas in New Jersey. Water Supply Critical Area No. 1 (CA1) is in northeastern NJ coastal plain and covers parts of Middlesex, Monmouth and Ocean counties. (fig. 1). The composite depleted zone covers about 740 mi^2. The composite threatened margin covers an additional 160 mi^2. CA1 was implemented in conjunction with construction of the Manasquan Reservoir in Monmouth County which supplied surface water to make up for the reductions in groundwater withdrawal (Whipple, 1987). The second, CA2, is in the west-central NJ coastal plain and was implemented in conjunction with a new intake on the Delaware River.

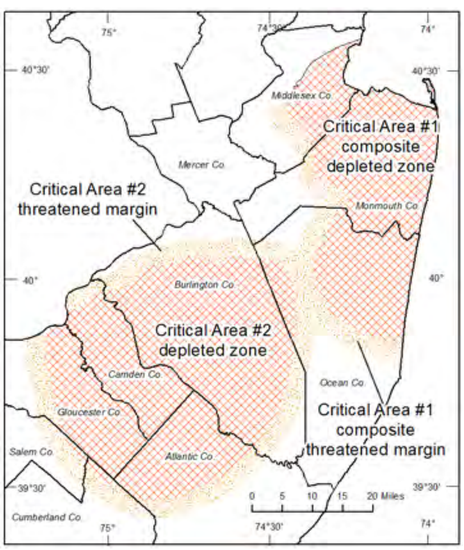


Figure 1. New Jersey water supply critical areas.

The Coastal Plain is underlain by a series of unconsolidated units dipping and thickening to the southeast (fig. 2). These have been mapped extensively over the past century. Increasing understanding of the area's stratigraphy, along with geologic models of depositional environments and detailed analysis of cores, has allowed for finer definition of observed units. In contrast, a water-supply point of view combines many of the water-bearing units into a smaller number of aquifers with a general lumping of non-water-bearing units into confining units (table 1).

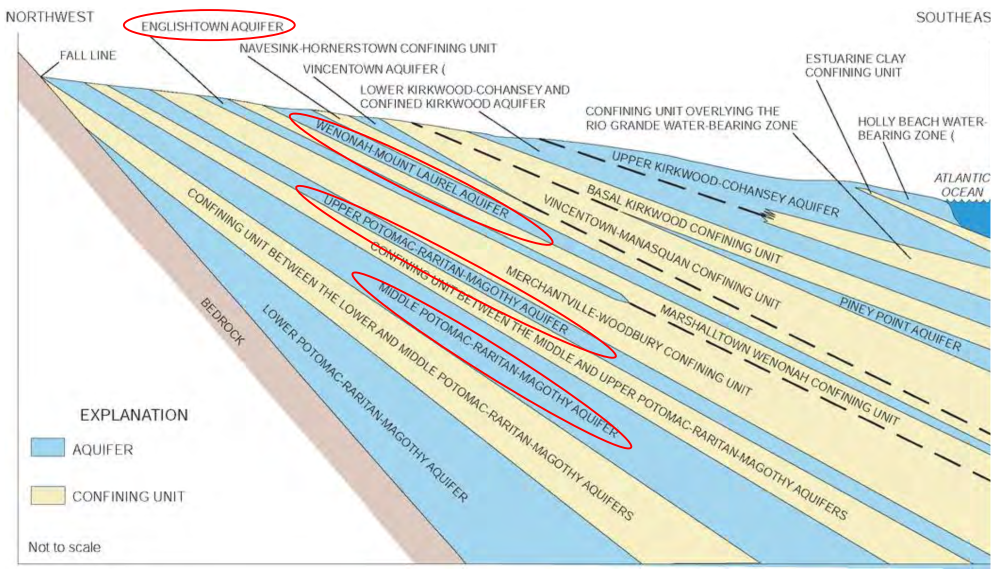


Figure 2. Generalized cross section of New Jersey Coastal Plain.

The aquifers regulated in CA1 are the Wenonah-Mt. Laurel aquifer (a combination of the Wenonah Formation and the Mt. Laurel sand), the Englishtown aquifer, Old Bridge aquifer (a water-bearing unit within the Magothy Formation, the upper portion of the Potomac-Raritan Magothy unit), and the Farrington aquifer (a water-bearing unit within the Raritan Formation, the middle portion of the Potomac-Raritan Magothy system). All units are upper Cretaceous in age.

Table 1. Surface to subsurface correlation of Critical Area No. 1 aquifers in New Jersey's northeastern Coastal Plain.

Formation[1]		Aquifer Name
Surface	Subsurface	
Wenonah	Kc3 cycle	Wenonah-Mt. Laurel
Mt.Laurel		
Englishtown	Kc1 cycle	Englishtown
Magothy (upper PRM[2])	Magothy	Old Bridge
Raritan (middle PRM[2])	Raritan	Farrington

1. From Owens and others, 1999.
2. PRM – Potomac-Raritan-Magothy formation

Threat to Water Supply

The population of the New Jersey's northeastern coastal plain was almost entirely dependent on groundwater supplies before 1990. The prolific aquifers underlying the area were able to meet demands. However, the withdrawals did create significant drawdowns. In the centers of the cones of depression groundwater levels were -185' (relative to sea level) in the Wenonah-Mt. Laurel aquifer, -240' in the Englishtown aquifer, -56' in the Old Bridge aquifer, and -82' in the Farrington aquifer (Battaglin and Hill, 1989). Additionally, the Old Bridge aquifer crops out under the saline Raritan Bay. Significant saltwater intrusion into the Old Bridge had created high levels of chloride in the wells serving the Key Port and Union Beach area on the south side of Raritan Bay (Schaefer and Walker, 1981).

NJDEP expected future demand increases to exacerbate these problems. A simulation of groundwater levels in the year 2000, assuming an unregulated increase in withdrawals, predicted water levels in the center of the cones depression would be -350' in the Wenonah-Mt Laurel aquifer, -420' in the Englishtown aquifer, -126' in the Old Bridge aquifer, and -126' in the Farrington aquifer (Battaglin and Hill, 1989).

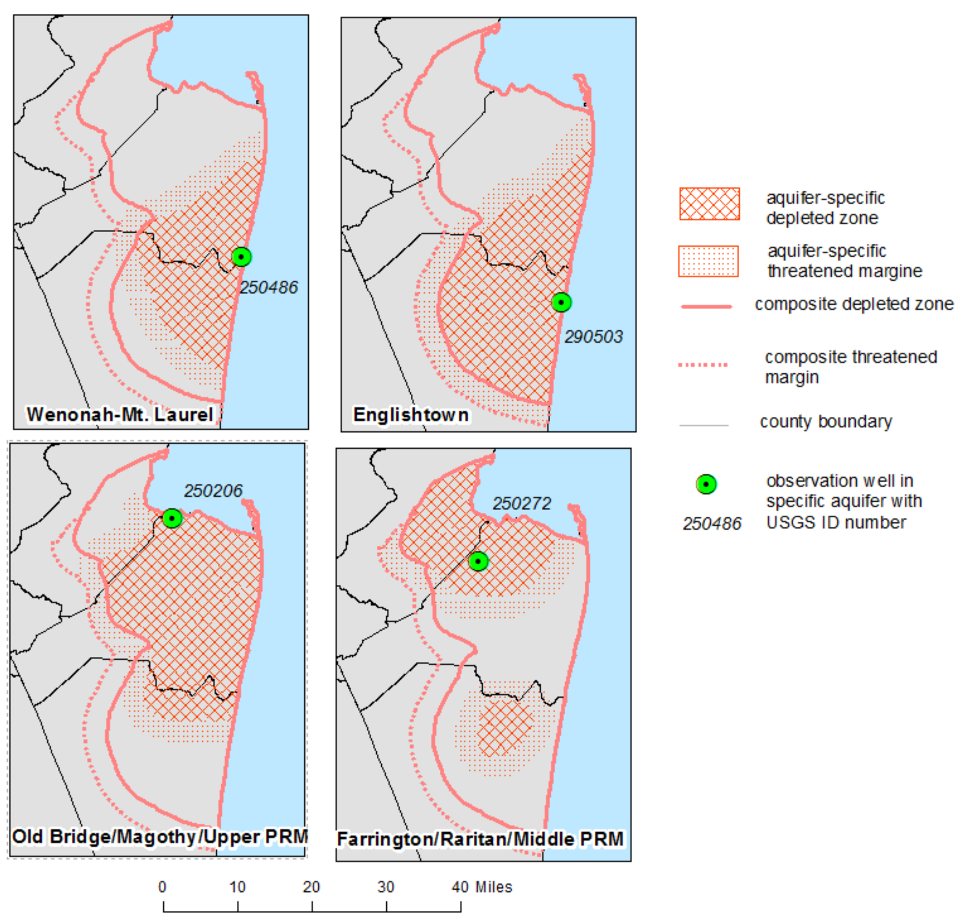


Figure 3. Critical Area 1 aquifer-specific depleted zones and threatened margins.

These observed and predicted problems led the NJDEP to declare a water supply critical area in order to protect the groundwater resources and preserve them for future use.

Depleted Zones and Threatened Margins

Each aquifer in CA1 has a different depleted zone and threatened margin (fig. 3). The depleted zone was initially defined by that area in each aquifer in which ground-water levels were at or lower than 30' below mean sea level in 1983 (Eckel and Walker, 1986) The threatened margin is a 3-mile-wide buffer zone outside of the depleted zone. The joint surface expression of all four forms the composite depleted zone and composite threatened margin.

Pumping Reductions

NJDEP arrived at the ordered pumping reductions in each aquifer in CA1 through a groundwater modeling effort. At NJDEP's request, the U. S. Geological Survey (USGS) simulated expected drawdown due to pumpage increases to support regional growth. In the Farrington aquifer the initial aquifer-specific depleted zone was centered near Raritan Bay (fig. 3). The simulation effort showed that anticipated future pumpage from the Farrington Aquifer in northern Ocean County would create a cone of depression that would fit the criteria for declaring a water supply critical area. This modeling insight led NDJEP to create a second depleted zone and threatened margin for the Farrington aquifer.

The modeling process also showed that anticipated future withdrawals from the Potomac-Raritan-Magothy aquifer system in the Camden area would create a drawdown cone that would propagate into the northeastern coastal plain. This additional drawdown would reverse some of the recovery created by reduction of withdrawals in CA1. This insight helped support the creation of Water Supply Critical Area No. 2 (CA2) which applies to all water-bearing units in the Potomac-Raritan-Magothy aquifer system in all of Camden County and parts of Gloucester, Salem, Cumberland, Atlantic, Burlington, Monmouth and Ocean counties (fig. 1). CA2 was implemented during the 1990's as surface water from a new intake on the Delaware River became available.

Aquifer	Pumpage as a percentage of 1983 rates	
	Depleted Zone	Threatened Margin
Wenonah-Mt. Laurel	50%	100%
Englishtown	50%	100%
Old Bridge	60%	100%
Farrington	50%	100%

From Whipple, 1987.

Table 2. Aquifer-specific pumpage reductions in Water Supply Critical Area No. 1.

NJDEP selected a range of cutbacks that balanced an initial guess at the reductions needed to create sufficient recovery with how much water would be available from alternate sources. This led to USGS simulations assuming withdrawal rates in the depleted zone of each aquifer were reduced to 70%, 60% and 50% of 1983 rates (Battaglin and Hill, 1989). In the threatened margin of each aquifer withdrawal rates were simulated as being held constant at 100% of 1983 rates. NJDEP determined that in order to adequately protect the groundwater resource in the future withdrawals in the depleted zone had to be reduced to either 50% or 60% of 1983 rates, depending on the aquifer (table 2).

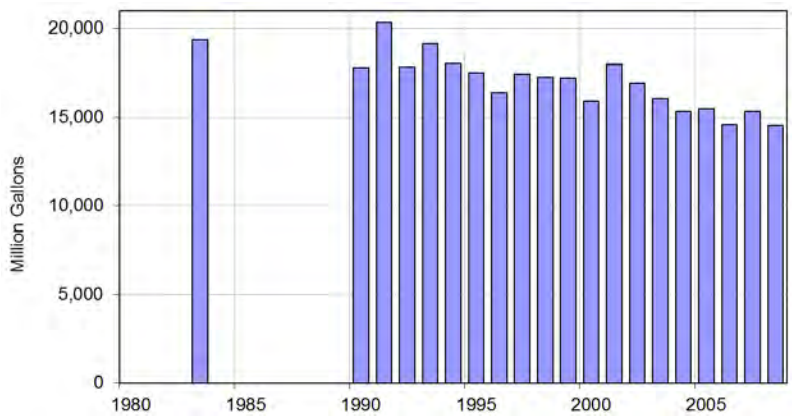


Figure 4. Withdrawals from aquifers in Water Supply Critical Area No. 1

Withdrawals in the affected areas of CA1's four regulated aquifers are estimated to have been 19,370 million gallons in 1983 (Battaglin and Hill, 1989). Withdrawals peaked a bit over 20,000 mg in 1991 but declined to about 14,500 mg in 2008, the latest year for which withdrawal data are available by critical area (S. Domber, NJDEP, written communication, 2011). This represents a total reduction in withdrawals of about 25% from the regulated aquifers in CA1.

Water-Level Recoveries

CA1 was implemented from approximately 1990 – 1995. Purveyors compensated for ordered withdrawal reductions by pumping other aquifers, switching to local surface-water sources, purchasing water from other purveyors, or by using surface water from the new Manasquan Reservoir.

The reduced pumpages has had a significant positive impact on groundwater levels in the four regulated aquifers of CA1. Figure 5 shows hydrographs from selected USGS observation wells in each aquifer. (Well locations shown on fig 3.) About 150 feet of recovery is seen in the Wenonah-Mt. Laurel and Englishtown wells, about 20 feet in the Old Bridge well, and about 50 feet in the Farrington well.

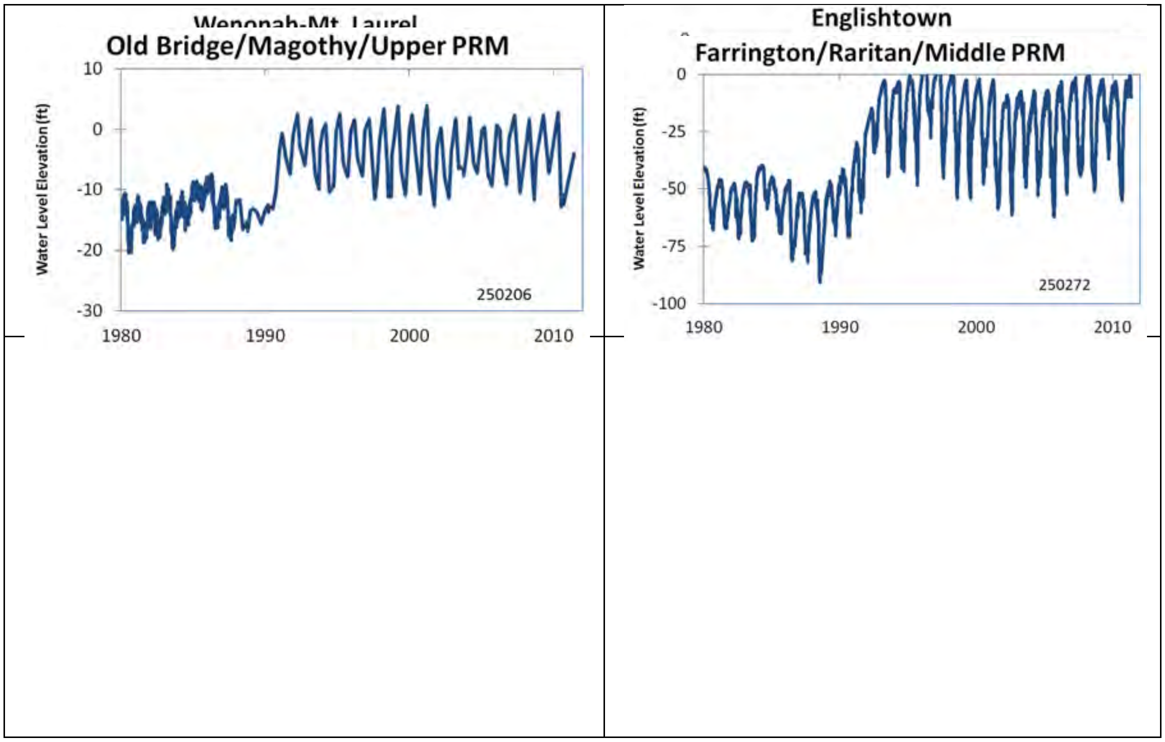
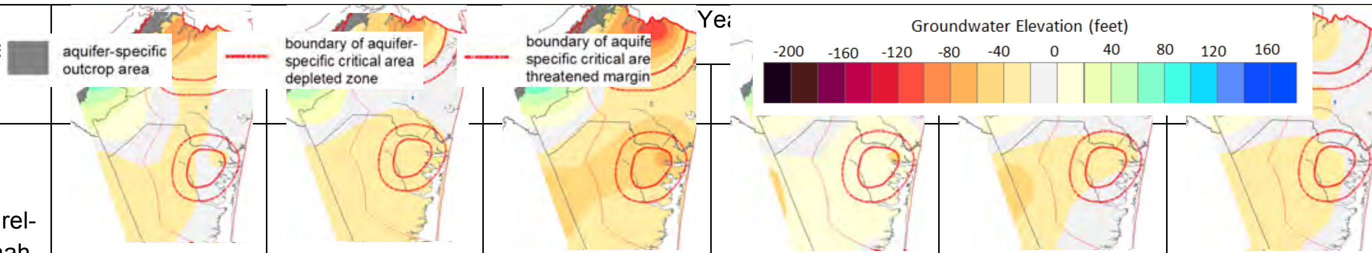


Figure 5. Hydrographs for regulated aquifers of Water Supply Critical Area No. 1, 1980-2011 (data from US Geological Survey, http://groundwaterwatch.usgs.gov, accessed 7/25/2011)

The U.S. Geological Survey conducts a synoptic observation of groundwater levels in the aquifers of New Jersey's coastal plain every five years. Figure 6 is a summary of water levels in 1978, 1983, 1988, 1993, 1998, and 2003. Groundwater elevations along the southern and southwestern borders of the displayed plots are estimated based in order to allow the GIS software to create a colored representation of the values. However, in the core of the drawdown areas figure 6 accurately displays reported water levels.

NJDEP has recently funded simulations of potential impacts of additional withdrawals from the regulated aquifers. Evaluation criteria included the area within the -30' potentiometric line in each aquifer and changes in the rate of salt-water intrusion. Results show that it may be possible to withdrawal additional water from these aquifers without significantly increasing the risk to the resource but this would require relocating new and existing pumpage away from the deepest cones of depression and away from current salt-water intrusion (Spitz and others, 2008; Spitz, 2009). Engineering and regulatory obstacles to relocating well fields may prevent significant additional withdrawals from CA1.



Aquife			Yea			
Mt. Laurel-Wenonah						
English-town						
Old Bridge/ Magothy/ upper PRM						
Farrington /Raritan/ Middle PRM						

key
:

Figure 6. Observed groundwater levels in regulated aquifers of Water Supply Critical Area No. 1, 1978-2003. (Water levels adapted from: a-Walker, 1983; b-Eckel and Walker, 1986; c-Rosman and others, 1995; d-Lacombe and Rosman, 1997; e-Lacombe and Rosman, 2001; f-DePaul and others, 2009)

Conclusions

Pumping reductions in New Jersey's Water Supply Critical Area No. 1 have created dramatic water-level recoveries. The availability of an alternate surface-water source allowed a 25% decrease in groundwater withdrawals from the Wenonah-Mt. Laurel, Englishtown, Old Bridge, and Farrington aquifers in the northeastern coastal plain. As a result groundwater levels recovered as much as 150 feet. This increase has greatly diminished the potential for saltwater intrusion and proven the success of the water supply critical area approach.

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Teachers' Workshop: Challenging Common Misconceptions in Earth and Environmental Science

Jane Alexander, Ph.D.
College of Staten Island/CUNY

When students enter college, it's not their lack of knowledge that causes the most problems, but the things they think they know but are wrong about. Once they have a misconception, it can be a barrier to learning anything that runs contrary to what they believe to be true. In order to understand these barriers in my students, I started to survey them at the beginning of the semester on topics that I plan to cover. This revealed some misconceptions that are common in students leaving grade school. Children encounter many teachers both in and out of school, but if we can demonstrate with simple, memorable classroom experiments the correct explanations in earth and environmental science, then any misinformation may more easily be discarded.

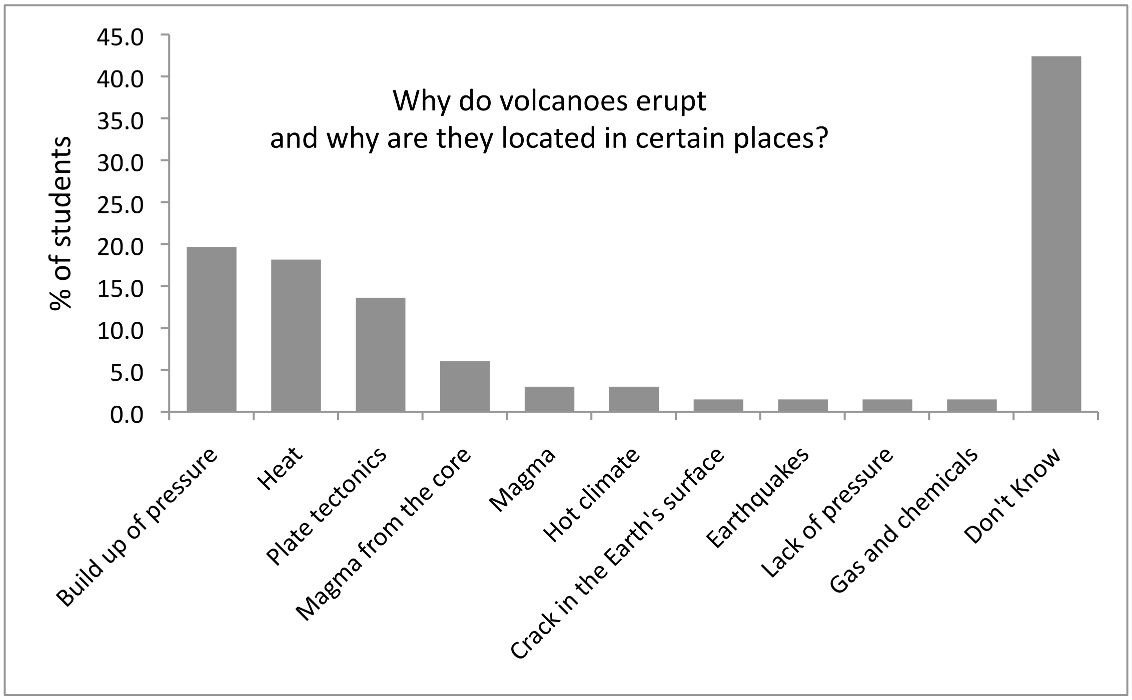
This workshop will cover four areas where misconceptions are commonly encountered and some activities that may help to improve student understanding.

1. How rocks melt and why volcanoes form
2. Resources used to produce electricity
3. Causes of human induced climate change
4. What happens to our garbage

1. Why do volcanoes erupt and why are they located in certain places?

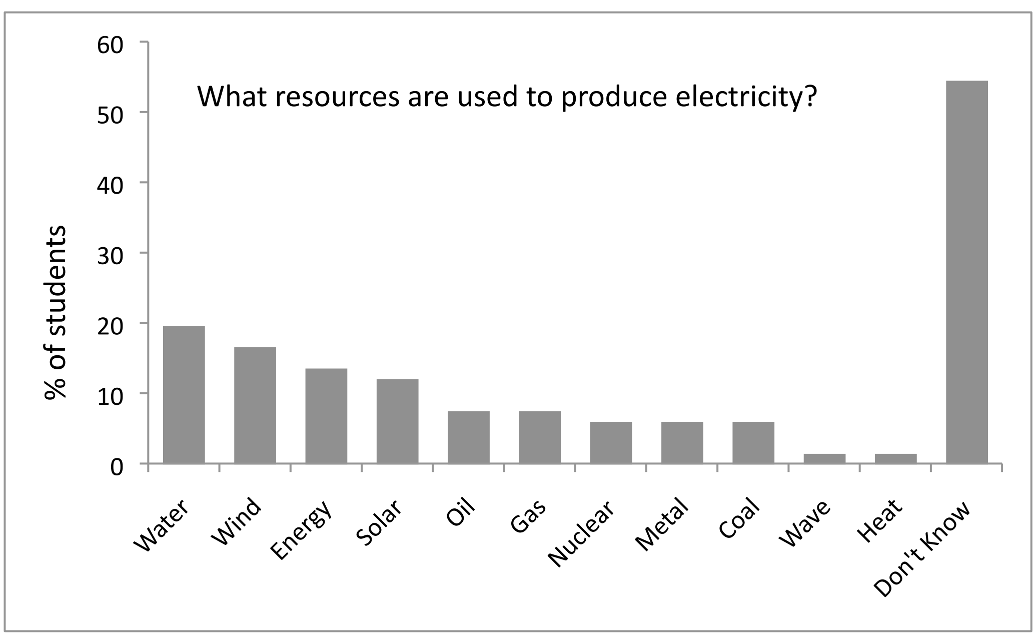
Many students realize that volcanoes are associated with heat, or that pressure builds up before an eruption. However, fewer make any connection with plate tectonic processes, and some believe that the lava comes from the Earth's core, or that the heat is due to a warm climate. Almost half could provide no answer.

We will explore some activities that map the locations of volcanoes, the different types of volcanoes, and factors that affect the temperature at which rocks melt. We will also do an experiment that illustrates how wet sugar cubes melt at a lower temperature than dry ones, to reinforce the importance of water in the melting process at subduction zones.



2. What resources are used to produce electricity?

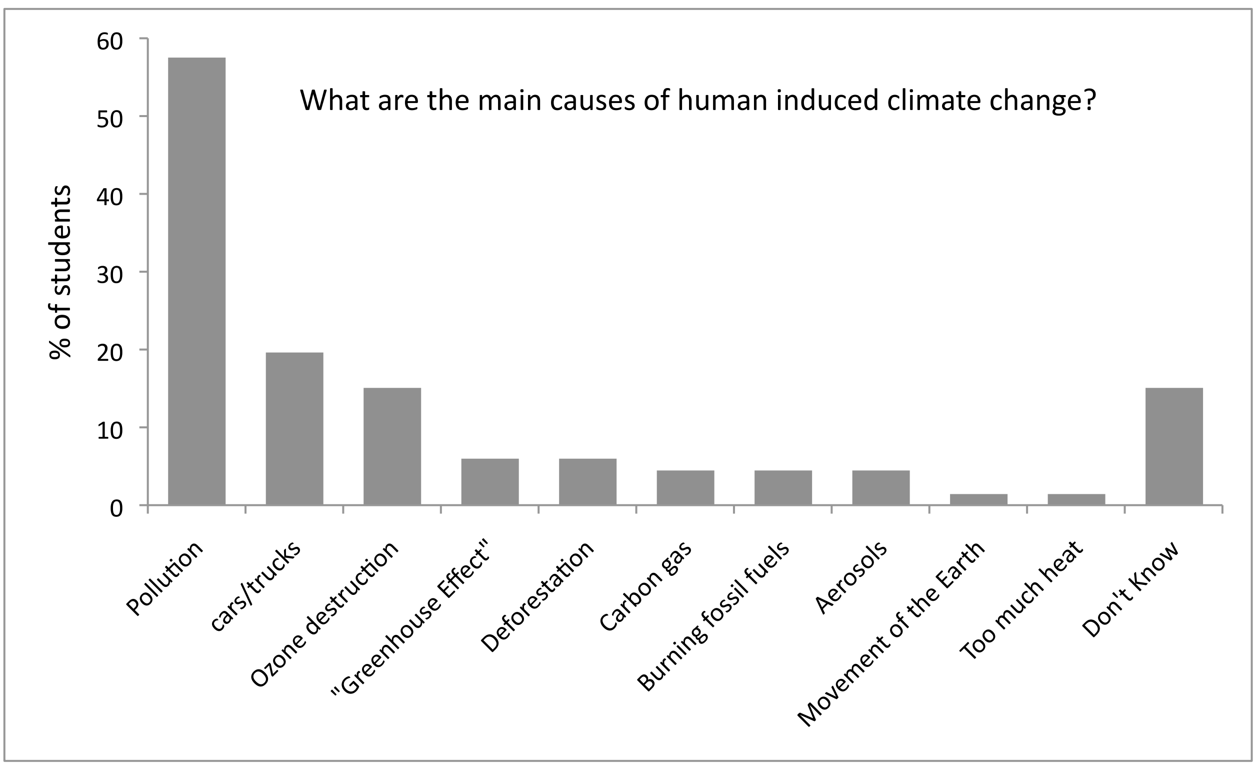
A surprisingly small number of students have any understanding of how we produce electricity. Most simply do not know, but those who did provide an answer think that we have solved the energy crisis and are using non-fossil fuel resources, such as hydro and wind power. Less than 10% of students mentioned coal, which is currently used to produce almost half of all electricity in the US.



We will look at a small experiment with a simple dynamo that demonstrates the necessity to turn a turbine to produce electricity. From there, students can explore how different resources can be used to achieve this. We will look at sources of data that can be used to investigate how this is done in the US and make comparisons with other nations worldwide.

3. What are the major causes of human induced climate change (sometimes called global warming)?

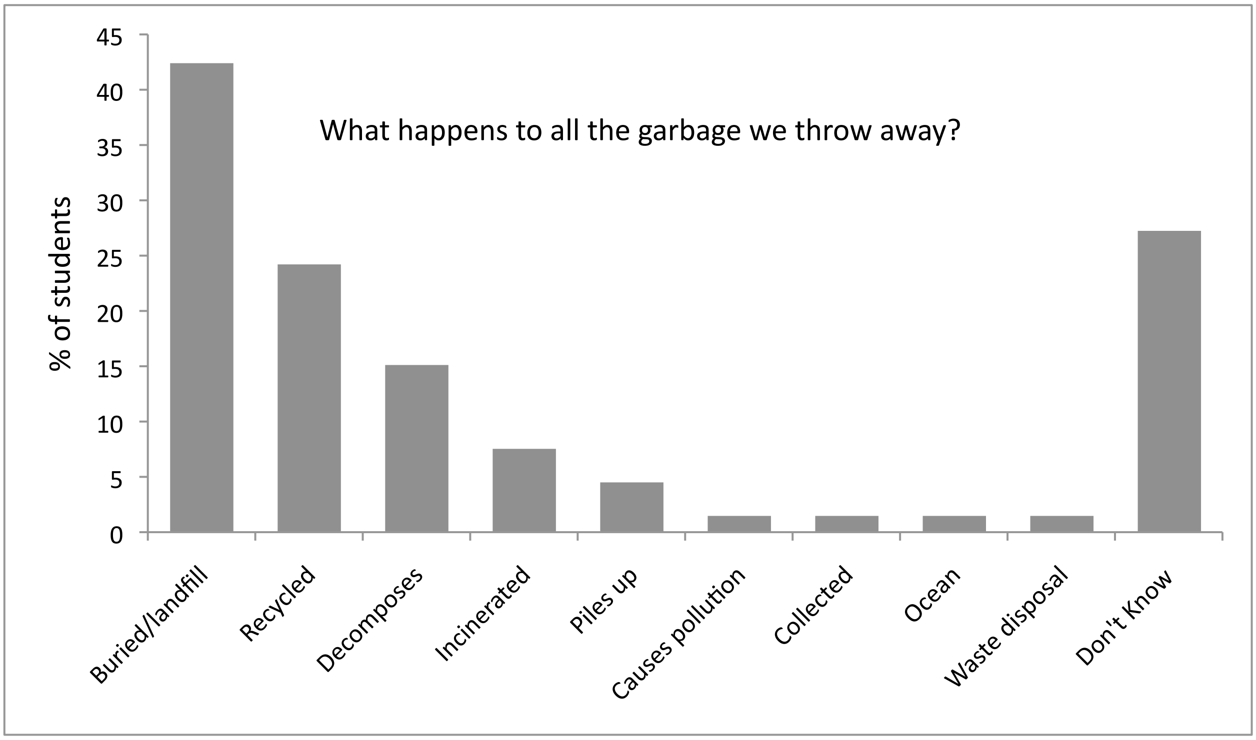
Given the prominence of "global warming" in politics and the media, it is incredible how little understanding students have of its causes. Although most realize that it has something to do with pollution, and that vehicles bear some of the responsibility, few mention carbon or greenhouse gases. In fact, more (15%) wrongly attribute the problem to ozone destruction. This, coupled with the fact that few realize how much coal we burn, means that a lot of misconceptions have to be dealt with before we can discuss the true processes influencing global temperature.



We will perform a simple experiment that illustrates how carbon dioxide acts as a greenhouse gas, and investigate an online exercise produced by NASA that allows older students (high school) to model the Earth's climate with and without an atmosphere, and to vary the quantities of greenhouse gases in the atmosphere. We will also look at sources of data available for investigating recorded changes in atmospheric chemistry.

4. What happens to all the garbage we throw away?

Teaching on Staten Island, it is no surprise that most students know that our garbage is buried in a landfill. Many are also aware that a lot of our waste is now recycled. However, almost a third have no idea what happens to their garbage and a significant minority (15%) believe that it simply decomposes "and returns to the soil".

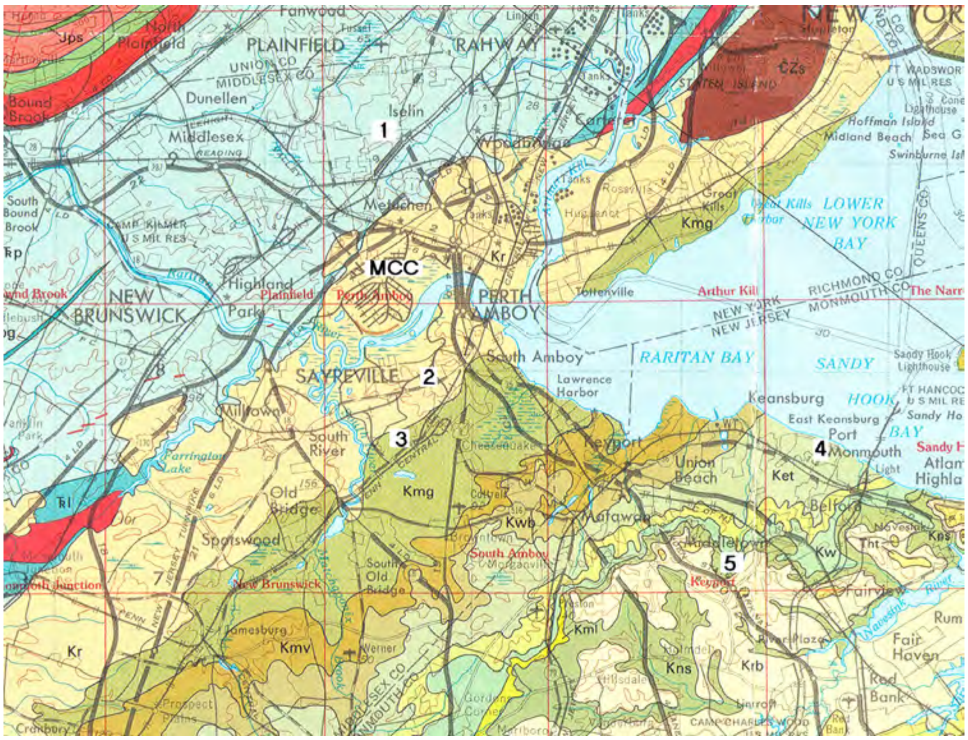


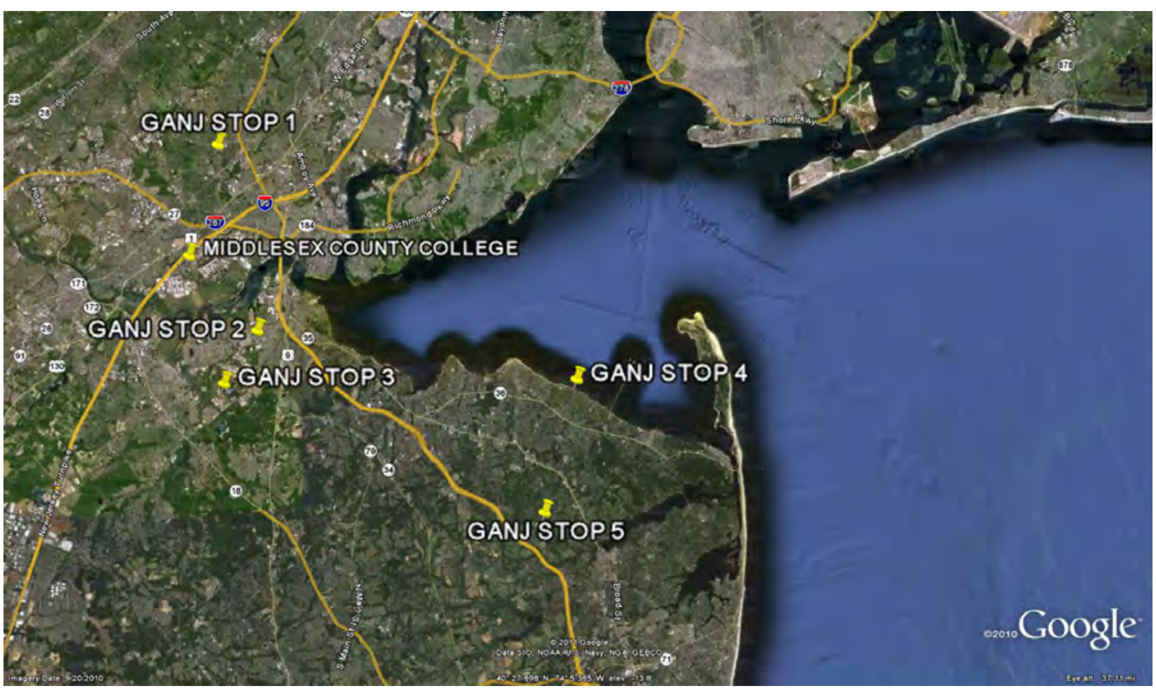
We will investigate sources of information about what happens to our garbage, and how landfills operate, including how to go about visiting one on a fieldtrip. We will see how to find out how much waste is recycled and incinerated, and how to compare this with other countries around the world. We will also set up an experiment (one that can last weeks, months, or even years) that will demonstrate what types of waste decompose and what will be around for a much longer time.

In conclusion, there are many short activities that will help to dispel these common misconceptions amongst students. After a brief introduction, participants in the workshop will be able to walk around the room and investigate the experiments and suggested activities that are most relevant or interesting to them.

Road Log

Alan Uminski





8:00 to 8:15 a.m.—Middlesex County College to Stop 1 5.5 mi, 14 mins
1. Turn right onto Co Rd 514 0.6 mi
2. Right lane Jug Handle to Turn left onto County Rd 531 N/Main St 2.0 mi
3. Turn right onto Middlesex Ave 0.6 mi
4. Turn left onto Grove Ave 0.5 mi
5. Keep left at the fork 0.6 mi
6. Turn right onto Calvert Ave E 0.5 mi
7. Turn left onto Elizabeth Ave 0.1 mi
Arrive 8:15 to 8:30 am

Stop 1-Passaic Formation (Triassic) and Rahway Till (late Pleistocene)
Coppermine Brook Outcrops
N 40° 33.959 W 074° 20.866

Field Stop Leaders: Bob Bond, P.G. and Kevin Kelly, Langan Engineering & Environmental Services

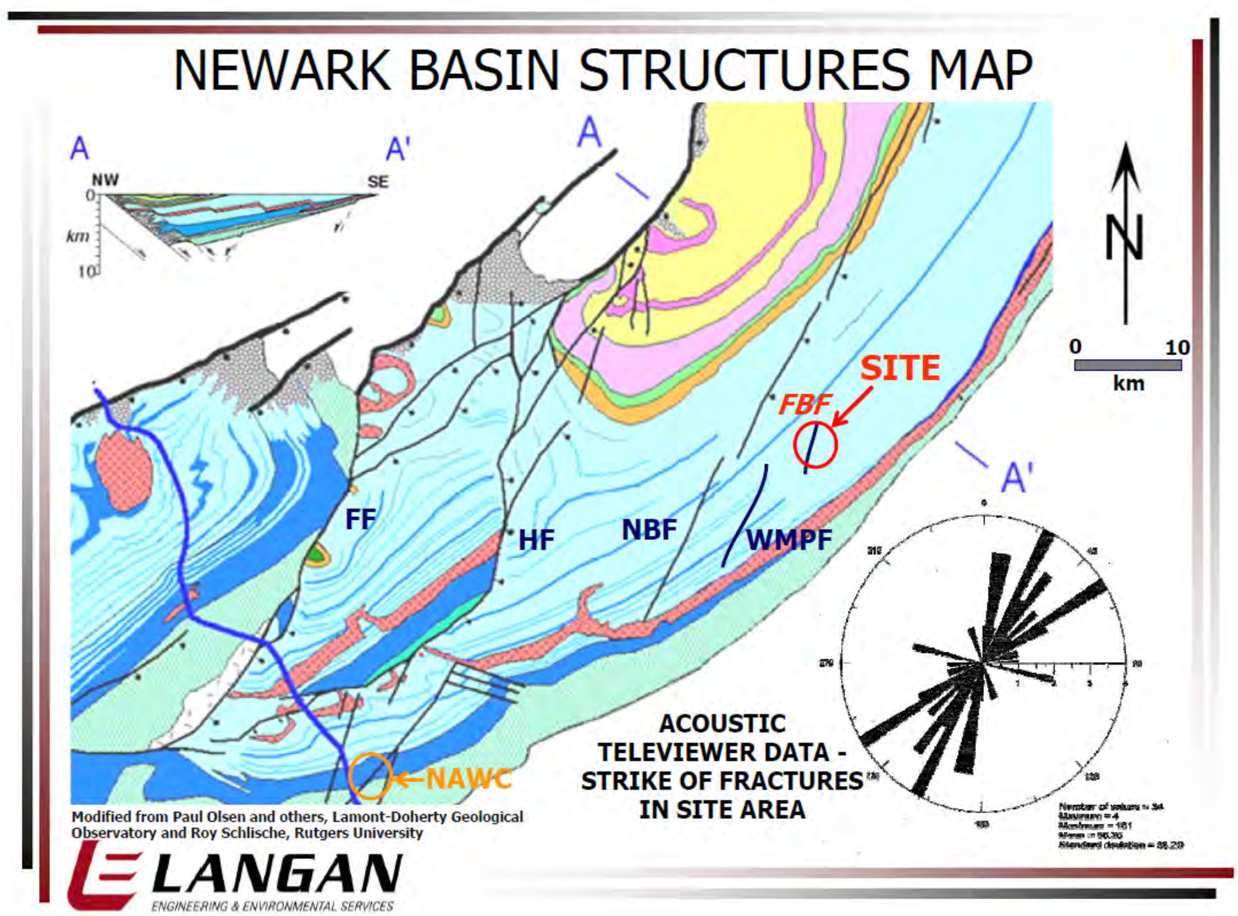
This location features fractured bedrock shale, siltstone and mudstone of the Passaic Formation. Bedrock in the study area is covered by till, outwash deposits, and the terminal moraine of the Wisconsinan glaciation. The outcrop furthest to the west along the brook features the Rahway Till, which is composed of silty sand to sandy silt with subrounded pebbles, cobbles and a few boulders, and is located approximately 1,500 feet behind (northeast) the terminal moraine deposits. The Passaic Formation is subdivided into many members, which are laterally extensive and can be traced by color and magnetic signature throughout much of the Newark basin. The Kilmer member and T-U members of the Passaic Formation are exposed in the outcrops along the Coppermine Brook. The bedrock strikes on average north 51 degrees east (N51E) and dips 10 degrees to the northwest. Rectangular jointing is observed in all outcrops, with the major partings along bedding planes and vertical joints perpendicular to bedding. The spacing of vertical joints in the outcrops ranges from a few inches to a foot. The predominant joint direction averages north 42 degrees east, with a steep dip ranging from 51 degrees southeast to 78 degrees northwest. The second most predominate joint direction averages north 53 degrees west, with a steep dip ranging from 71 degrees southwest to 86 degrees northeast.

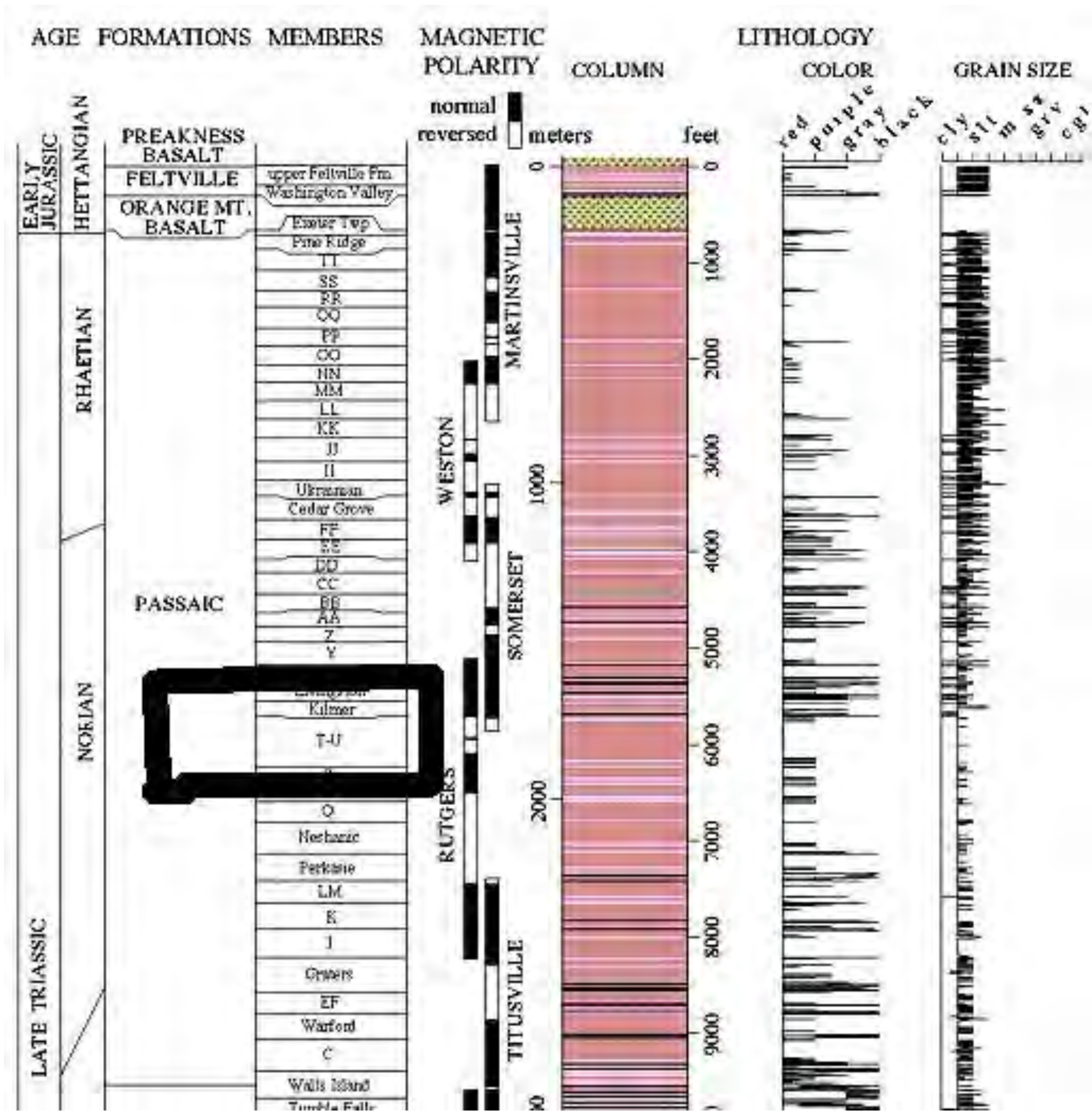
Many exposed surfaces of the Passaic Formation have black manganese oxide coatings as well as light gray color clay minerals along bedding planes and near vertical joints. Fracture walls and root casts observed in these outcrops are also commonly bleached, from red to tan, because of the reduction of ferric iron (hematite) and partial leaching of ferrous iron.

<u>Depositional Environment</u>
The Passaic Formation was derived from freshwater lakes and alluvial fan deposits resulting from the rifting of Pangea. The red color is evidence that the sediments were deposited in oxygen rich arid conditions.

Groundwater Flow

The Passaic Formation has minor primary porosity or openings between grains or particles through which, groundwater migrates. Groundwater movement through the Passaic Formation is controlled by secondary porosity including the fractures or openings formed by faulting and along bedding planes.





(modified from Schlische and Olsen)

Passaic Formation outcrop along Coppermine Brook.

Glacial erratic.

9:30 Board Bus, depart for Stop 2 (10.4 mi, 19 mins)
1. Head southwest on Elizabeth Ave 0.1 mi
2. Turn left onto Calvert Ave E 0.3 mi
3. Take the 2nd right onto Dellwood Rd 0.4 mi
4. Turn left onto NJ-27 N 0.7 mi
5. Turn right onto County Rd 649/S Wood Ave 0.6 mi
6. Keep right at the fork, follow signs for US-1 and merge onto Garden State Pkwy S 6.1 mi
7. Take exit 124 for Main St toward Sayreville/S Amboy 0.2 mi
8. Turn left onto County Rd 670/Main St 0.2 mi
9. Take the 1st right onto Washington Rd 1.3 mi
10. Kennedy Park will be on the Right 0.4 mi

Stop 2 - Magothy Formation (Late Cretaceous)
Kennedy Park –Sayreville
N 40° 27.947 W 074° 19.165

Field Stop Leader: John Jengo, MWH Global Inc.

At the time of Cook and Smock (1878), this location and the expansive clay pit just north of here across the Raritan River Railroad, were part of the George Such Clay Works; by 1904, these clay banks were being worked by J.R. Crossman. These clay banks were among the largest operations between Sayreville and South Amboy for extracting the various clay facies of the South Amboy Fire Clay, which was utilized primarily for the production of fire brick, with less refractory clays being sold for production of alum, wall plaster, paper manufacture, and other uses. The South Amboy Fire Clay is a geotechnically stiff to hard, massive to laminated, white, light-blue to gray and red-mottled (which often turns brown on exposure), somewhat lignitic clay, with occurrences of disseminated pyrite, pyritic logs, so-called "sulphur balls" (round aggregations of pyrite crystals), and pieces of amber (Owens et al., 1977; Sugarman et al., 2005). Lithologic and grain size analyses samples of the South Amboy Fire Clay obtained from a site just south of this location indicated a predominantly micaceous clayey silt, sandy clayey silt, silty clay, and sandy silty clay that contained lignite and marcasite, with intervals of silty fine-grained sand (Jengo, 1995). The Such-Crossman clay banks were historically notable because the extended area of excavation revealed a noticeably irregular upper surface of the South Amboy Fire Clay, reflecting the cut-and-fill channel scouring and deposition of the overlying Old Bridge Sand. As a consequence, thickness of the unit varied widely depending on location, and even the maximum thickness of 30 feet referenced in the historic literature included interbedded sands that subdivided the South Amboy Fire Clay into locally distinguishable units.

Exposed on the higher elevation surfaces, are the well rounded quartz gravels of the Pennsauken Formation.

Geologic And Hydrogeologic Units Of The Magothy And Raritan Formations

System	Geologic Unit		Lithology	Hydrogeologic Unit	
Cretaceous	Magothy Formation	Cliffwood Beds	Sand, quartz, light-gray, fine- to coarse-grained; local beds of dark-gray lignitic clay	Potomac – Raritan – Magothy Aquifer System	Confining Unit
		Morgan Beds			
		Amboy Stoneware Clay Member			
		Old Bridge Sand Member			Upper Aquifer [1]
	Raritan Formation	South Amboy Fire Clay Member	Sand, quartz, light-gray, fine to coarse-grained, pebbly, arkosic, red white and variegated clay, and saprolitic clay developed on bedrock.		
		Sayreville Sand Member			Confining Unit
		Woodbridge Clay Member			
		Farrington Sand Member			Middle Aquifer
		Raritan Fire Clay			Confining Unit
Pre-Cretaceous	Bedrock		Precambrian and lower Paleozoic crystalline rock, metamorphic shist and gneiss; locally Triassic, sanstone, shale and Jurassic basalt.	Bedrock Confining Unit	

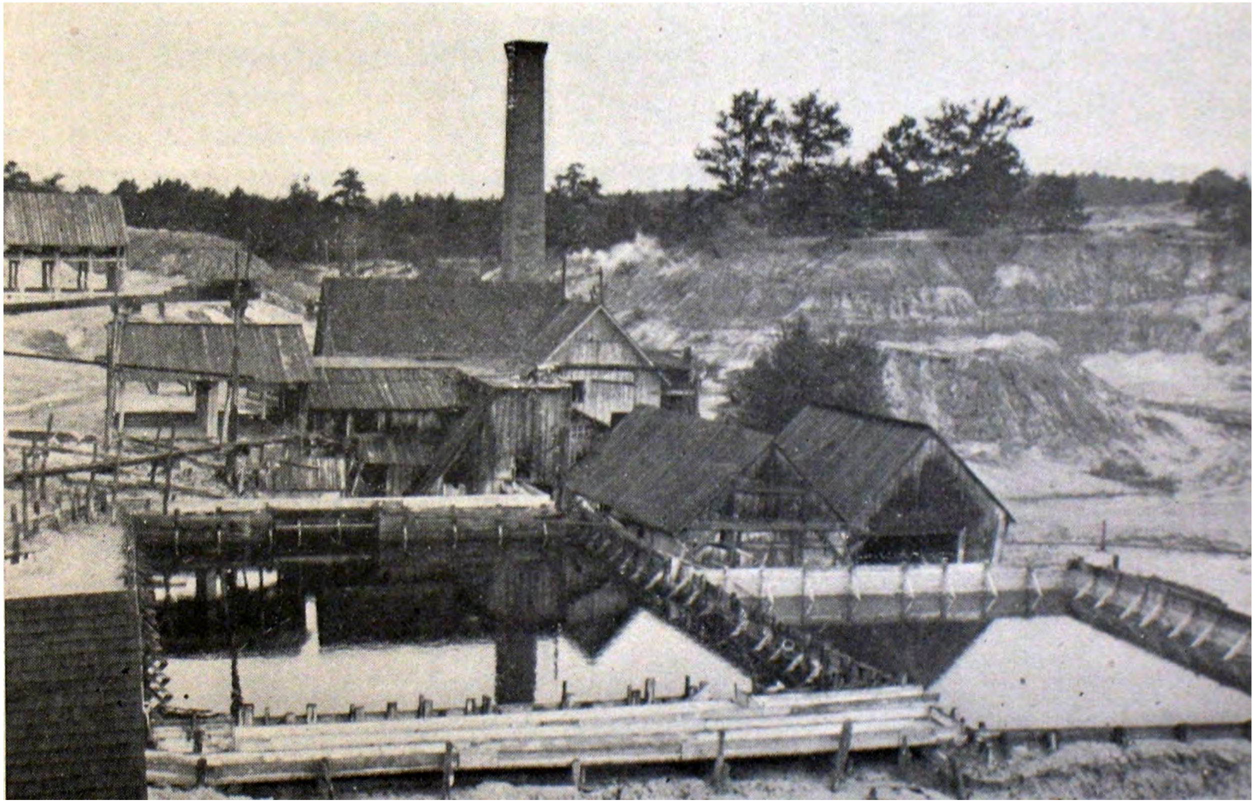
Pucci, 1989

Economic Resources

The development of the Sayreville area clay and sand deposits of the Raritan and Magothy Formations that commenced in the early 1800s transformed the landscape in this area. Kennedy Park and the former J.R. Crossman Pit just north of this area were some of the more extensive excavations south of the Raritan River. This area was renowned by the late 1800s for the quality and variety of its clay resources, and for its wide-ranging uses (pottery, common brick, fire brick, tiles, piping, ceramics, paint fillers, among many other applications). By 1878, there were eight Raritan River brickyards turning out 54,000,000 bricks annually. The largest of these was the Sayre & Fisher works founded in 1850 by James Sayre of Newark, and Peter Fisher of New York. Soon, they owned 2,000 acres of prime clay beds in the vicinity, and the town changed its name from Wood's Landing (named after an earlier brick maker) to Sayreville. (http://www.sayre-fisher.com)

Kennedy Park, site of the former Such and Crossman clay works.

Sayreville, circa 1890 (Sayreville Historical Society)



J.R. Such Washing Plant and Clay Works circa 1900

Paleontology

Well preserved insect-bearing amber deposits, and fossil flora and fauna have been discovered in the former clay bank excavations north of Kennedy Park. Insects of many varieties have been found in the amber and other plant material, including fossil flowers, have been found in the clay deposits.

http://www.sunstar-solutions.com/sunstar/Sayreville/Kfacies.htm

Regional Hydrogeology

The unconsolidated coastal plain sediments underlying the area comprise the Potomac-Raritan-Magothy (PRM) aquifer system. The upper PRM aquifer, which subcrops through this area, includes the Old Bridge Sand and the Sayreville Sand informal members of the Magothy Formation, and can reach thickness of over 100 feet. The Woodbridge Clay, which underlies the Sayreville Sand, comprises the middle/upper PRM confining unit and ranges in thickness from 50 to 100 feet in the vicinity of its outcrop area. The Farrington Sand informal member of the Raritan Formation comprises the middle PRM aquifer and ranges in thickness from 44 to 104 feet in the vicinity of South River, Sayreville, and Old Bridge. The PRM aquifers in this region are critical public and industrial water supply sources and much of the environmental work in the region is focused on mitigating dissolved phase contaminant impacts to these aquifers.

11:00 Board Bus, depart for Stop 3 (4.8 mi, 10 mins)
1. Exit Park Turn Right on Washington Road Head 2.8 mi
2. Turn Left onto Jernee Mill Rd 2.2 mi
3. Turn Left onto Route 615 Bordentown Ave 0.2 mi
4. Turn left into Sayreville Park
5. Drive .25 miles to last parking lot

Stop 3 - Old Bridge Sand Formation
N 40° 26.234 W 074° 20.631
Field Stop Leader: Scott Stanford, N. J. Geological Survey

The Old Bridge Sand member of the Magothy Formation is the upper aquifer of the Potomac-Raritan-Magothy (PRM) aquifer system in this region. It can be traced downdip into Monmouth County and along strike to the southwest to the Jamesburg-Hightstown area. It is a tidal-delta sand between 80 and 100 feet thick. Upsection, it is overlain by the Amboy Stoneware Clay, the Morgan beds, and the Cliffwood beds (fig. 3-1). These members of the Magothy are carbonaceous clay and silt interbedded with laminated to cross-bedded sand. They were deposited in coastal swamp and muddy intertidal settings. The clay and silt limit the aquifer potential of this upper Magothy sequence. The South Amboy Fire Clay, the basal member of the Magothy, underlies the Old Bridge. It is a carbonaceous, woody clay and silt with lenses of fine-to-medium sand, deposited in a coastal swamp like the upper Magothy members. Thicker sand lenses within and at the base of the South Amboy Fire Clay are known as the Sayreville Sand, which locally is an aquifer but is too thin and discontinuous to map regionally. Below the South Amboy Fire Clay and Sayreville Sand is the Woodbridge Clay member of the Raritan Formation. The Woodbridge is a 100 to 120-foot thick carbonaceous clay and silt, with thin beds of sand, again deposited in a coastal swamp setting. It acts as a confining layer in the PRM aquifer system. The contact between the Raritan and Magothy is an unconformity, marked by gentle erosional topography and, in places, oxidized clays indicating subaerial exposure, at the top of the Woodbridge. The Woodbridge Clay is underlain by the Farrington Sand member of the Raritan Formation. The Farrington is a medium-to-coarse fluvial sand, with some lenses of fine gravel and minor silt and clay. It rests on Newark Basin and Piedmont bedrock in the outcrop belt but overlies sand and clay of the Potomac Formation downdip from outcrop. It is as much as 100 feet thick and is the middle PRM aquifer in this region. Like the Old Bridge Sand, the Woodbridge Clay and Farrington Sand can be traced downdip into Monmouth County and along strike to the Hightstown area. The lower PRM aquifer consists of sands within the Potomac Formation. The Potomac does not crop out in the northern Coastal Plain. It is present in the subsurface downdip from the outcrop belt but is too deep or clayey to be tapped as an aquifer in this region.

This outcrop shows lignitic, micaceous fine-to-medium sand in cross-bedded strata 6 to 8 inches thick. The cross beds are of planar-tabular to low-angle trough form (fig. 3-2). Dark-colored lignitic sand is segregated into thin laminae that highlight the cross bedding. In places, particularly in the westernmost gully farthest from the parking lot, white clay drapes the bedding surfaces in the sand. At the top of the westernmost gully, a thin gray clay caps the sand sequence. This clay may mark the upsection transition to the Amboy Stoneware Clay. The quartz pebbles and ironstone fragments on the top surface of the exposure are lag residues from the Pensauken Formation, a fluvial sand and gravel of Pliocene age that caps the hills and uplands in the Sayreville area.

The thin, stacked, cross-bedded strata, and the clay drapes, are characteristic of tidal-flat deposition. The daily flood and ebb of tidal flows across sandy tidal flats generates sand waves and ripples. As these bedforms migrate under the force of the flows, they leave thin, stacked sets of cross-bedded sand. At high tide when flow stops, suspended mud settles onto the ripples, forming clay drapes. The dominance of sand and scarcity of clay and silt in the Old Bridge indicates that these tidal flats developed either in a deltaic environment with an abundant sand supply from rivers, or on a tide-dominated shallow shelf with sufficient tidal-current velocity to transport clay and silt to deeper water. The abundance of lignite, which is of terrestrial origin, perhaps favors a deltaic setting.

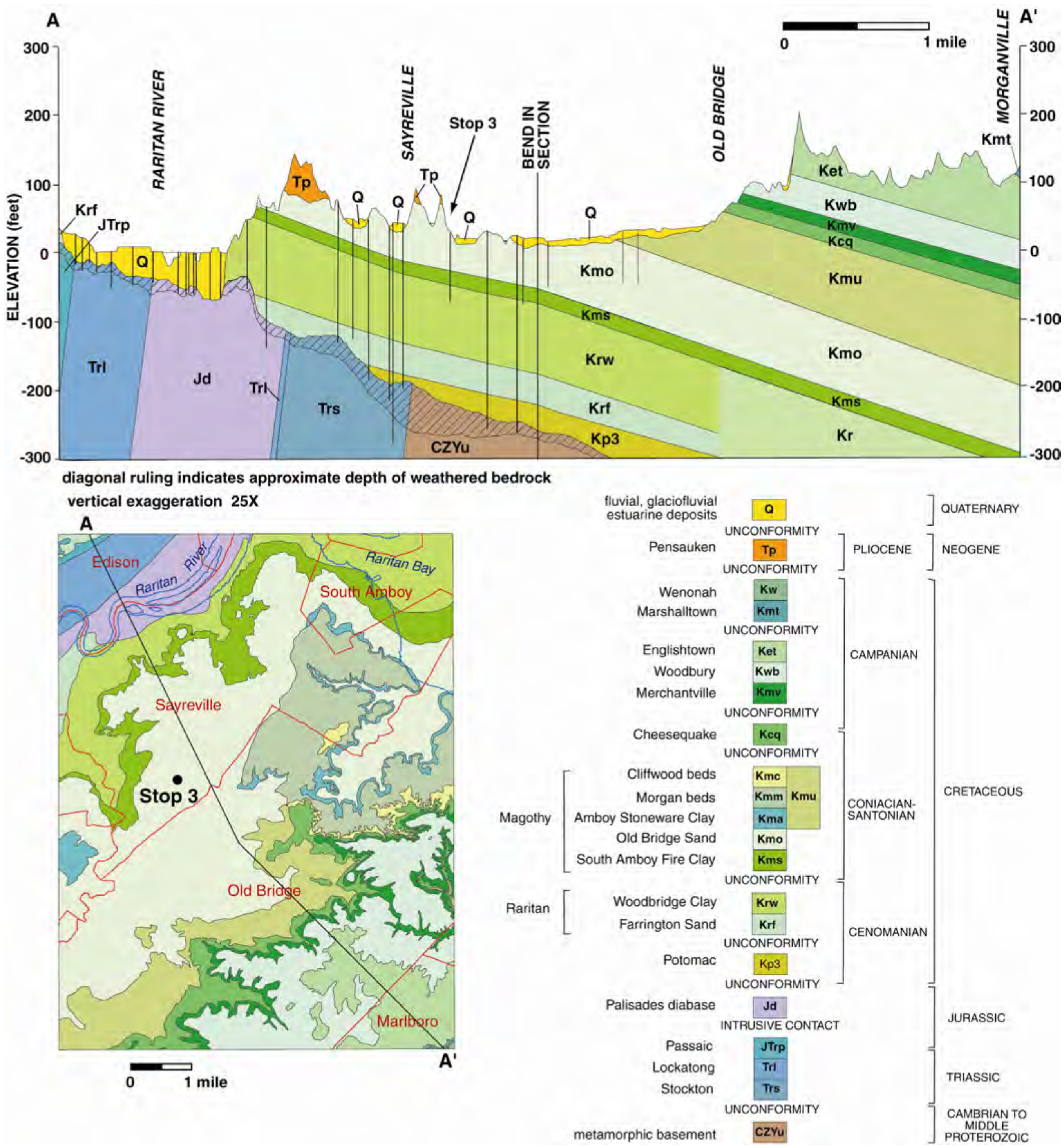


Figure 3-8. Geologic map, section, and stratigraphic column of the Sayreville-Old Bridge area, with location of Stop 3. Modified from Stanford (1993) and Sugarman and others (2005).

Figure 3.9. Stacked sets of cross-bedded sand in Old Bridge Sand, stop 3.

References:

Stanford, S. D., 1993, Surficial geology of the South Amboy quadrangle, Middlesex and Monmouth counties, New Jersey: N. J. Geological Survey Open-File Map OFM 18, scale 1:24,000.

Sugarman, P. J., Stanford, S. D., Owens, J. P., and Brenner, G. J., 2005, Bedrock geology of the South Amboy quadrangle, Middlesex and Monmouth counties, New Jersey: N. J. Geological Survey Open-File Map OFM 65, scale 1:24,000.

12:15 Board Bus, depart for Stop 4 (17 miles/ 35 minutes)
1. Head south toward Jernee Mill Rd 0.2 mi
2. Turn left onto Jernee Mill Rd 0.7 mi
3. Turn left onto Bordentown Ave/County Rd 615 2.8 mi
4. Turn right onto County Rd 673/Ernston Rd 1.8 mi
5. Continue onto Lorraine Ave 0.5 mi
6. Continue onto NJ-35 S 4.4 mi
7. Merge onto NJ-36 S via the ramp on the left to Keansburg/Atl Highlands 5.6 mi
8. Turn Right (jug Handle) onto Main St 0.4 mi
9. Slight left onto Wilson Ave 0.7 mi
10. Turn left onto Port Monmouth Rd Destination will be on the right

Stop 4 - Bayshore Waterfront Park, Port Monmouth NJ
N 40° 26.390 W 074° 05.611

Sea-level Rise Drives Environmental Changes at Bayshore Waterfront Park, Port Monmouth, NJ

Field Stop Leader: Reed A. Schwimmer, Department of Geological, Environmental, and Marine Sciences, Rider University Lawrenceville, NJ 08648

Bayshore Waterfront Park is located on the Raritan Bay shoreline of Port Monmouth (Monmouth County). The park lies between Pews Creek to the NE and Compton Creek to the SE. Most of the nearby land between these two creeks is salt marsh. The salt marsh is divided into two sections by a linear stretch of uplands trending NE (Figures 1 and 2). Most of the houses in this area are built on this upland ridge. Presently, each of the marsh areas are heavily ditched and the main flow of surface water into and out of the marshes is confined to the creeks.

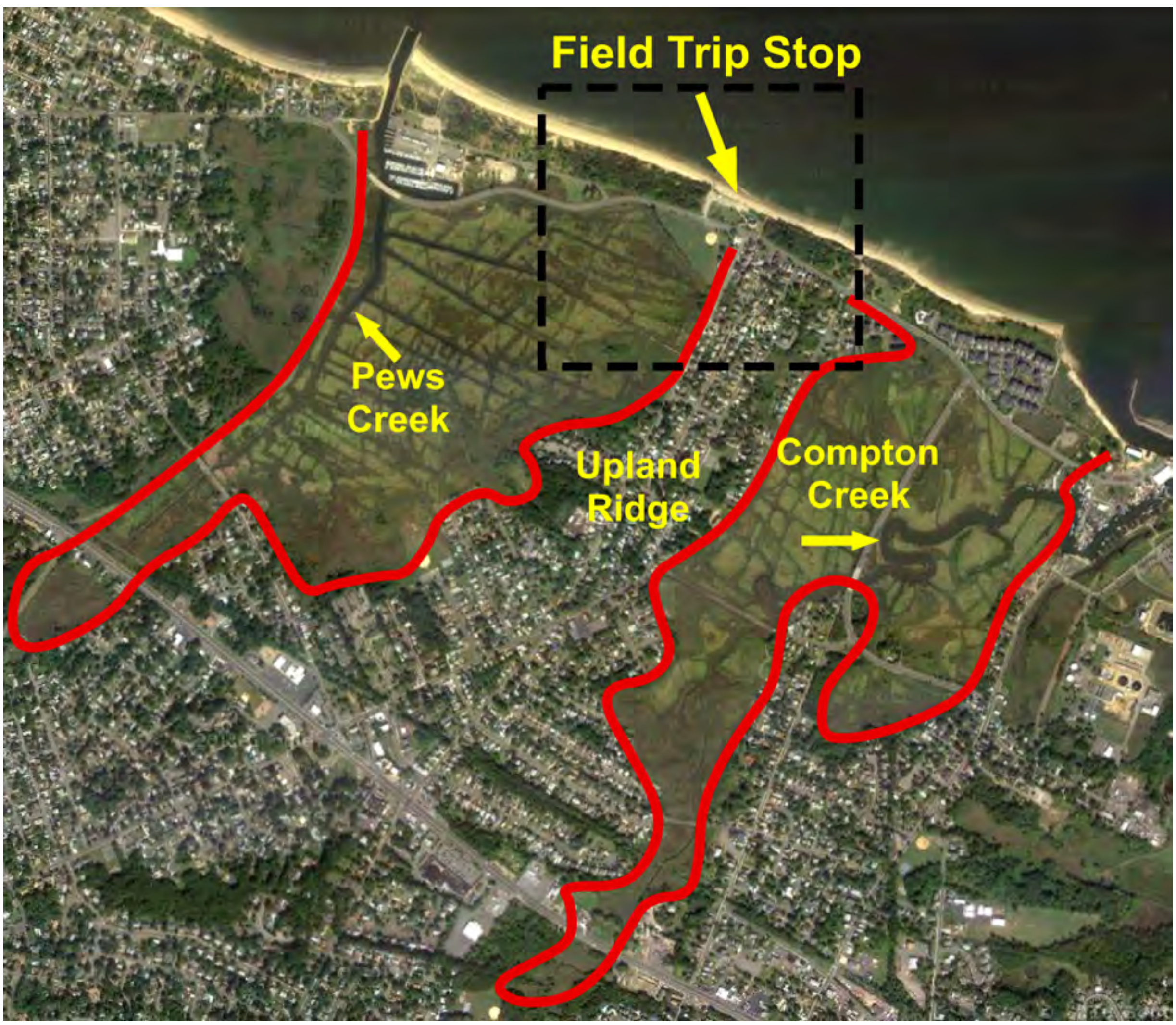


Figure 1. The geography adjacent to Waterfront Bay Park. The red lines outline the two marsh areas in the region. The dashed-line box is the extend of Figure 2.

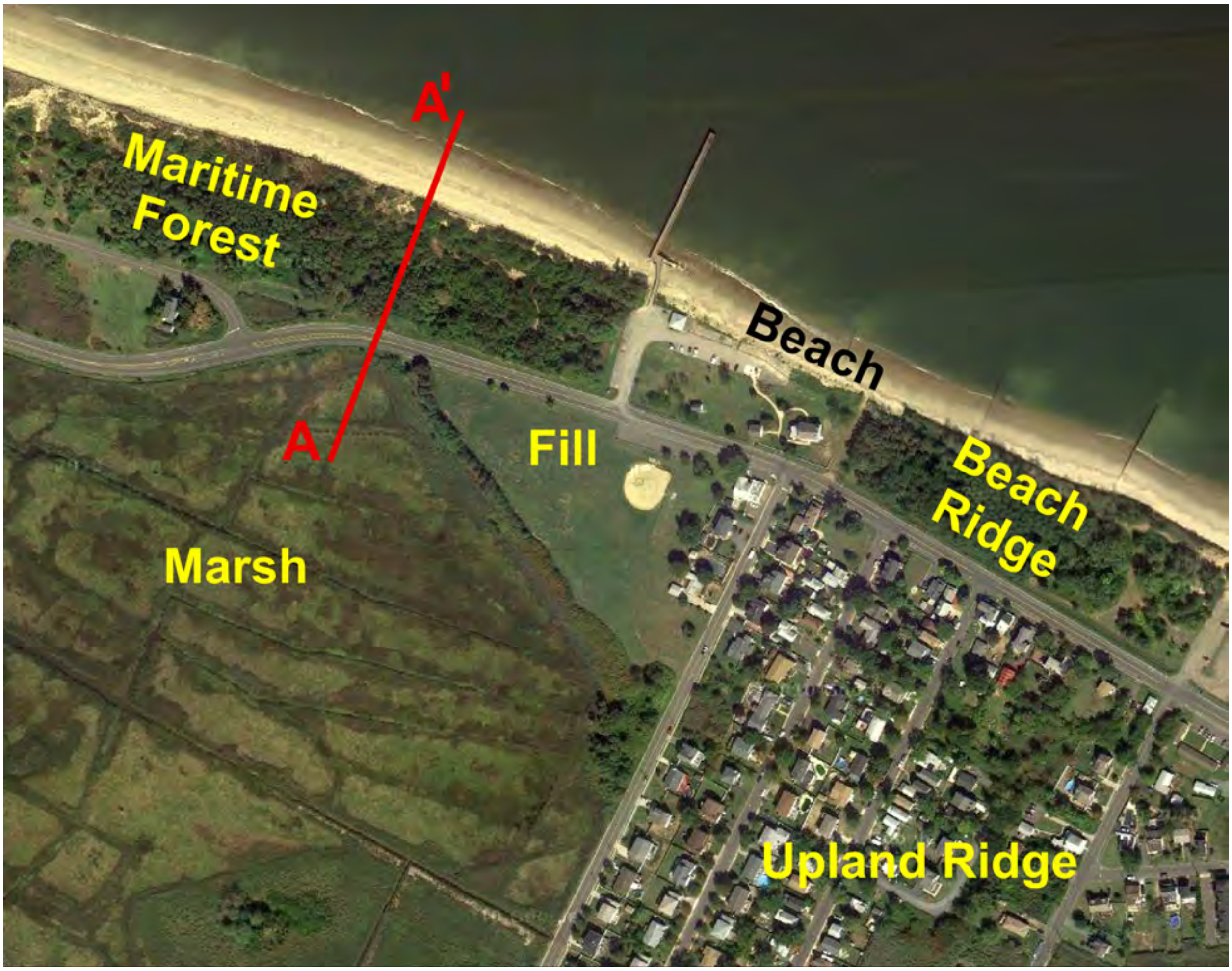


Figure 2. Close-up of the field stop location. The ditches in the marsh and the groins along the shoreline can be seen. The topographic profile along the A-A' transect is presented in Figure 3.

Bayshore Waterfront Park represents a very good example of not only how the natural couplet of beach and marsh form, but also how these environments respond to relative sea-level rise. It is important to distinguish between this long-term evolutionary process and the daily or monthly changes that occur at the shoreline. Such short-term processes include waves, tides, and longshore current. The combined action of waves and tides move the beach sediment perpendicular to the shoreline. The line of "debris" (e.g., shells, algae, etc.), or wrack line, on the beach face represents the highest elevation reached by the previous tide. Due to the partial protection provided by the Sandy Hook spit, wave activity is relatively low compared to the open ocean shoreline. Consequently, the longshore current strength at the park is also relatively low. However, over time, large amounts of sediment are transported parallel to the shoreline. In an effort to capture the moving sediment, groins were built perpendicularly to the shoreline to act as a barrier to sediment movement. While these barriers do enhance sediment deposition on the up-current side of groins, erosion is typically increased on the down-current side. To counteract this erosion, another groin can be built farther down-current, and while this approach helps trap sand between the two groins, it simply shifts the area of erosion still farther down the shoreline. The end result is a series of constructed groins that divide the shoreline into many beach "compartments." These groins alter the natural shoreline movement of both water and sand, potentially changing the physical conditions that influence coastal biodiversity. This approach to shoreline management is evident not only at this field site, but along most of the ocean shoreline of New Jersey.

Long-term changes to the shoreline are driven primarily by relative sea-level rise (RSL). As relative sea level (RSL) continues to rise, wave attack will erode the beach scarp at higher elevations. During storm events, the higher waters will wash over the beach ridge inundating more of the land surface. During these storms, the larger volume of water and the greater energy of waves will erode the beach ridge sands inland. Over time, this erosional process will relocate the entire beach ridge farther inland and cause the shoreline to move landward as well. This shift of ecosystems affects not only shoreline features, but also the marshes. Sediment transported from the beach ridge and deposited on the marsh will bury the marsh grasses killing them. The resulting slight rise in surface elevation provides conditions that promote *Phragmites* growth. *Phragmites* is an invasive grass that grows quickly, expands through an extensive network of rhizomes, and outcompetes the existing marsh vegetation. In many marshes, *Phragmites* dominates, creating a monoculture, which greatly diminishes biodiversity.

Figure 3. Exposure of marsh muds in the beach scarp.

As the beach ridge and shoreline move landward, the marsh continues to get buried. Evidence of this process is a layer of partially-lithified marsh mud exposed in the beach scarp (Figure 3). The presence of marsh mud indicates that at one time the present-day shoreline area was the former location of the marsh (Figure 4). Since then, the marsh environment has moved to its present location, driven by RSL rise. As this process of beach ridge movement and sediment deposition continues, the areal extent of the marsh can be greatly reduced. This in turn can create other environmental problems, because salt marshes play an integral role in (1) providing habitat for numerous birds, fish, and invertebrate species, (2) protecting upland areas from storms, and (3) filtering pollutants in upland runoff before they reach the ocean.

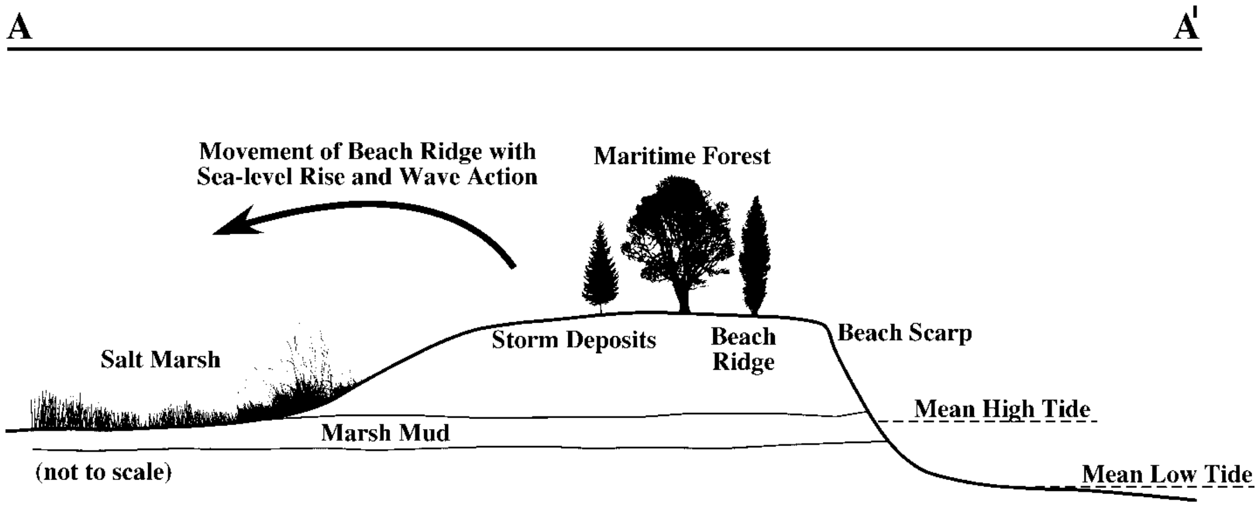


Figure 4. A layer of marsh mud extends from the present marsh to the beach scarp, providing evidence of landward migration of the beach ridge. This sketch represents a possible profile that would be found along transect A–A' shown in Figure 2.

One process that can maintain the extent of the marsh is the landward movement of the upland edge of the marsh. Rising sea level will drive the marsh both upwards and landwards, filling in the lower-elevations first as it follows the natural topography of the land. The effectiveness of this process, however, depends on a complex relationship among the rates of RSL rise, sediment supply to the marsh, and sedimentation in the bay; along with slope variations of the upland topography and changes in tidal range. But even if the interaction of these factors promote vertical marsh movement, there is still one factor that might prevent marsh migration: housing developments. The density of homes adjacent to the upland margin of the marshes will certainly act as a barrier to migration. The houses likely will not be moved as RSL rises (beach front houses are rarely relocated due to storms, for example) and instead barriers will probably be built for protection. If this happens, then the marsh will eventually disappear due to wave erosion and submergence.

Overall, this site provides a good example of how natural coastal processes operate and how environmental consequences, both natural and human-made, are caused by sea-level rise.

2:30 Board Bus: depart for Stop 5 (7.8 mi, 18 mins)

1. Head east on Port Monmouth Rd toward Wilson Ave 272 ft
2. Turn right onto Wilson Ave 1.1 mi
3. Turn left onto NJ-36 S 0.7 mi
4. Take the 3rd right onto Main St 0.4 mi
5. Turn right onto Leonardville Rd 0.5 mi
6. Continue onto New Monmouth Rd 1.4 mi
7. Turn right onto Kings Hwy 0.2 mi
8. Take the 3rd left onto Church St 0.3 mi
9. Continue onto Middletown Lincroft Rd

Destination will be on the left 1.5 mi

Stop 5 – Red Bank and Navesink formations (late Cretaceous)
Poricy Brook
N 40° 22.088 W 074° 06.970
Trip Leader: Dr. James O. Brown

The Poricy Brook is in Middletown Township and cuts through the Red Bank Formation and the glauconitic marl of the Navesink Formation. Both of these geologic formations are from the Late Cretaceous period of the Mesozoic Era.

The Poricy Brook Fossil Beds are well known to fossil collectors in the Northeast. The fossils are from the Cretaceous period of the Mesozoic era, approximately 72 million years ago. During the Cretaceous period, the area of Poricy Brook was a shallow ocean. The marine shell beds consist mainly of extinct oyster species, belemnites, brachiopods, and occasional sharks teeth.

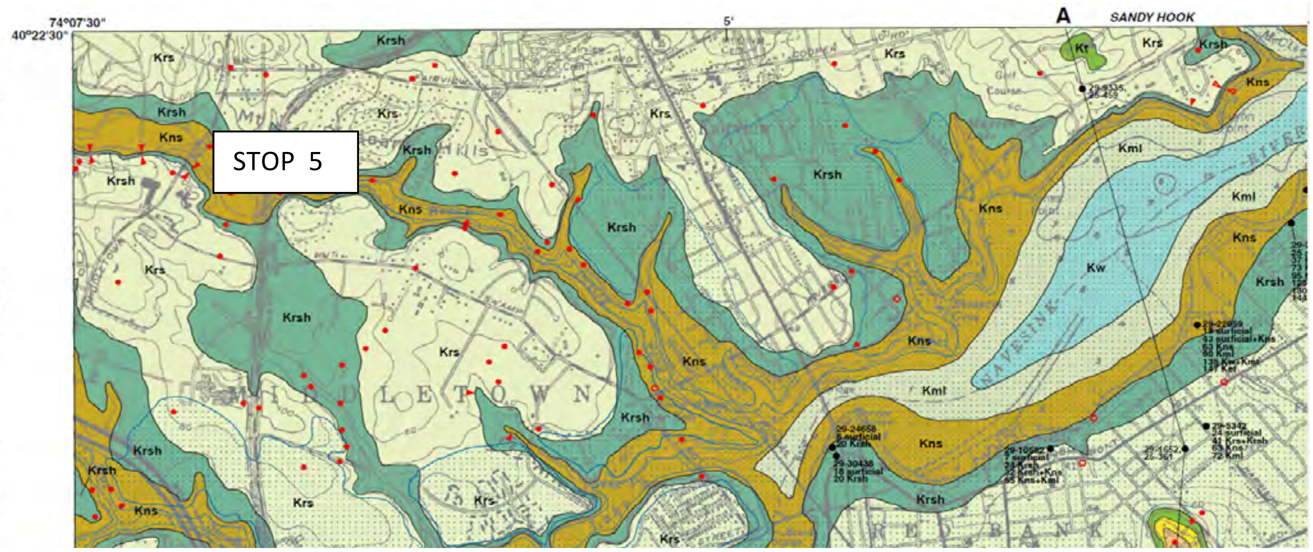
The host sediment of the Navesink Formation is a glauconitic marl deposited far out on the shallow marine shelf. The tops of the higher cutbanks consist of an iron-oxide-stained sand, the Red Bank Formation. This dominantly quartz sand unit lacks fossils, but displays cross bedding typical of sediments deposited in shallow marine environments closer to shore.

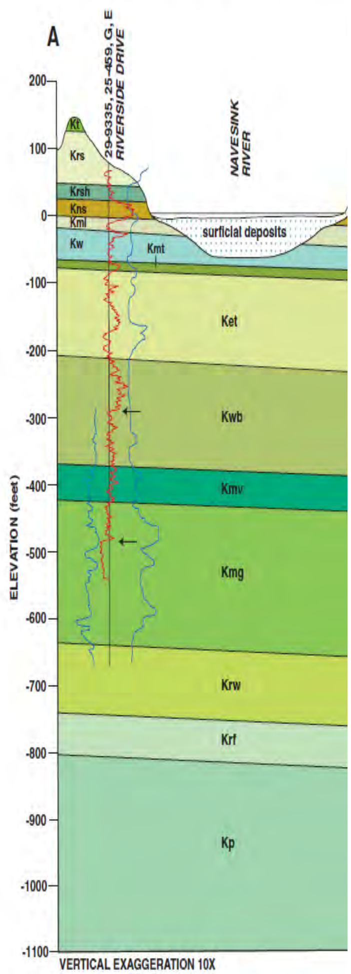
REDBANK FORMATION - (Late Cretaceous [Maastrichtian]) - The Redbank Formation consists of gray to red sand deposited in nearshore environments. Groundwater flowing through the sand has leached away most fossil remains, and has altered the glauconite to limonite (hence the red color). A lower brownish- black micaceous sand unit is called the Sandy Hook Member displaying abundant concretions in bioturbated horizons; it is locally fossiliferous. The upper Shrewsbury Member consists of yellow to orange-gray sand. The unit is a approximately 120 feet thick near Sandy Hook along the valley of the Navesink and Shrewsbury Rivers, but grows progressively thinner until it eventually pinches out to the southwest.

NAVESINK FORMATION - (Late Cretaceous [Early Maastrichtian]) - The Navesink consists of peloidal glauconitic marl and sand that is locally thick bedded or crossbedded, and is locally clay-rich. Fossils are very abundant in some areas. Carbonaceous matter and phosphatic material is present, especially at the base. Mollusk fossils are abundant in the lower and middle portions of the unit. Common Navesink fossils include *Belemnitella americana*, *Exogyra costata*, *Exogyra cancellata*, *Pyncnodonte* sp., *Ostrea falcata*, *Ostrea mesenterica*, *Choristothyris plicata*, and many others. The fossils occur in concentrated horizons within the unit. The fauna suggest a marine shelf environment. The Navesink Formation ranges in thickness from 45 to 65 feet throughout the Atlantic Highlands region.

Representative fossils from the Late Cretaceous Navesink Formation. Mollusks: A-B: *Exogyra cancellata*, C. *Pyncnodonte mutabilis*, D. *Belemnitella americana*, E. *Spondylus gregalis*, F. *Ostrea mesenterica*, G. *Ostrea falcata*; Brachiopod: H. *Choristothyris plicata*

Stream bank along Poricy Brook. The Late Cretaceous Navesink Formation is the predominant feature. Weathered red sand of the Late Cretaceous Redbank Formation is exposed near the top of the cutbank.





BEDROCK GEOLOGY OF THE LONG BRANCH QUADRANGLE MONMOUTH COUNTY, NEW JERSEY

by
Scott D. Stanford and Peter J. Sugarman
2010

SCALE 1:24 000

1 MILE — 7000 FEET — 1 KILOMETER

CONTOUR INTERVAL 20 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

Krs RED BANK FORMATION, SHREWSBURY MEMBER—Fine-to-medium quartz sand, minor medium-to-coarse sand, slightly silty, glauconitic (<5%), and micaceous; reddish-yellow, yellow where weathered, light gray and gray where unweathered; unstratified to weakly horizontally bedded; locally iron-cemented. As much as 100 feet thick. Late Cretaceous (late Maestrichtian) in age based on fossils in the underlying Sandy Hook Member; the Shrewsbury Member is unfossiliferous. Grades downward within 2-3 feet to the Red Bank Formation, Sandy Hook Member. On geophysical well logs, transition to Sandy Hook Member is marked by increased gamma-ray intensity and decreased resistance.

Krsh RED BANK FORMATION, SANDY HOOK MEMBER—Fine-sandy clayey silt, micaceous, slightly glauconitic (<5%); brown to yellowish-brown where weathered, dark gray, olive-gray where unweathered; unstratified. Calcareous brachiopod, pelecypod, and gastropod fossils are common. As much as 20 feet thick. Late Cretaceous (late Maestrichtian) in age based on calcareous nannofossils (Sugarman and Owens, 1996), foraminifera (Olsson, 1964; Olsson and Wise, 1987; Owens and others, 1977), and strontium-isotope ratios (Sugarman and others, 1995). Grades downward within 2-3 feet into the Navesink Formation. On geophysical well logs, transition to Navesink is marked by increased gamma-ray intensity and slightly decreased resistance.

Kns NAVESINK FORMATION—Glauconitic (20-50%) clayey-silty fine-to-medium quartz sand to fine-sandy clayey silt; dark gray, gray, grayish-brown, olive-gray where unweathered, brown to yellowish-brown where weathered; unstratified. Glauconite occurs chiefly in soft grains of fine-to-medium sand size. Calcareous brachiopod, pelecypod, and gastropod fossils are common. Late Cretaceous (late Maestrichtian) in age based on calcareous nannofossils and foraminifera (Olsson, 1964; Miller and others, 2006), macrofossils (Sohl, 1977), and strontium-isotope ratios (Sugarman and others, 1995). Unconformably overlies the Mount Laurel Formation. Contact with Mount Laurel is commonly marked by a sharp peak in gamma-ray intensity on geophysical well logs, with reduced intensity in the Mount Laurel.

MAP SYMBOLS

Contact—Approximately located. Solid triangle indicates contact observed in outcrop. Open triangle indicates contact formerly observed, as reported in permanent note collection of the N. J. Geological Survey.

Formation observed in outcrop or excavation, or penetrated in hand-auger hole.

4:00 pm Return to Middlesex County College (22.5 mi, 30 mins)

1. Head southwest on Middletown Lincroft Rd 0.2 mi
2. Slight right onto Dwight Rd 1.8 mi
3. Turn left onto Red Hill Rd 456 ft
4. Turn left to merge onto Garden State Pkwy N 3.7 mi
5. Take the exit on the left onto Garden State Pkwy N 10.8 mi
6. Take exit 127 for NJ-440 S/Industrial Ave toward I-287 N 0.4 mi
7. Follow signs for NJ-440 N/I-287 N and merge onto NJ-440 S 1.6 mi
8. Take the I-95 exit toward County Rd 514 W 0.6 mi
9. Follow signs for County Rd 514 W/Bonhamtown and merge onto Co Rd 514 1.6 mi
10. Slight left to stay on Co Rd 514 0.9 mi
11. Make a U-turn at Co Rd 667/Mill Rd 0.6 mi
12. Take the 2nd right onto Edward Stec Blvd 0.2 mi
13. Take the 1st right 0.2 mi

Arrive Middlesex County College