NEW JERSEY
GEOLOGICAL AND WATER SURVEY

Open-File Report 20-2

MEASUREMENT OF BACKGROUND pH IN SELECTED, POTENTIAL ACID-SULFATE PRODUCING SEDIMENTS OF THE COASTAL PLAIN OF NEW JERSEY

New Jersey Department of Environmental Protection

STATE OF NEW JERSEY
Philip D. Murphy, *Governor*
Sheila Y. Oliver, *Lieutenant Governor*

Department of Environmental Protection
Catherine R. McCabe, *Commissioner*

Water Resources Management
Michele Putnam, *Assistant Commissioner*

New Jersey Geological and Water Survey
Jeffrey L. Hoffman, *State Geologist*

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

As a national leader in environmental protection, the New Jersey DEP uses the best science available to protect public health, support its diverse natural resources and create vibrant and sustainable communities that provide economic opportunity for all.

NEW JERSEY GEOLOGICAL AND WATER SURVEY

The mission of the New Jersey Geological and Water Survey is to map, research, interpret and provide scientific information regarding the state's geology and groundwater resources. This information supports the regulatory and planning functions of DEP and other governmental agencies and provides the business community and public with information necessary to address environmental concerns and make economic decisions.

For more information, contact:
New Jersey Department of Environmental Protection
New Jersey Geological and Water Survey
P.O. Box 420, Mail Code 29-01
Trenton, NJ 08625-0420
(609) 292-1185
www.njgeology.org

Cover photo: The author taking samples. *Photo by Walt Marzulli.*

New Jersey Geological and Water Survey Reports (ISSN 0741-7357) are published by the New Jersey Geological and Water Survey, P.O. Box 420, Mail Code 29-01, Trenton, NJ 08625-0420. This report may be reproduced in whole or part provided that suitable reference to the source of the copied material is provided.

More information on NJGWS reports is available on the Survey's website: www.njgeology.org

Note: Any use of trade, product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the New Jersey state government.

New Jersey Geological and Water Survey
Open-File Report 20-2

Measurement of Background pH In Selected, Potential Acid-Sulfate Producing Sediments of The Coastal Plain Of New Jersey

by

John H. Dooley

New Jersey Department of Environmental Protection
New Jersey Geological and Water Survey
P.O. Box 420, Mail Code 29-01
Trenton, NJ 08625

2020

TABLE OF CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENT

I am indebted to Walter Marzulli of the NJGS for augering the holes, lugging equipment, GPS measurements and data reduction, and enduring the 100° plus weather while remaining upbeat at all times. The Bureau of Freshwater and Biological Monitoring is thanked for permission to use their pH meter and calibration standards. Otto Zapecza, Richard Dalton and Ray Bousenberry of the NJGWS are thanked for their critical reviews that enhanced the readability of the text. Zehdreh Allen-Lafayette is thanked for creating the geologic map of sample localities and formatting the entire manuscript for publication.

MEASUREMENT OF BACKGROUND pH IN SELECTED, POTENTIAL ACID-SULFATE PRODUCING SEDIMENTS OF THE COASTAL PLAIN OF NEW JERSEY

INTRODUCTION

The New Jersey Department of Environmental Protection (NJDEP) publication, *Standards for Soil Erosion and Sediment Control in New Jersey*, now available from the New Jersey Department of Agriculture (NJDA, 2014), states there are certain geologic formations in the Coastal Plain of New Jersey with the potential for producing acid-sulfate sediment and water when exposed to sufficient oxygen. The geologic formations with high acid sulfate-producing potential were listed in the *Flood Plain Management Technical Manual, Stream Encroachment* (Division of Water Resources, 1983). The list included the following geologic formations: Kirkwood, Red Bank Sand, Englishtown, Marshalltown, Woodbury Clay, Merchantville, Magothy, and Raritan.

The New Jersey Geological and Water Survey (NJGWS) published in 2009 *Coastal Plain Sediment with Potential to Form Acid (Sulfate) Soils* as the digital geodata series DGS 09-2. The NJGWS recommended adding to the NJDEP's technical regulations the following geologic formations: Cheesequake (formerly the upper part of the Magothy Formation), Hornerstown, Manasquan, Shark River, Tinton, and Wenonah Formations. With the publication of DGS 09-2, the NJDA adopted the new list in their subsequent update. Limited information was available regarding pH values for these additional potential acid-sulfate producing deposits. This report provides the methods and results of a NJGWS study in May 2010 to provide initial background pH values for these additional geologic formations.

Potential acid-sulfate sediment becomes actual acid-sulfate sediment when land is drained or sulfidic material is excavated. Exposing sulfide-bearing sediment to oxygen during earth moving activities or disturbing the natural hydrology results in serious environmental problems. As noted by the NJDA (2014), most vegetation is incapable of growth at this pH level. Adjacent land and receiving waters can be negatively impacted by the acid leachate. Calcium-containing materials such as sidewalks, culverts and other structures and some metallic materials are also susceptible to

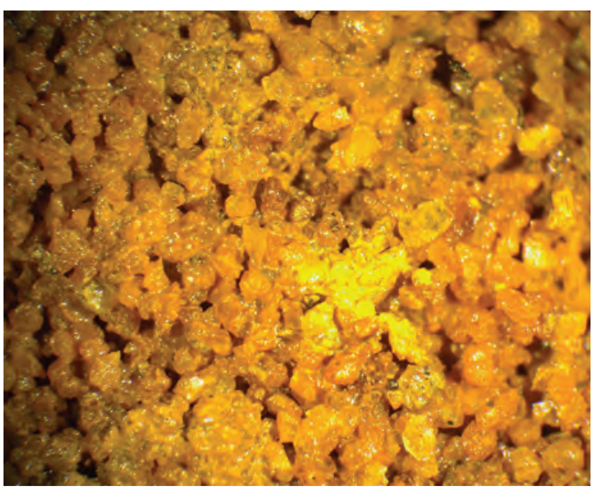


Figure 1. Photomicrograph of Merchantville Formation sediment, magnified 23 times, from Cheesequake State Park. The yellow coating, lower center, on the iron-oxide stained quartz sand is jarosite.

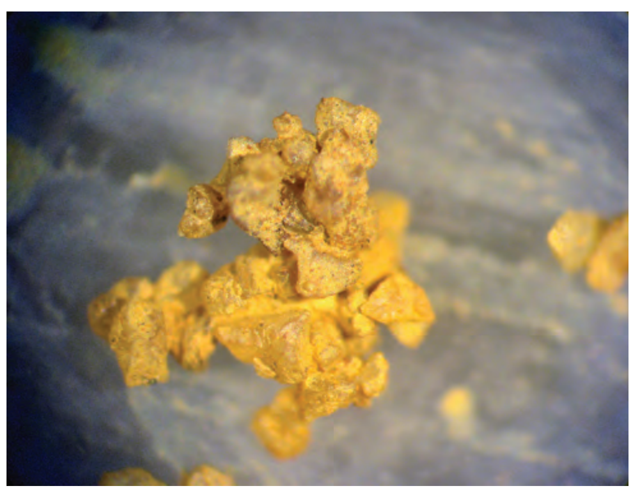


Figure 2. Photomicrograph of a quartz sand aggregate cemented with jarosite from the Merchantville Formation at Cheesequake State Park. 50 times magnification.

degradation.

Upon exposure to aerobic conditions, sulfide-bearing sediment oxidizes rapidly to form straw yellow jarosite ($KFe_3(SO_4)_2(OH)_6$) mottles and coatings (Figures 1 and 2), highly soluble ferrous (Fe^{+2}) sulfosalts, and significant sulfuric acid (Rabenhorst and Valladares, 2005). When oxidation of sulfides occurs and free acid is leached, jarosite slowly hydrolyzes to iron oxides producing characteristic strong brown goethite, or red hematite mottles in mature acid-sulfate sediment and soils of the Coastal Plain.

Acid-sulfate sediment may form wherever sulfide minerals accumulate. Sulfides within waterlogged sediments remain stable indefinitely in anaerobic environments. In most acid-sulfate sediments, pyrite (FeS_2) is the reduced sulfur mineral. Less commonly reduced are elemental sulfur, monosulfide, and/or polysulfide minerals. Potential acid–sulfate sediments are common in tidal swamps and marshes, former tidal areas that are now built up into deltas and floodplains, and in the beds of brackish lakes and lagoons. Sediments that have accreted slowly and under lush vegetation have much higher pyrite contents than in those that accumulate quickly (van Mensvoort and Dent, 1997). Many of the abundant greensand (glauconite) formations in the Coastal Plain developed in areas of slow to no sedimentation under deep marine conditions, and therefore are locally pyritic (Figure 3 and Appendix B). Local pyrite accumulation can occur when inland marshes and swamps are flushed by sulfate-rich water.

Figure 3. Photo of the stream bank in Manasquan River at Allaire State Park. Top layer (light brown, approximately 5 feet thick) is the Kirkwood Formation resting on the glauconitic Shark River Formation. Note the iron oxyhydroxide, near the rubble pile, leaching from the Shark River Formation.

METHODS

Site Selection

Sites selected for sediment sampling were chosen from soils or flood plain lag deposits from the following geologic formations: Hornerstown, Manasquan, Shark River, Tinton, and Wenonah. Additionally, the Navesink and Marshalltown formations, already listed as potential acid-sulfate producing geologic formations by the NJDA, were sampled. Bedrock maps of the Coastal Plain, prepared by the NJGWS, were used in the site selection process. Air photos were used to assess accessibility and the surrounding area. Natural Resources Conservation Service (NRCS) online soil maps were consulted. A sampling station adjacent to a stream was a necessary condition for site selection.

In the field, orangish to yellowish stream water and gelatinous ochre/iron oxyhydroxide precipitates on the bed sediment (Figure 4) and poor vegetation are strong indicators of active acid-sulfate producing sediment.\

Figure 4. Natural water color, due to iron oxyhydroxide ± jarosite (?) Pre-ipitates in a stream draining sediments on the Merchantville Formation in Cheesequake State Park. Note the paucity of undergrowth.

Sampling

A stainless steel, clay auger, 5 feet in length, was used to core the section. The 6- to 12-inch sediment samples were extruded from the auger head on to plastic sheeting. Potential sulfide-bearing strata were identified in the field by the first appearance of uniformly dark color sediment that lacked redoximorphic features.

Samples selected for pH measurements were placed in borosilicate glass bottles with lined screw caps. The bottles with the samples were filled completely with ambient stream water to displace air, then tightly sealed while submersed. The bottles were immediately stowed in an ice-filled cooler. A sample of stream water was taken at each site. At the lab, samples were refrigerated at 4°C until analyzed. An aliquot of each sample is archived at the NJGWS.

pH Measurements

Sediment pH was measured in the lab according to the procedure by Hendershot and others (1993). A 0.01M $CaCl_2$ solution was prepared by dissolving 2.940 g of calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) with doubly distilled, deionized water in a 2000 mL volumetric flask with a 5.65 pH. This **standard method** using 0.01M $CaCl_2$, in opposition to the 0.5M $CaCl_2$ solution recommended in the technical notes of the New Jersey Department of Environmental Protection, better approximates the natural electrolyte concentration in the soil solution. Furthermore, 0.01M $CaCl_2$ approximates a constant ionic strength for all soils regardless of mineral composition, natural fertility, and past management (NRCS, 2001).

Aliquots of the sediments were air-dried at room temperature for 36 to 48 hours in plastic sample boats. Ten grams of air-dried sediment and 20 mL $CaCl_2$ were placed in a glass test tube. This mixture was stirred intermittently for approximately 30 minutes and allowed to stand for 1 to 1½ hours. The combination electrode of the pH meter (Orion Research Model 601A) was inserted in the supernatant liquid. The pH was recorded once the reading stabilized. Prior to, during (every 5 to 6 readings) and following pH readings, calibration was checked using pH 7.00 and 4.00 buffer solution standards. All pH measurements were taken at a room temperature of 73º F (22.8º C).

Following the initial pH reading, select samples were emptied into 4 oz, borosilicate glass jars. The samples were stirred periodically and pH readings recorded following days of incubation by exposure to air. At the conclusion of the incubation experiment, approximately 2 mL of hydrogen peroxide (23% v/v H_2O_2) was added to the incubation bottles, stirred, allowed to stand overnight, and pH measured the following day.

RESULTS

Location of the sites sampled in relation to geologic units in the New Jersey Coastal Plain are shown in Figure 5. GPS latitude and longitude and site-specific details are given in Appendix A. Natural pH and pH of air-dried sediment in 0.01M $CaCl_2$ (henceforth referred to as the standard method), as a function of depth below the ground surface in inches, are tabulated in Table 1.

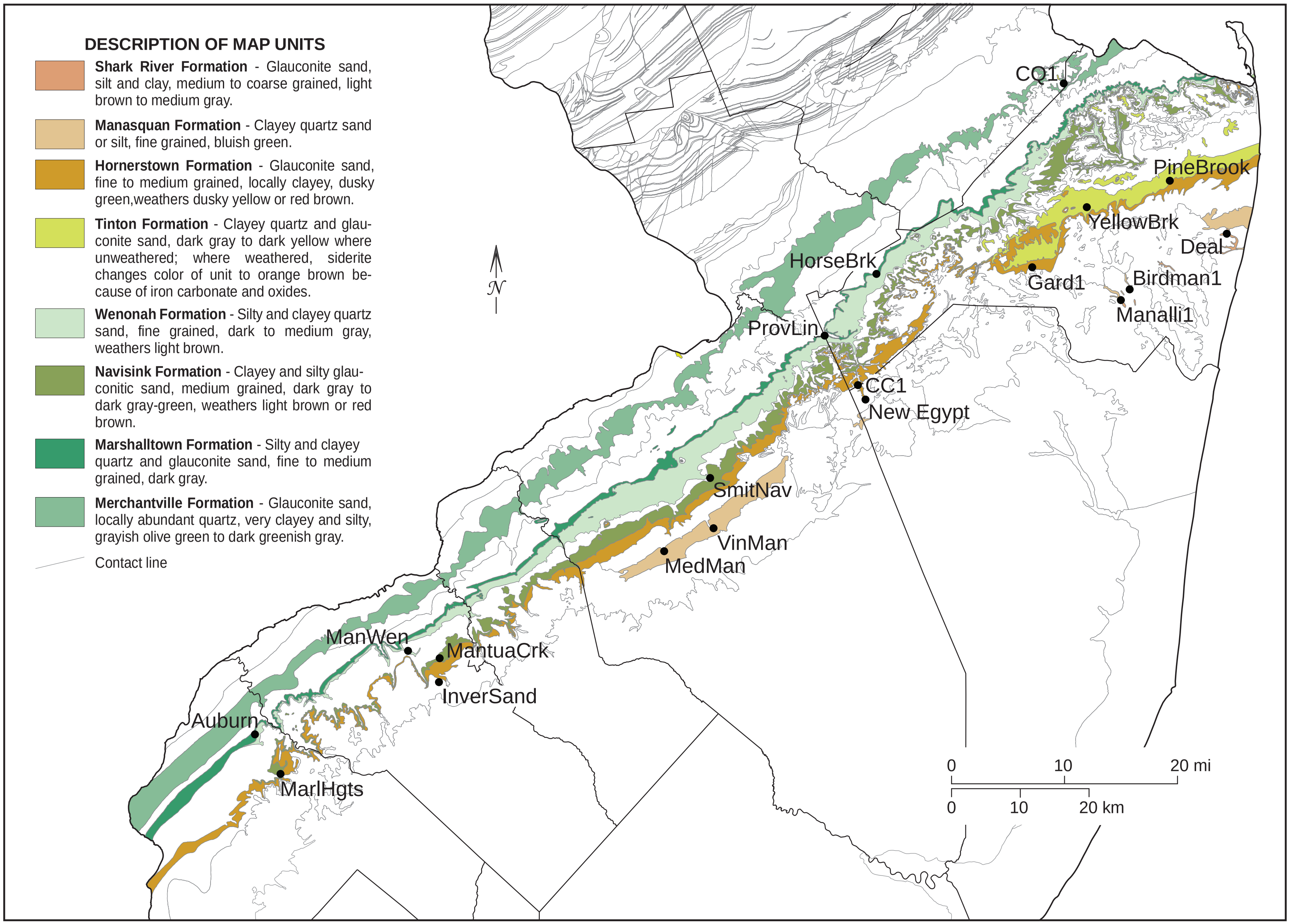


Figure 5. Geologic map showing the location of sites sampled for background pH in the New Jersey Coastal Plain. Source: Bedrock Geologic Map of New Jersey 2014. Note: Technical term used by geologists for “clayey” is “argillaceous”.

Table 1. Depth and pH at room temperature for the samples.

Formation	Station	Depth in inch, bgl*	pH natural	pH_{CaCl2}
Merchantville				
	Cq 1	13 - 17	4.97	3.77
		24 - 28	6.20	4.10
		54 - 59	6.18	4.18
		stream water	6.72	
Hornerstown				
	CC 1	26 - 30	5.31	4.08
		39 - 42	5.76	4.97
		48 - 51	5.66	4.57
		stream water	6.42	
	NEW EGYPT	10 - 14	5.90	5.12
		25 - 28	5.98	4.95
		48 - 57	6.19	4.90
		stream water	6.39	
Manasquan				
	BIRDMAN 1	9 - 12	5.51	4.07
		13 - 16	5.16	4.27
		30 - 33	6.09	4.26
		stream water	6.22	
	VINMAN	20 - 23	5.36	4.63
		38 - 41	5.55	4.91
		50 - 54	5.70	4.99
		stream water	4.83	
	MEDMAN	24 - 26	4.95	3.98
		38 - 40	4.66	3.87
		51 - 54	4.76	3.92
		stream water	6.26	
Marshalltown				
	HORSEBRK	16 - 20	4.90	3.85
		30 - 34	4.69	3.84
		50 - 54	4.90	3.79
		stream water	5.94	
	AUBURN	8- 12	5.60	4.11
		20 - 24	5.58	4.08
		46 - 51	5.12	4.01
		stream water	5.97	
Wenonah?				
	PROVLIN	21 - 24	4.31	3.44
		33 - 36	5.28	4.58
		48 - 50	5.72	4.52
		stream water	6.07	
Wenonah				
	MANWEN	14 - 18	5.98	5.08
		22 - 26	5.80	4.97
		48 - 52	6.10	4.96
		stream water	6.27	

Table 1. con't

Formation	Station	Depth in inch, bgl*	pH natural	pH_{CaCl2}
Navesink				
	MARLHGTS	14 - 18	5.06	3.98
		32 - 36	4.68	3.86
		50 - 54	4.91	4.30
		stream water	5.70	
	MANTUACRK	8 - 12	3.98	3.63
		24 - 28	4.45	3.91
		stream water	5.04	
	SMITVAV	24 - 26	5.43	4.13
		32 - 34	5.51	4.33
		54 - 57	5.93	5.12
		stream water	6.06	
	INVERSAND	grab	NA	3.88
Shark River				
	MANALLI1	16 - 19	4.42	3.34
		24- 27	4.46	3.60
		33 - 36	4.56	3.91
		stream water	6.56	
	DEAL	15 - 18	4.74	3.73
		23 - 26	4.76	3.97
		40 - 44	5.68	5.49
		stream water	6.04	
Tinton				
	GARD1	16 - 18	4.65	3.89
		23 - 26	4.83	4.37
		44 - M48	5.74	4.56
		stream water	5.87	
	YELLOWBRK	9 - 12	5.10	4.02
		34 - 37	6.21	4.30
		43 - 48	6.00	4.50
		stream water	5.85	
	PINEBROOK	Tinton Falls	NA	5.12

* bgl = below ground level.
grab = see Appendix A.
# pH natural = pH of sediment + stream water at room temperature.
^ pH_{CaCl2} = pH of air-dried sample in 0.01M CaCl2.
Station = field identification.

pH_{nat}

pH_{nat} ranges from 3.98 (Navesink Formation – MANTUA CRK at 8 to 12 inches below ground level [bgl]) to 6.21 (Tinton Formation – YELLOWBRK at 34 to 37 inches bgl) with a 5.36 median and 5.31 ± 0.59 arithmetic mean pH_{nat} for all samples (Table 2).

The NRCS (1998) defines soil quality in terms of pH as:

pH	class
3.5 – 4.4	extremely acid
4.5 – 5.0	very strongly acid
5.1 – 5.5	strongly acid
5.6 – 6.0	moderately acid
6.1 – 6.5	slightly acid
6.6 – 7.3	neutral

Median and arithmetic mean pH_{nat} for the sample set indicate the sediments are strongly acid and range from extremely acid to slightly acid.

Table 2. Statistical summary of pH for all samples as a function of depth in inches below ground level (bgl), excluding the two grab samples.

	Minimum	Maximum	Medium	Arithmetic Mean	Standard Deviation	n
Depth						
all sediment	10	56.5	27.3	31.2	14.3	50
0 - 24”	10	24	16	16.1	4.6	17
>24 - 46”	24.5	46	32.5	32.7	7.1	21
>46”	46	56.5	52	51.3	2.9	12
pH nat.						
all sediment	3.98	6.21	5.36	5.31	0.59	50
0 - 24”	3.98	5.98	5.13	5.16	0.59	17
>24 - 46”	4.45	6.21	5.37	5.31	0.60	21
>46”	4.76	6.19	5.71	5.58	0.52	12
pH_{CaCl2}						
all sediment	3.34	5.49	4.13	4.29	0.51	50
0 - 24”	3.34	5.12	4.05	4.17	0.58	17
>24 - 46”	3.60	5.49	4.20	4.29	0.47	21
>46”	3.79	5.12	4.54	4.49	0.45	12
pH nat/str						
all sediment	0.67	1.18	0.89	0.88	0.11	50
0 - 24”	0.67	1.11	0.87	0.86	0.11	17
>24 - 46”	0.68	1.15	0.89	0.88	0.12	21
>46”	0.76	1.18	0.93	0.93	0.11	12
$pH_{CaCl2/nat}$						
all sediment	0.66	0.97	0.81	0.81	0.06	50
0 - 24”	0.73	0.87	0.79	0.80	0.05	17
>24 - 46”	0.66	0.97	0.82	0.81	0.07	21
>46”	0.68	0.88	0.80	0.81	0.05	12

Stream water, used to displace air in the samples stored in bottles, had pHs ranging from 4.83 to 6.72 with a 6.06 median and 6.01 $\pm$ 0.49 arithmetic mean. The difference between stream water and pH_{nat} measurements yielded a median and arithmetic mean difference of 0.69 and 0.73 pH units, respectively. Stream water pH exceeded pH_{nat} in all samples except for a site in the Manasquan Formation (VINMAN and one in the Tinton Formation (YELLOWBRK). The largest pH difference between stream water and the sediment was recorded at approx. 2.1 units for a site (MANELLI 1) in the Shark River Formation.

Median and arithmetic mean pH_{nat} increases with increasing depth, generally approaching the stream water pH at depths exceeding 46 inches bgl (Table 2). This trend of increasing pH with increasing depth in the sediment applies to the standard method (pH_{CaCl2}) as well. A statistical evaluation of pH as a function of a given geologic formation is precluded by the small sample size for each formation.

pH in 0.01M Calcium chloride (pH_{CaCl2})

pH_{CaCl2} for the entire sample suite ranges from 3.34 (Shark River Formation – MANELLI 1 at 16 to 19 inches bgl) to 5.49 (Shark River Formation – DEAL at 40 to 44 inches bgl) with a 4.13 median pH and 4.29 $\pm$ 0.51 arithmetic mean. The median and arithmetic mean pHs place these sediments in the 'extremely acid' category of soil quality as defined by the NRCS.

The median and arithmetic mean difference in pH between the natural samples and the standard method is 1.02 and 1.03 $\pm$ 0.40 pH units (Table 3) with the standard method having a consistently lower pH than the corresponding pH_{nat}. The difference for the entire sample suite ranges from 0.19 (Shark River Formation – DEAL at 40 to 44 inches bgl) to 2.10 pH units (Merchantville Formation – Cq1 at 24 to 28 inches bgl). Ninety percent (46 of 51) of the sample suite, measured by the standard method, were 'extremely acid' to 'very strongly acid' with approximately 60 percent being 'extremely acid'.

The pH difference between the minimum and maximum pH differences for pH_{nat} and pH_{CaCl2} (Table 3) for a particular geologic formation varies widely. The pH difference ranges from 0.51 (Hornerstown Formation) to 1.45 units (Tinton Formation).

Table 3. Statistical summary of the difference between pH_{nat} and pH_{CaCl2} for the entire data set and by geologic formation.

Formation	Minimum	Maximum	Arithmetic Maximum	Standard Medium	Mean Deviation	n
Merchantville	1.20	2.10	2.00	1.77	0.49	3
Hornerstown	0.78	1.29	1.13	1.10	0.18	6
Manasquan	0.64	1.83	0.84	0.99	0.40	9
Marshalltown	0.70	1.50	1.08	1.06	0.25	12
Navesink	0.35	1.30	0.82	0.84	0.33	8
Shark River	0.19	1.08	0.83	0.76	0.32	6
Tinton	1.91	1.13	1.15	0.52	0.52	6
all samples	0.19	2.10	1.02	1.03	0.40	50

n = number of samples.

Incubation Experiment and Oxidation pH

Oxidation pH tests were performed to detect the presence of sulfidic matter and to predict the occurrence of sulfidic horizons. This laboratory procedure accelerates the natural formation of microbial acid sulfate (NRCS, 2001). Microbial oxidation of sulfidic matter is controlled by incubating saturated soil samples in closed containers at room temperature. Occasional stirring of the samples incorporates oxygen necessary for oxidation. Immediately following pH measurements by the standard method, select samples in the $CaCl_2$ solution were transferred to 4-ounce glass jars with lined screw caps.

The results for this test are tabulated in Table 4. The standard method pH remained essentially constant over the duration of the incubation for MANELLI (Shark River Formation), HORSEBRK (Marshalltown Formation), MARL HGTS (Navesink Formation), MEDMAN (Manasquan Formation), and INVERSAND (Navesink Formation). A pH decrease was measured for BIRDMAN (Manasquan Formation), Cq1 (Merchantville Formation), NEW EGYPT (Hornerstown Formation), and YEL BRK (Tinton Formation). CC1 (Hornerstown Formation) produced an increase in pH. Those samples which maintained a constant pH can be interpreted to contain insignificant sulfide- and iron-oxidizing microbes. Those showing a decrease in pH with oxidation suggest that sufficient microbial oxidation of sulfides occurs. It is not clear why CC1 (Hornerstown Formation) had an increase in pH over the duration of the experiment.

For a rapid test of oxidation potential, hydrogen peroxide (H_2O_2) was added to the soil suspension. Violent effervescence and an extremely acidic suspension indicate the presence of acid sulfate matter. Adding 10 drops H_2O_2 to the soil suspension generally produced a decrease in pH_{CaCl2} compared to the final reading on 7/6/2010. Adding an additional 1.5 mL H_2O_2 and allowance to react overnight produced a significant pH decrease compared to the final pH measurements for the incubation experiment (Table 4), except for YEL BRK (Tinton Formation) which remained essentially unchanged. As shown in Table 4, the YEL BRK sample decreased by 0.99 pH unit during the incubation and no further pH change was measured following addition of the H_2O_2. Relative to the final pH measurements for the incubation, adding sufficient H_2O_2 decreased pH from 0.44 units (Navesink Formation – MARL HGTS at 50 to 54 inches bgl) to 1.52 units (Hornerstown Formation – CC1 at 48 to 51 inches bgl) with a 0.80 median and 0.88 arithmetic mean.

Table 4. pHs for the incubation experiment and oxidation by hydrogen peroxide.

Sample	Jar Date	Initial pH	5/24/2010	6/1/2010	7/6/2010	10 drops H_2O_2 7/6/2010	1.5 mL H2O2 7/7/2010
CC1	19-May	4.57	5.02	4.88	5.04	4.91	3.52
MANALLI	19-May	3.91	3.92	3.93	3.97	3.96	3.17
BIRDMAN	20-May	4.26	4.56	4.54	4.03	2.92	3.28
CQ1	20-May	4.18	4.28	4.01	4.03	3.91	3.08
HORSEBRK	21-May	3.79	3.80	3.78	3.80	3.64	3.12
MARLHGTS	21-May	4.30	4.39	4.38	4.32	4.48	3.88
NEWEGYPT	24-May	4.90		4.74	4.43	4.23	3.09
YELLOWBRK	24-May	4.50		4.64	3.51	3.77	3.52
MEDMAN	1-Jun	3.92			3.97	3.86	3.03
INVERSAND	1-Jun	3.88			3.85	3.79	3.33
tap water	6-Jul				6.84	6.80	6.84

Jar date = date placed in incubation jar.
H_2O_2 = oxidized with 23% v/v hydrogen peroxide.
Tap water = tap in NJGS lab.

DISCUSSION

In the field, highly sulfidic sediment emits an odor of sulfur similar to rotten eggs that permeates the air. Less sulfidic sediment may smell fetid when held to one's nose. Though most sediment in this study smelled fetid, there was no pyrite apparent, macro and microscopically, in any of the samples. It is likely that pyrite, if present, occurs as finely dispersed particles with the sediment matrix. The fetid odor of the sediment, in addition to yellowish/orangish stream water and gelatinous ochre on the bed sediment are strong evidence of sulfidic sediment. Distribution of pyrite in these marine and marine-influenced sediments is highly spatially variable.

Measuring soil pH in 0.01M $CaCl_2$ lowers the pH by about 0.5 pH units compared to soil pH in water (Schofield and Taylor, 1955). Kissel and others (2009) report a 0.67 median difference in pH when comparing pH in water with pH in 0.01M $CaCl_2$ for 1186 soil samples. Furthermore, they report that 20% of the samples had a difference of >0.8 and 10% had a difference of >0.9 pH units. The median difference in this study is 1.02 pH units with 25% >1.2 and 10% $\geq$ 1.50 pH units. It is unclear if the large median difference in this study reflects a unique character of sulfidic sediment as a whole and/or by measuring pH_{nat} in stream water as opposed to tap water.

Data herein show a wide variability in pH among the geologic formations and within a particular geologic formation. Therefore, a site-specific evaluation of the sediment's potential to generate acid sulfate is warranted. Moreover, the fact that potential acid-sulfate producing sediment is normally water-saturated presents problems with water management during site perturbation/development.

Sulfide-bearing matter usually occurs at depths greater than those addressed in traditional soil surveys. Depth to sulfidic matter in the sediment of the Maryland Coastal Plain ranges from <9 feet (<3 m) to >36 feet (>12 m) bgl (Rabenhorst and Valladares, 2005). The relative position of the water table influences the depth of oxidation and the depth to sulfides by controlling oxygen diffusion into the sediment. Sulfide oxidation lowers pH in the oxidized zone relative to the unoxidized zone. Based on the work by Rabenhorst and Valladares (2005) and data collected for this study, it is unlikely that true unoxidized, sulfidic sediment was encountered – a limitation of hand augers. To sample the sulfide horizon at >5 feet bgl, sampling methods such as trenching or drilling rather than hand augering are necessary.

CONCLUSION

Data herein support the NJGS's recommendation to include in the *Standards for Soil Erosion and Sediment Control in New Jersey* the following geologic formations: Merchantville, Hornerstown, Manasquan, Shark River, Tinton and Wenonah, as sediments with the potential to produce acid sulfate. High spatial variability in pH within a geologic formation and among geologic formations demands a site-specific evaluation of its potential to produce acid sulfate, particularly when excavation exceeds 6 feet bgl.

Certainly, additional pH data for these sediments deposited in a marine to marine-influenced environment would provide stronger support for the NJGS's recommendation to include said geologic formations in the *Standards for Soil Erosion and Sediment Control in New Jersey*.

REFERENCES

Flood Plain Management Technical Manual, Stream Encroachment, 1983, Division of Water Resources, New Jersey Department of Environmental Protection.

Hendershot, W. H., Lalande, H., and Duquette, M., 1993, Soil reaction and exchangeable acidity. *In*: Carter, M. R., ed., Soil sampling and methods of analysis, Lewis Publishers, CRC Press, Boca Raton, Fl., p. 141- 145.

Kissel, David E., Sonon, Leticia, Vendrell, Paul F., and Isaac, Robert A., 2009, Salt concentration and measurement of soil pH: Communications in Soil Science and Plant Analysis, v. 40, p. 179-187.

Munsell Soil Color Charts, 1975, Kollmorgan Corp., Baltimore, MD.

NJDA, 2014, The standards for soil erosion and sediment control in New Jersey, 7th ed., 432 p. accessed May 4, 2020.

NRCS, 1998, Soil Quality Indicators: pH: Soil Quality Information Sheet, accessed June 2010 at http://soils.usda.gov., 1 p.

NCRS, 2001, Use of reaction (pH) in soil taxonomy: USDA, Soil Survey Technology Notes, 3 p. accessed April 8, 2010.

Rabenhorst, Martin C., and Valladares, Terry M., 2005, Estimating the depth to sulfide-bearing materials in Upper Cretaceous sediments in landforms of the Maryland coastal plain: Geoderma, v. 126, p. 101-116.

Schofield, R. K., and Taylor, A. W., 1955, The measurement of soil pH: Soil Sci. Soc. Am. Proc., v. 19, p. 164-167.

van Mensvoort, M. E. F., and Dent, D. L., 1997, Acid sulfate soils. *In*: Lal, R., Blum, W. H., Valentine, C., and Stewart B. A., eds., Methods for assessment of soil degradation, Lewis Publishers, CRC Press, Boca Raton, Fl., p. 301-335.

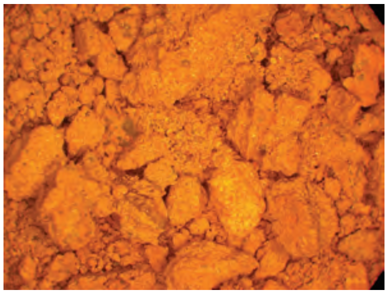
Appendix A

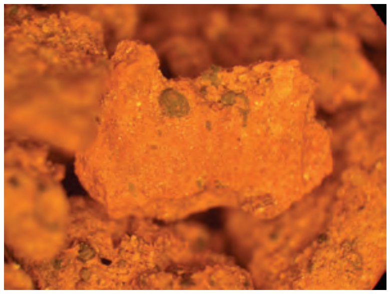
GPS location, field notes summarized, and site particulars. Binocular microscopy was used to examine wet samples. Soil color is measured wet by comparison with a Munsell soil color chart (1975). Most samples described have two photomicrographs. The left photo is a general view of the sample magnified 7.5 times, and the right photo is a detailed view magnified 15 times, unless indicated otherwise.

Merchantville Formation – Cq1 (field designation)
Latitude: 40 24 37.71, Longitude: 74 15 03.63

Augered hole approximately 8 feet east of stream and 30 to 36 inches above stream level to a total depth (TD) of 60 inches. Water in bottom of auger hole. The entire cored interval was strongly fetid (sulfur odor) with the interval from approximately 52 to 60 inches appearing to be unoxidized, sulfidic, dark gray/black sediment.

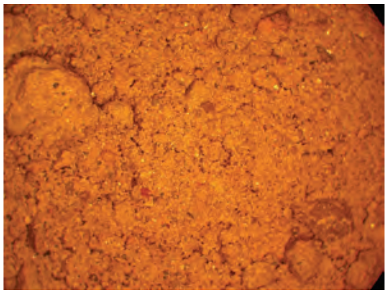
13 - 17 inches:
reddish brown (5YR 4/4) sandy silt, quartz sand is moderately iron stained to no staining, iron oxyhydroxide stained silt coats the sand, poorly sorted, approximately 10% light pistachio green to very dark green glauconite sand, few iron stained quartz pebbles and glauconite-bearing ironstone fragments, some siderite, approximately 7% white mica silt, trace plant debris.





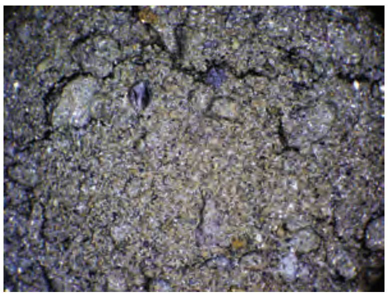
30X magnification

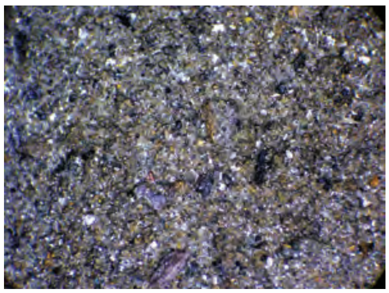
24 - 28 inches:
reddish brown (5YR 4/4) silty quartz sand, very fine to fine quartz sand with some medium to coarse, moderate to no iron stained clasts, approximately 2% dark green to black glauconite sand, approximately 15% white mica silt, trace plant debris.



7.5X magnification

54 - 59 inches:
dark brown (10 YR 3/3) micaceous sandy silt, very fine to fine quartz sand, most clasts lack iron stain and some are slightly iron stained, approximately 1% very dark green to black glauconite sand, trace plant debris.



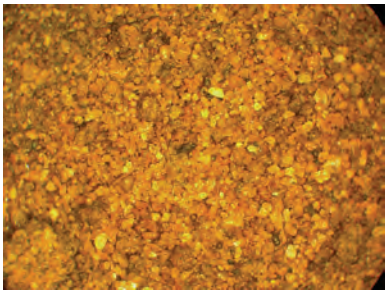


Shark River Formation – DEAL

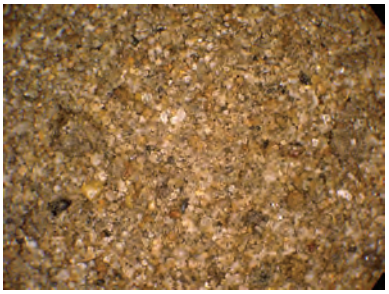
Latitude: 40 14 50.25, Longitude: 74 01 15.14

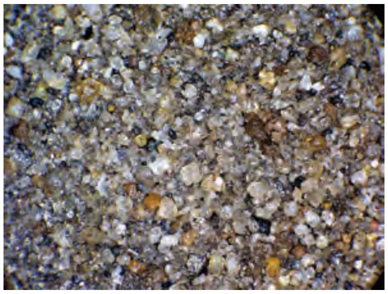
Augered hole approximately 8 feet from iron-stained stream and 12 to 18 inches above stream level to 54-inch TD. Water in auger hole rose to approximately 12 inches below ground level. Mild to moderately fetid. At this site and the one above (Figure 4) the undergrowth is virtually non-existent – ground surface is covered solely with leaf litter. A symptom of extreme soil acidity?

15 - 18 inches:
dark brown (7.5 YR 3/4) medium to fine, iron oxyhydroxide stained quartz sand, moderately well sorted, 1% black glauconite sand, minor plant debris.

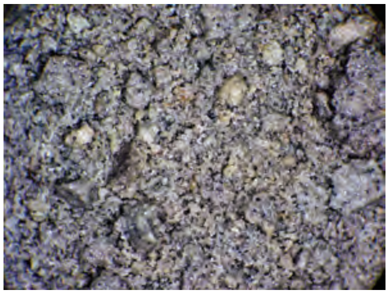


23 - 26 inches:
dark grayish brown (10YR 4/2) medium to fine quartz sand, moderately sorted, slight to no iron oxyhydroxide stain, approximately 2% black glauconite sand, very sparse plant debris, trace heavy minerals.





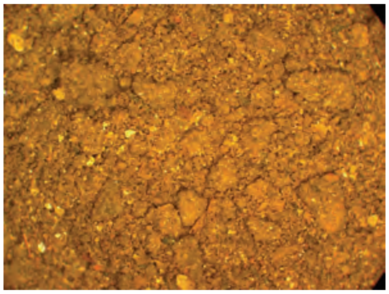
40 - 44 inches:
dark gray (10YR 4/1) silt, approximately 7% black very fine to fine glauconite sand, minor plant debris. Sample appears calcareous but did not react with HCl, possibly gypsiferous.



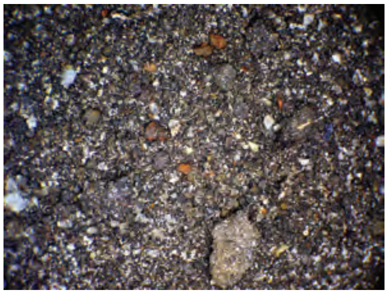
Shark River Formation -- MANALLI 1
Latitude: 40 10 33.97, Longitude: 74 10 14.00

Augered hole approximately 6 feet from and 30 inches above water level in Manasquan River at the river access site in Allaire State Park. Water in hole rose rapidly to stream level. 36-inch TD – from 36 to 48 inches washed out (no recovery) in a blackish grayish, clayey/silty glauconite (?) sand. Top 6 inches of hole was moderately fetid becoming less fetid down section.

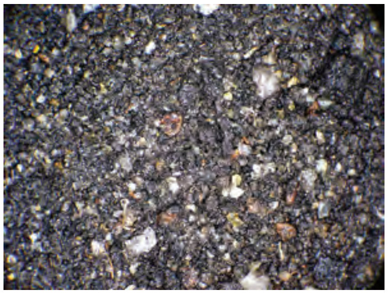
16 - 19 inches:
dark reddish brown (5YR 3/2) fine to very fine sandy quartz silt, quartz clasts range from predominantly unstained to iron stained, silt is extensively stained/cemented with iron oxyhydroxides, approximately 1% black to light grayish green glauconite sand, common plant debris, very rare mica.

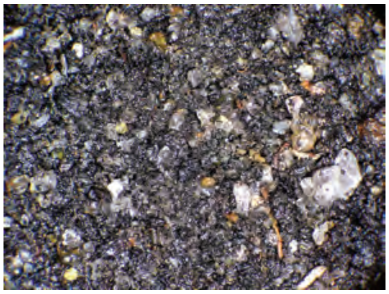


24 - 27 inches:
dark reddish brown (5YR 3/2), poorly sorted, quartz sandy silt, very fine to medium quartz sand with little to no stain, silt is gray brown (organics?), few brick red iron cemented aggregates, less than 1% black glauconite sand - difficult to identify, common plant debris and some charcoal.



33 - 36 inches:
black (5YR 2.5/ 1) quartz sandy silt with organics imparting a very dark brown to black stain, very poorly sorted, fine to very coarse quartz sand, a few quartz pebbles, lacks staining with iron or organics, less than 1% black glauconite sand - most difficult to identify in this unwashed sample, abundant plant debris.

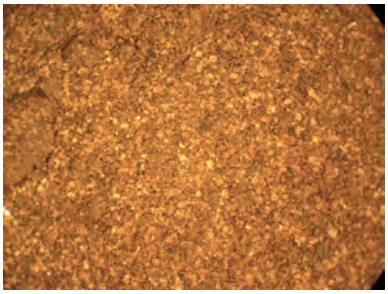


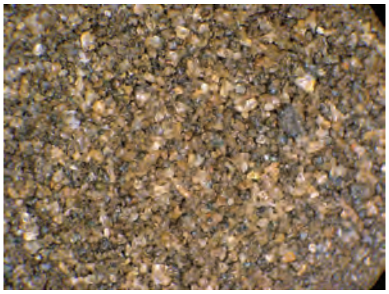


Hornerstown Formation – CC1
Latitude: 40 05 04.89, Longitude: 74 32 27.40

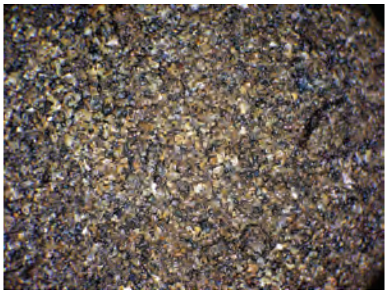
Hole augered to 60 inches TD approximately 7 feet from and 30 inches above stream level in coffee-brown Crosswick Creek north of Route 537. Water rose in auger hole to within 30 inches below ground level. No recovery from 51 to 60 inches due to water-saturated, unconsolidated, glauconite sand. Weakly to no apparent fetid odor.

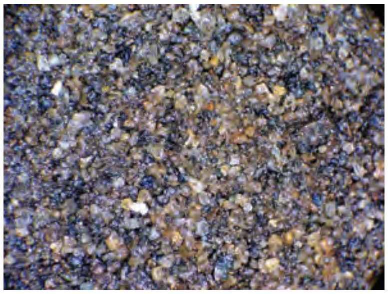
26 - 30 inches:
very dark grayish brown (10YR 3/2) very fine to medium quartz sand, well sorted, most quartz is lightly stained with organics and iron oxyhydroxide, approximately 10% very dark green to black glauconite sand, trace plant debris.



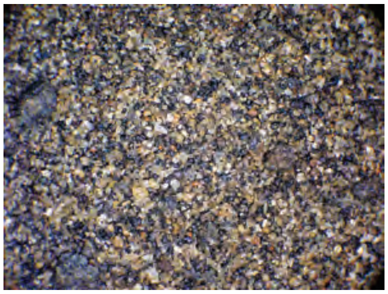


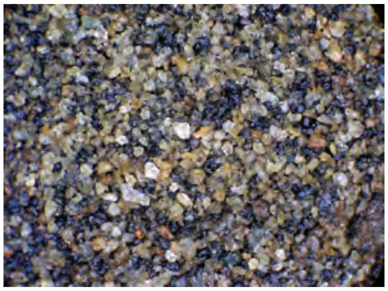
39 - 42 inches:
very dark grayish brown (10YR 3/2) medium to fine quartz sand, well sorted, light organic stain on quartz clasts, sparse iron staining, approximately 7 – 10% very dark green to black glauconite sand, trace organic debris.





48 - 51 inches:
very dark grayish brown (10YR 3/2) medium quartz sand, some fine quartz sand, well sorted, light organic stain on quartz clasts, sparse iron staining, approximately 15% very dark green to black glauconite sand, no apparent plant debris.

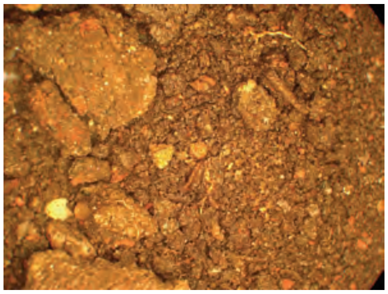


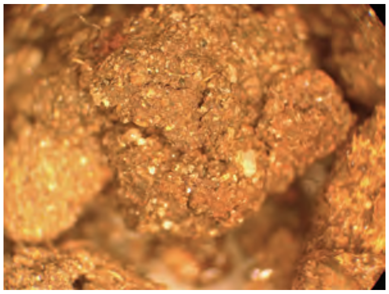


Hornerstown Formation – NEW EGYPT
Latitude: 40 04 08.69, Longitude: 74 31 48.94

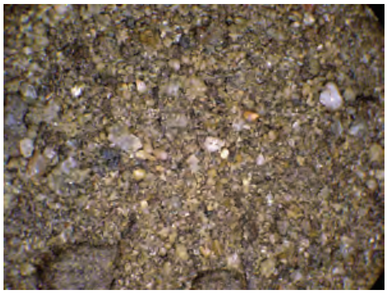
Augered hole to 57 inches TD approximately 6 feet from and 24 inches above an iron oxyhydroxide encrusted stream. Water in hole rose to stream level. Slightly to moderately fetid. From 24 to 57 inches, the sediment consisted of water-saturated glauconite sand with mottles of creamy, very light green ooze around 42 inches below ground surface.

10 - 14 inches:
dark reddish brown (5YR 2.5/2) weathered glauconite and iron oxyhydroxides, approximately 5 – 7% very coarse to fine quartz sand, some clasts lacking iron stain while others have variable iron oxyhydroxide stain, 5 – 7% black to very dark green glauconite sand, minor plant debris.



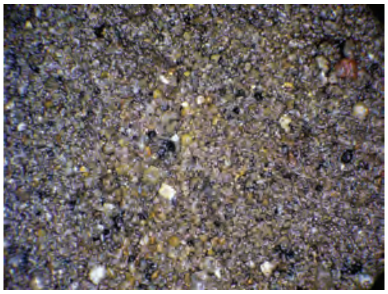


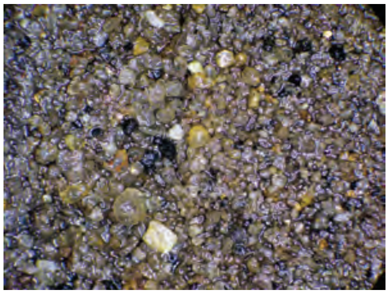
25 - 28 inches:
dark brown (10YR 3/3) very fine to coarse quartz sand, some very coarse quartz sand, most clasts lack iron stain but organic stain is apparent, approximately 2% mainly black with some very dark green glauconite sand with no iron stain, trace mica and plant debris.



7.5X magnification

48 - 57 inches:
dark brown (10YR 3/3) medium to coarse quartz sand with scarce iron stain, very light tan organic (?) stain, approximately 3% black glauconite sand, trace very fine mica and plant debris.

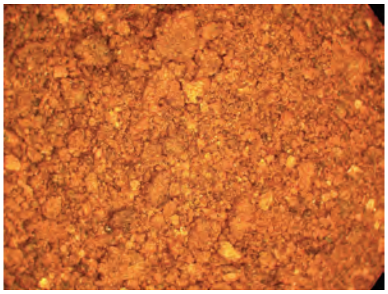


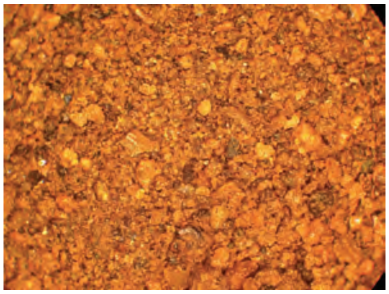


Manasquan Formation – BIRDMAN 1
Latitude: 40 11 15.50, Longitude: 74 09 29.18

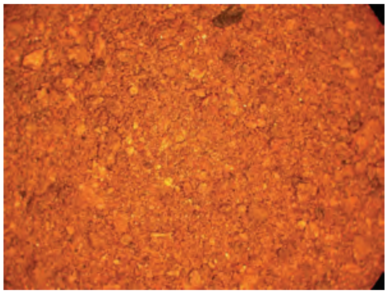
Hole augered approximately 18 inches from and 18 inches above stream level to 42 inches TD. Stream bank sediment at site is strongly stained by iron oxyhydroxides. Poor sample recovery from 12 to 18 inches due to water-saturated, unconsolidated sediment. Grayish black, glauconite-rich, silty sand occurs from 34 to 42 inches TD.

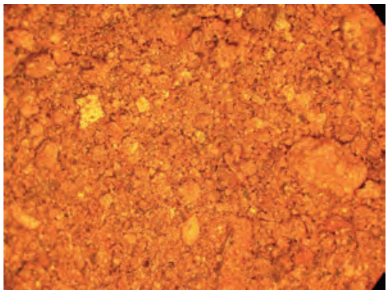
9 - 12 inches:
dusky red (10R 3/2) very fine to medium quartz sand, poorly sorted, moderate to strong iron stain, approximately 3% very dark green to black with some medium to light green (disaggregated) glauconite sand, trace very fine mica, very sparse plant debris.



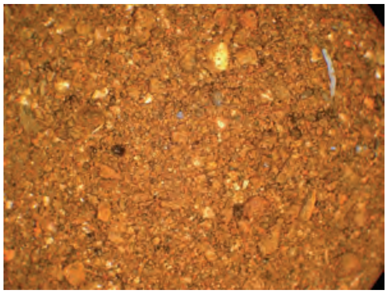


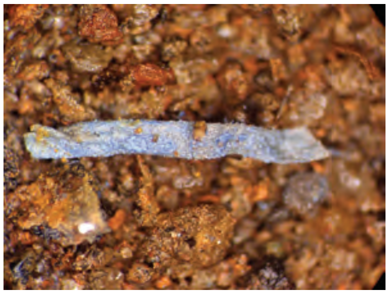
13 - 16 inches:
dusky red (10R 3/3) strongly weathered sandy quartz silt, very fine to fine quartz sand extensively iron oxyhydroxide stained/coated, 1 – 2% medium green to black glauconite sand, trace plant debris.





30 - 33 inches:
very dusky red (10R 2.5/2) very strongly weathered sandy quartz silt to silty fine quartz sand, most sand lacks iron staining to occasional spotty iron staining, 1 – 2% black glauconite sand, approximately 1% blue anhedral vivianite associated with plant debris, minor plant debris.



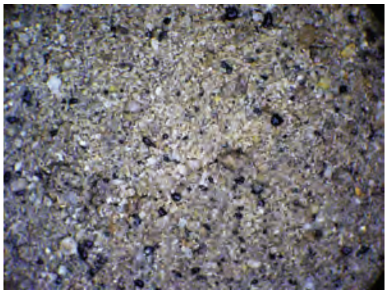


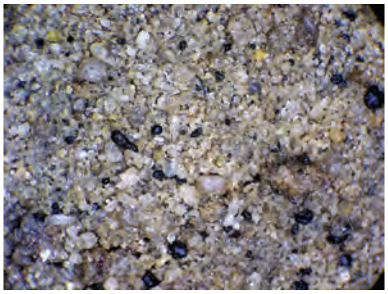
45X magnification

Manasquan Formation – MEDMAN
Latitude: 9 54 17.31, Longitude: 74 48 45.69

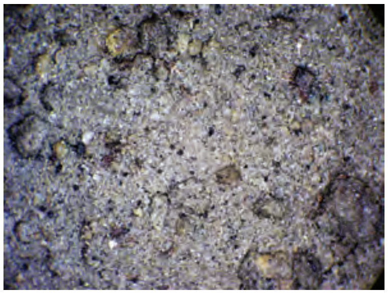
Hole augered to 54 inches TD approximately 25 feet from and approximately 36 inches above Haynes Creek. Stream water is chocolate brown. Water encountered at approximately 48 inches – samples from 48 to 54 inches were moist, but not saturated.

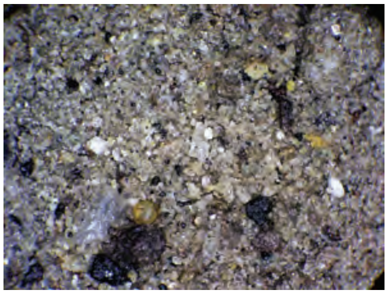
24 - 26 inches:
yellowish brown (10YR 5/4) fine to medium quartz sand with some coarse to very coarse quartz sand, moderately well sorted, most lack iron oxyhydroxide stain, light to no organic stain, approximately 4% black glauconite sand, trace mica, lacks plant debris.



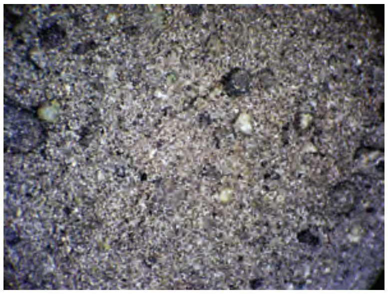


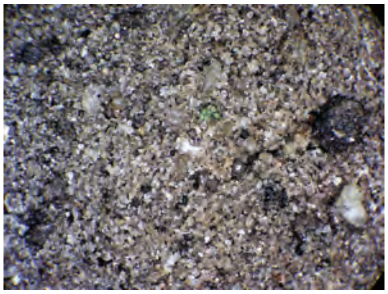
38 - 40 inches:
grayish brown (10YR 5/2) fine quartz sand with minor medium quartz sand, well sorted, lacks iron and organic stains, sand aggregates in photomicrograph are very weakly consolidated, approximately 3% black to very dark green glauconite sand, trace heavy minerals and mica, minor plant debris.





51 - 54 inches:
dark grayish brown (10YR 4/2) fine quartz sand with some coarse quartz sand, very well sorted, lacks iron and organic stains, sand aggregates in photomicrograph are very weakly consolidated, 1 – 2% black glauconite sand, trace heavy minerals and mica, lacks plant debris.





Manasquan Formation – VINMAN
Latitude: 39 55 47.28, Longitude: 74 44 36.66

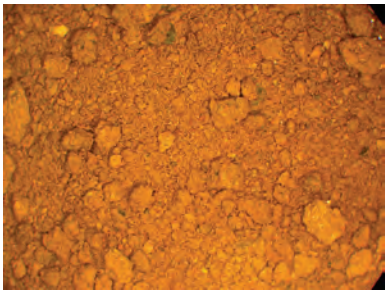
Augered hole to 54 inches approximately 15 feet from and approximately 30 inches above the stream. Water is a deep brown. Water in hole rose to approximately 24 inches below the ground surface. Samples from around 24 inches had a strong sulfur odor (fetid).

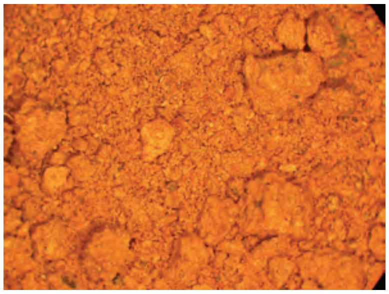
Samples are missing from the archive.

Tinton Formation – GARD 1
Latitude: 40 12 42.67, Longitude: 74 17 43.12

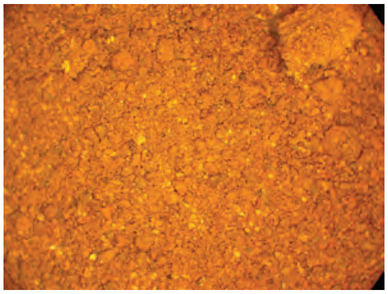
Augered hole to 48 inches TD approximately 10 feet from and 36 inches above stream level having an iron oxyhydroxide encrusted stream bed in Michael J. Tighe Park. No water was apparent in hole although swabbing near TD was heard. Slightly fetid. Most of section was clayey and tight making augering difficult.

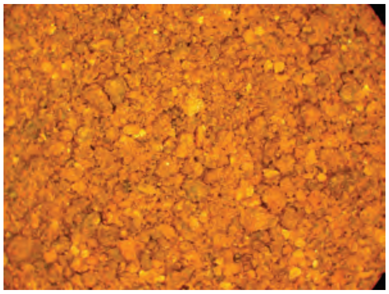
16 - 18 inches:
dark brown (7.5YR 3/4) clayey very fine silt, heavily iron oxyhydroxide stained, approximately 2% black to moderate green glauconite sand – difficult to identify, trace quartz sand, mica, and plant debris.



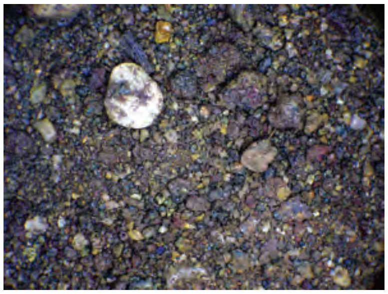


32 - 36 inches:
dark brown (7.5YR 3/4) quartz sandy silt, medium to fine quartz sand ranging from no stain to extensively iron coated, approximately 5% very dark green to light (army) green glauconite sand, light green glauconite sand is weathered and broken, minor plant debris.





44 - 48 inches:
very dark grayish brown (10YR 3/2) pebbly, silty, glauconite and quartz sand, most clasts are coated in oranges and reds with iron oxyhydroxides, glauconite/quartz ratio is ~1, approximately 30% very dark green to bluish green (weathered) glauconite sand, brick-red (hematite?) cemented aggregates containing glauconite sand are very common, minor organic debris.

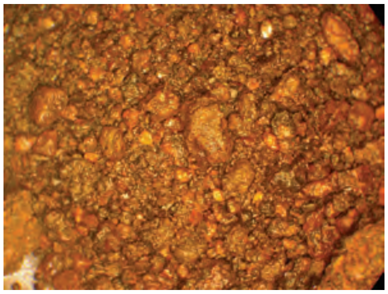


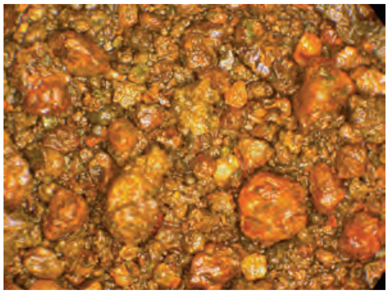
Tinton Formation – PINE BROOK
Latitude: 40 18 17.43, Longitude: 74 06 03.06

The Tinton Formation crops out at Route 537 and Sycamore Road in Tinton Falls. Could not auger the well-indurated Tinton Formation. Two indurated samples were taken from the exposure.

12 - 15 inches:

dark brown (7.5YR 3/2) sandy silt, medium to very coarse quartz sand, clasts are strongly coated with iron oxides and weakly cemented by iron oxides, approximately 5% dark green to greenish gray weathered glauconite sand, trace phosphate sand, sparse plant debris.



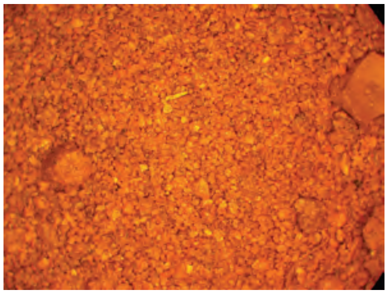


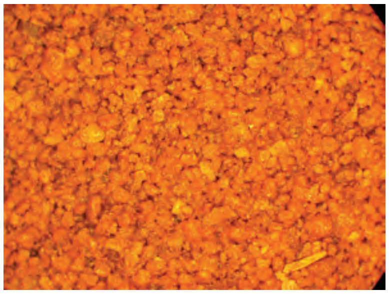
7.5X magnification

Tinton Formation – YELLOWBRK
Latitude: 40 16 35.90, Longitude: 74 13 05.28

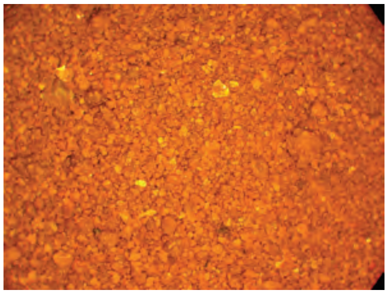
Augered hole to 54 inches TD approximately 20 feet from and 36 inches above Yellow Brook at Colts Neck. Water in auger hole rose to approximate level of stream. No recovery from 48 to 54 inches due to swabbing.

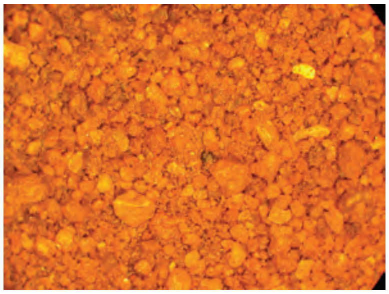
9 - 12 inches:
brown (7.5YR 4/4) slightly silty medium to fine quartz sand, clasts are strongly coated in iron oxyhydroxides, 1% black to army green (weathered) glauconite sand, very rare mica, trace plant debris.



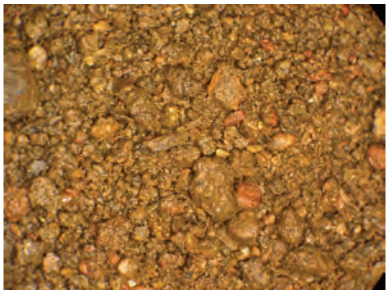


34 - 37 inches:
dark brown (7.5YR 3/4) silty, medium to fine quartz sand, strongly iron oxyhydroxide coated, approximately 1% black to very dark green glauconite sand, slightly micaceous.





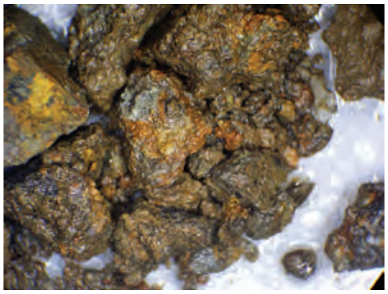
43 - 48 inches:
dark brown (7.5YR 3/2) slightly clayey silt coated with organics + iron oxyhydroxides, brick red aggregates are common, glauconite concealed by fine grain character of unwashed sample, minor plant debris, trace vivianite in association with plant debris.



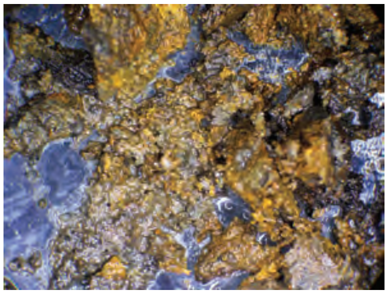
Marshalltown Formation – HORSEBRK
Latitude: 40 12 17.46, Longitude: 74 30 53.75

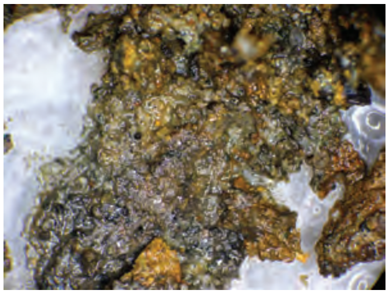
Hole augered to 54 inches TD in marsh bordering the north side of Horse Brook in Assumpink State Park WMA. Water rose in hole to approximately 12 inches below ground surface. Slightly to moderately fetid.

16 - 20 inches:
dark grayish brown (10YR 4/2) mottled with orangish iron oxyhydroxide silty/clayey fine to very fine quartz sand with some medium to very coarse quartz sand, orangish quartz sand is strongly iron oxyhydroxide stained, remainder of quartz sand has no to light iron oxyhydroxide stain, approximately 3% very dark green to black glauconite sand with identification very difficult, slightly micaceous.



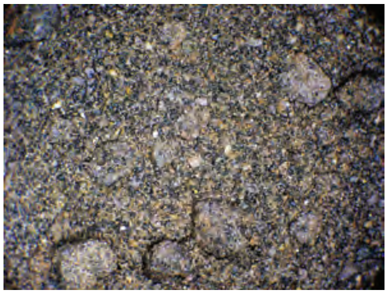
30 - 34 inches:
very dark grayish brown (10YR 3/2) mottled with orangish iron oxyhydroxide clayey/silty quartz sand, poorly sorted, medium to very fine quartz sand with some very coarse sand to fine white pebble quartz, 3 – 5% very dark green to black glauconite sand with identification very difficult, trace very fine mica.

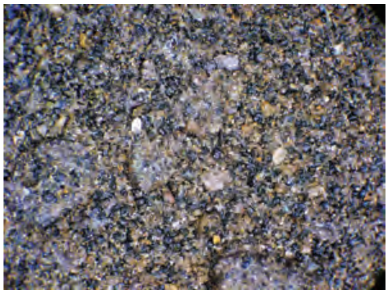




20X magnification

50 - 54 inches:
brown (10YR 4/3) silty glauconite and quartz sand, most quartz is stained with organics and iron oxyhydroxides, approximately 20% black to very dark green glauconite sand, mainly fine to very fine quartz sand, minor mica, lacks plant debris.

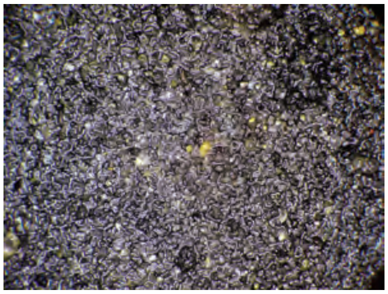


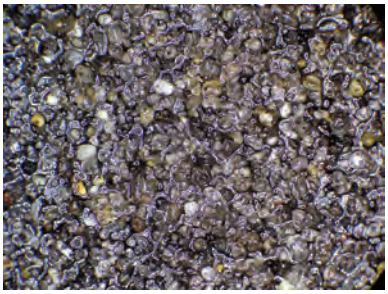


Marshalltown Formation – AUBURN
Latitude: 39 42 13.66, Longitude: 75 23 04.80

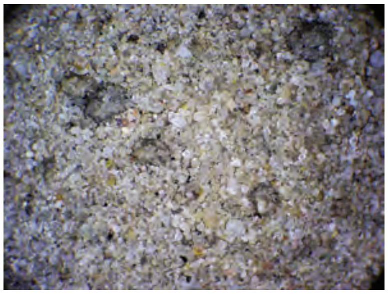
Hole augered to 51 inches TD in a swampy drainage plain approximately 75 feet north of a field cultivated with wheat. Water taken from stream approximately 200 feet from sample site. Stream lacks evidence of high iron oxyhydroxide concentration. Water rose in hole to approximately 10 inches below ground surface. Some washout (poor recovery) for deep samples. Strong to moderate fetid odor in cored section. Top 12 inches is a black soil with a strong fetid odor in sharp contact with underlying greenish sand.

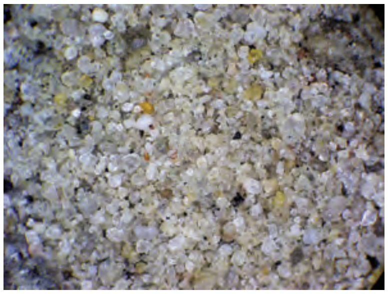
8 - 12 inches:
very dark gray (10YR 3/1), well sorted, medium quartz sand, some coarse quartz sand, most quartz is gray to dark gray from organics and few are iron stained, approximately 2 – 3% black glauconite sand which is difficult to identify due to masking by prevalent organics, unidentifiable organic debris.



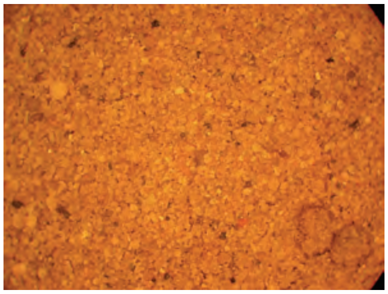


20 - 24inches:
light gray (10YR 7/2), frosted, clean, well sorted, medium to fine quartz sand, approximately 1% black glauconite sand, rare organic debris, resembles beach sand.





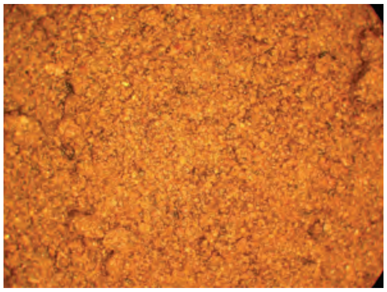
46 - 51 inches:
brownish yellow (10YR 6/6) medium to fine quartz sand coated with iron oxyhydroxide film imparting orange color, approximately 1% black to light green (weathered) glauconite sand, very rare mica.



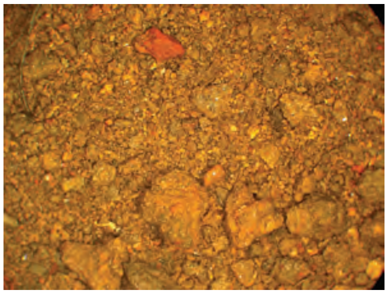
Marshalltown/Wenonah(?) Formation – PROVLIN
Latitude: 40 08 17.45, Longitude: 74 35 16.04

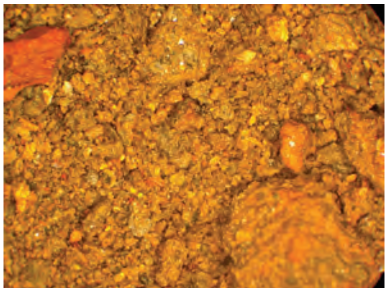
Hole augered to 58 inches TD approximately 8 feet from and 36 inches above stream level. Water in hole rose to stream level. Poor recovery from 36 to 58 inches due to swabbing of water-saturated sediment.

21 - 24 inches:
dark yellowish brown (10YR 4/4) medium to fine quartz sand coated with tannish iron oxide and/or organics?, very silty to clayey, approximately 2% dark green to black glauconite sand coated like quartz sand, trace plant debris.

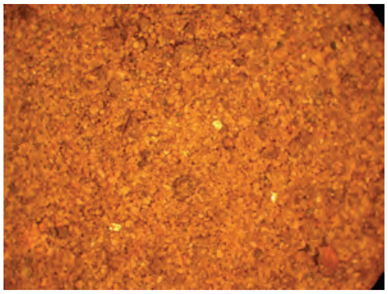


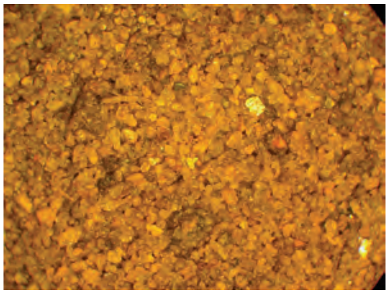
33 - 36 inches:
dark brown (7.5YR 4/4) silty fine quartz sand most of which is coated with orangish to brick red iron oxyhydroxide-rich silt/clay, approximately 1% brick red to orangish iron oxyhydroxide cemented sand, approximately 1% glauconite sand (most difficult to identify in unwashed sample), sample is very weathered, minor plant debris and iron oxyhydroxide tubules (root casts?).





48 - 50 inches:
strong brown (7.5YR 4/6) medium to fine quartz sand, well sorted, most clasts coated with an orangish brown to tan iron oxyhydroxide, approximately 1% mica, less than 1% very fine glauconite sand to silt, no plant debris.

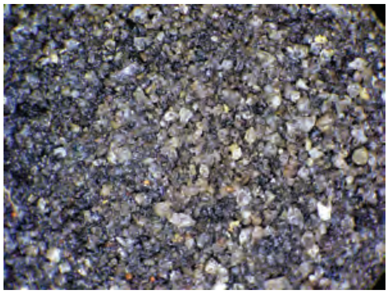




Wenonah Formation – MANWEN
Latitude: 39 47 44.23, Longitude: 75 10 15.72

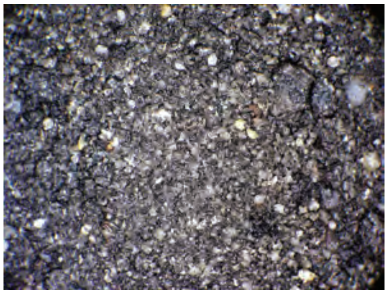
Hole augered to 54 inches TD approximately 20 feet from and 21 inches above the stream. Water rose in the hole to approximately 30 inches below the ground surface.

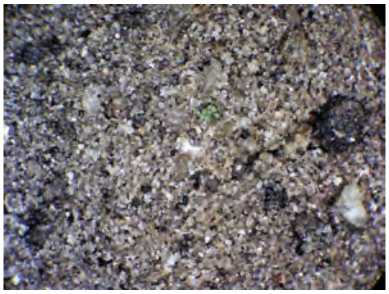
14 - 18 inches:
very dark reddish brown (5YR 2.5/2) medium to fine quartz sand with some sand aggregates held together loosely by a dark gray silty matrix, few very coarse to coarse white quartz sand, lacks iron stain but organic stain is apparent, approximately 2% black to very dark green glauconite sand.



22 - 26 inches:
very dark reddish brown (5YR 2.5/2) sandy quartz silt, quartz sand is very fine to coarse, lacks iron stain, approximately 1 – 2% black glauconite sand, assorted lithic fragments/grains/aggregates, minor plant debris

48 - 52 inches:
black (5YR 2.5/1) silty medium to fine quartz sand with few white, very coarse quartz sand, approximately 7% very dark green to black glauconite sand, trace mica, minor plant debris.

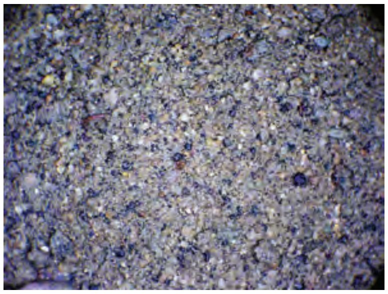


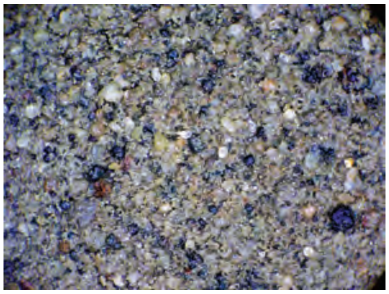


Navesink Formation – MARLHGTS
Latitude: 39 42 14.62, Longitude: 75 20 56.21

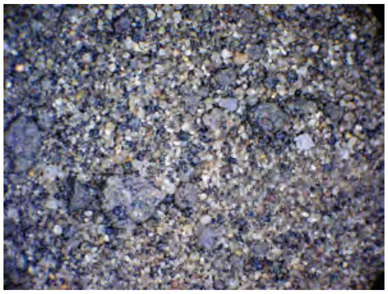
Augered hole to 54 inches TD approximately 20 feet from and 48 inches above stream level at Marlton Heights. Slight swabbing near TD and water was not visible in hole. Core section was strongly fetid.

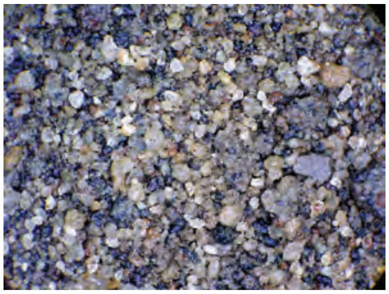
14 - 18 inches:
dark grayish brown (10YR 4/2) slightly silty, poorly sorted medium to very fine quartz sand, most quartz has a very light iron oxyhydroxide film, approximately 6% black glauconite sand, few weathered green, very sparse plant debris, few white quartz pebbles.



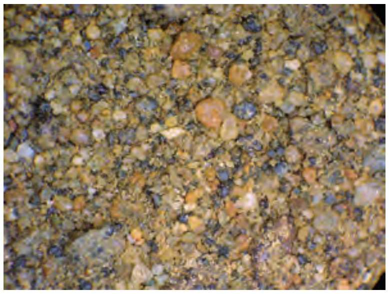


32 - 36 inches:
dark grayish brown (10YR 4/2) medium to fine, some very fine, quartz sand, most clasts lack obvious film/coating, approximately 10% black glauconite sand, very rare plant debris.





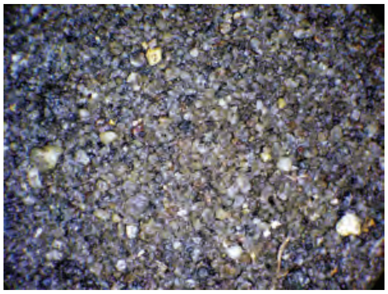
50 - 54 inches:
dark grayish brown (10YR 4/2) slightly silty medium to fine quartz sand, few coarse to very coarse quartz sand, poorly sorted, quartz sand coated with iron oxyhydroxide film, approximately 10% black to very dark green glauconite sand, very sparse, very fine mica.

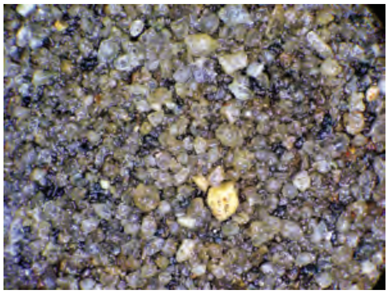


Navesink Formation – MANTUA CRK
Latitude: 39 47 16.46, Longitude: 75 07 35.95

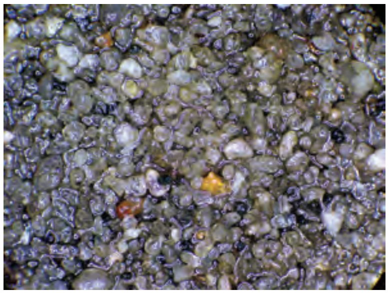
Hole augered to 54 inches TD approximately 100 feet from iron-stained Mantua Creek and 30 feet from a swampy area bordering the creek. Sample site approximately 30 inches above swamp. Water level in hole rose to approximately 6 inches below ground surface. Minor to no recovery (wash out) in a light, pistachio-green sand from approximately 24 to 54 inches.

8 - 12 inches:
brown (10YR 4/3) medium quartz sand, some fine quartz sand and few coarse sand to pebble quartz + feldspar?, moderately well sorted, slight film of organics imparts a very light gray color to clasts, approximately 3% black to green glauconite sand, trace mica and plant debris.





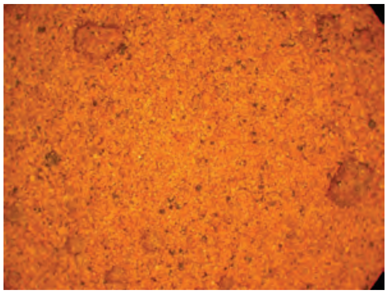
24 - 28 inches:
dark grayish brown (10YR 4/2) medium to coarse quartz and feldspar? sand, well sorted, very light organic film on clasts, approximately 3% black to green glauconite sand, trace mica, minor plant debris. Approximately 5% white (feldspar?) clasts.



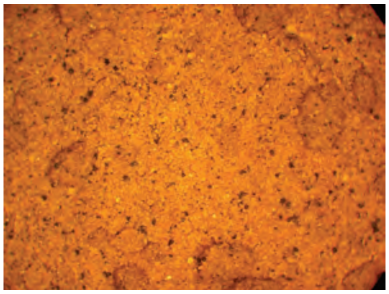
Navesink Formation – SMITNAV
Latitude: 39 59 02.71, Longitude: 74 44 54.63

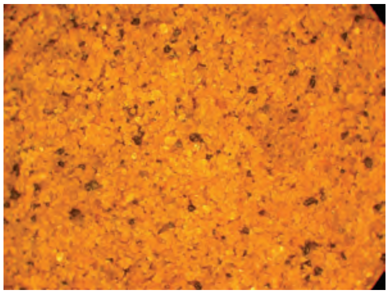
Augered hole to 57 inches TD approximately 3 feet from and 18 inches above stream at Smitville. Water in stream is a dark chocolate brown. Water in hole rose slowly to within approximately 18 inches below grade.

24 - 26 inches:
dark yellowish brown (10YR 4/6) fine quartz sand coated with iron oxyhydroxides, well sorted, 2 – 3% very dark green glauconite sand some with light, spotty iron oxyhydroxide coat, trace mica.

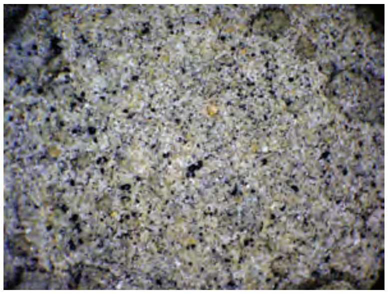


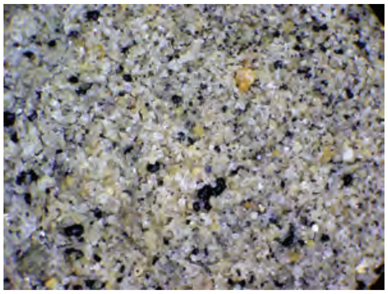
32 - 34 inches:
yellowish brown (10YR 5/4) well sorted, fine quartz sand, some medium quartz sand, clasts lightly stained by iron oxyhydroxide, 5% black glauconite sand lacking iron stain, 1% mica.





54 - 57 inches:
pale olive (5Y 6/3) well sorted, fine quartz sand, some medium quartz sand, most clasts show no stain, very few are lightly iron stained, 7% black glauconite sand, trace mica and heavy minerals.

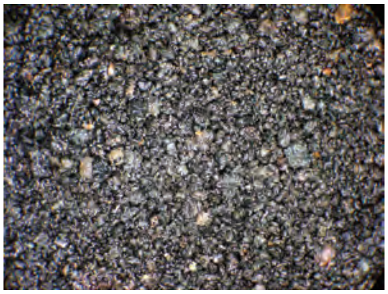




Navesink Formation – INVERSAND
Latitude: 39 45 43.32, Longitude: 75 07 38.67

Grab sample taken from former working face of pit. Entering the pit and while in the pit, a very strong odor of sulfur permeated the air despite being a breezy day. A white efflorescence admixed with glauconite sand from the pit face had a very strong odor of sulfur.

Grab:
very dark greenish black (5Y 2.5/2), medium to coarse glauconite sand, very rare quartz sand, trace euhedral gypsum, approximately 1% phosphate (apatite) sand, shell fragments.



Appendix B

Photomicrograph of glauconitic and pyritic Merchantville Formation at 1228 feet below grade in the Millville corehole. Magnified 18 times.