NEW JERSEY COASTAL PLAIN STRATIGRAPHY & COASTAL PROCESSES

CONFERENCE PROCEEDINGS

EDITED BY

DEBORAH FREILE

NEW JERSEY CITY UNIVERSITY

GEOLOGICAL ASSOCIATION OF NEW JERSEY

XXVI ANNUAL CONFERENCE AND FIELD TRIP

OCTOBER 9-10, 2009

RICHARD STOCKTON COLLEGE OF NEW JERSEY

POMONA, NJ

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Front Cover: Stratigraphic section at the current excavation, Inversand Pit, Sewell, NJ. Maastrichtian Navesink Formation at base; green sand and Hornerstown Formation form the bulk of the cliff; lighter colored Miocene units (Kirkwood, Cohansey) on top. Total thickness= approximately 60 feet (20 m). (photo credit-William Gallagher).

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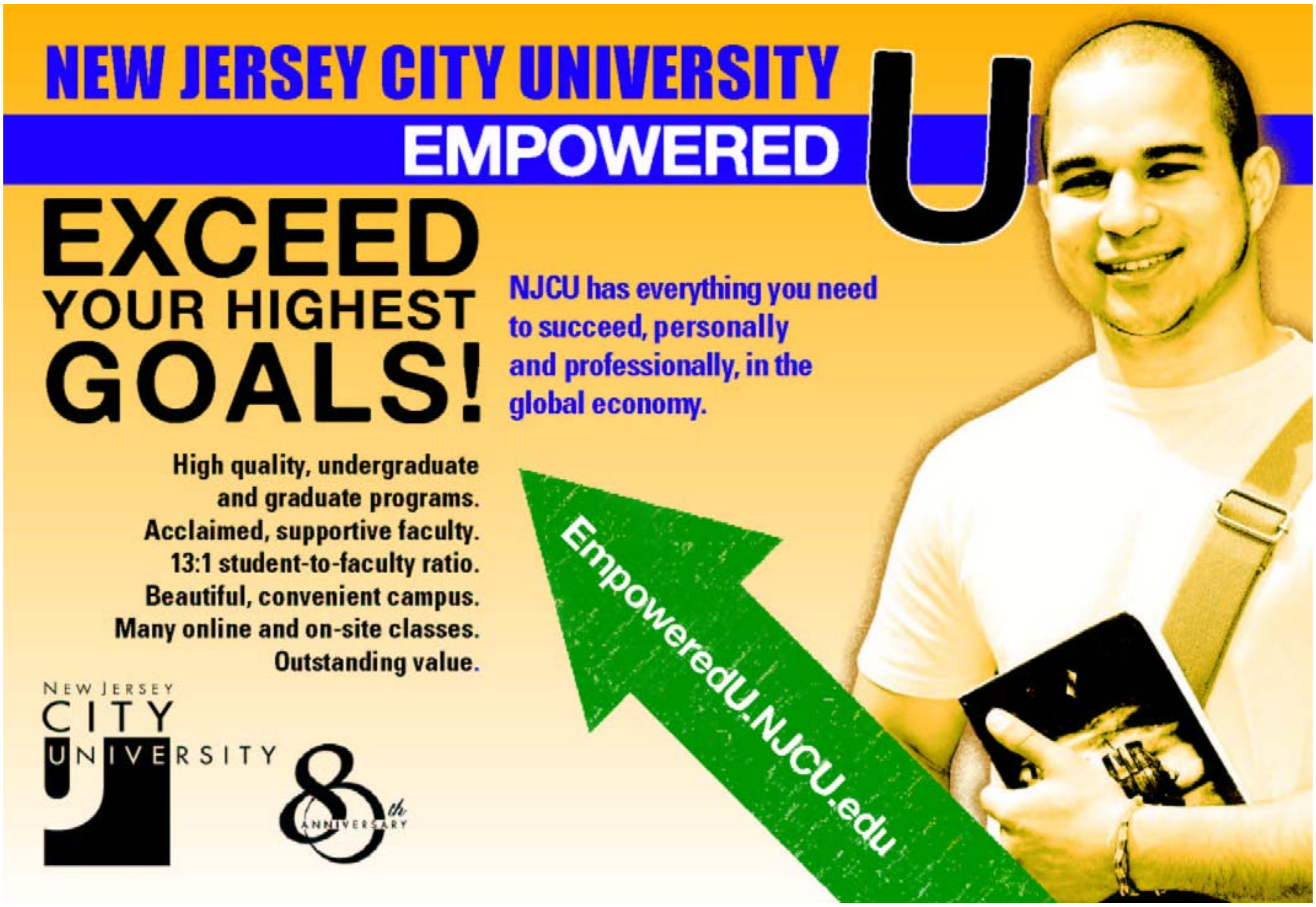
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First Annual Meeting – 1984: Puffer, John H., ed., 1984, *Igneous Rocks of the Newark Basin: Petrology, Mineralogy, and Ore Deposits, and Guide to Field Trip.*

Second Annual Meeting - 1985*: Talkington, Raymond W., and Epstein, Claude M., eds., 1985, *Geological Investigations of the Coastal Plain of Southern New Jersey: Part 1 - Field Guide; Part 2A - Hydrology and Coastal Plain; Part 2B - Paleontologic Investigations (The set, Parts 1, 2A, 2B, priced as one volume).*

Third Annual Meeting – 1986: Husch, Jonathan, M., and Goldstein, Fredric R., eds., 1986, *Geology of the New Jersey Highlands and Radon in New Jersey.*

Fourth Annual Meeting - 1987*: Gallagher, William B., ed., 1987, Paleontology and Stratigraphy of the Lower Paleozoic Deposits of the Delaware Water Gap Area.

Fifth Annual Meeting – 1988: Husch, Jonathan, M., and Hozik, Michael J., eds., 1988, *Geology of the Central Newark Basin.*

Sixth Annual Meeting - 1989*: Grossman, I. G., ed., 1989, Paleozoic Geology of the Kittatinny Valley and Southwest Highlands N. J.

Seventh Annual Meeting – 1990: Brown, James O., and Kroll, Richard L., eds., 1990, *Aspects of Groundwater in New Jersey.*

Eighth Annual Meeting – 1991: Crawford, Maria L., and Crawford, William A., eds., 1991, *Evolution and Assembly of the Pennsylvania - Delaware Piedmont.*

Ninth Annual Meeting – 1992: Ashley, Gail M., and Halsey, Susan D., eds., 1992, *Environmental Geology of the Raritan River Basin.*

Tenth Annual Meeting – 1993: Puffer, John H., ed., 1993, Geologic Traverse Across the Precambrian Rocks of the New Jersey Highlands.

Eleventh Annual Meeting – 1994: Benimoff, Alan I., ed., 1994, *Geology of Staten Island*, *New York.*

Twelfth Annual Meeting – 1995: Baker, John E. B., ed., 1995, *Contributions of the Paleontology of New Jersey.*

Thirteenth Annual Meeting – 1996: Dalton, Richard F., and Brown, James O., eds., 1996, *Karst Geology of New Jersey and Vicinity.*

Fourteenth Annual Meeting – 1997: Benimoff, Alan I., and Puffer, John H., 1997, *The Economic Geology of Northern New Jersey.*

Fifteenth Annual Meeting – 1998: Puffer, John H., ed., 1998, *The Economic Geology of Central New Jersey.*
Sixteenth Annual Meeting – 1999: Puffer, John H., ed., 1999, New Jersey Beaches and Coastal Processes from a Geologic and Environmental Perspective.

Seventeenth Annual Meeting – 2000: Harper, David P. and, Goldstein, Fredric L., eds., 2000, *Glacial Geology of New Jersey.*

Eighteenth Annual Meeting – 2001: Lacombe, Pierre, and Herman, Gregory, eds., 2001, *Geology in Service to Public Health.*

Nineteenth Annual Meeting – 2002: D'Amato, Dana, ed., 2002, *Geology of the Delaware Water Gap Area.*

Twentieth Annual Meeting – 2003: Hozik, Michael J., and Mihalasky, Mark J., eds., 2003, *Periglacial Features of Southern New Jersey.*

Twenty-first Annual Meeting – 2004: Puffer, John H., and Volkert, Richard A, eds., 2004, Neoproterozoic, Paleozoic, and Mesozoic Intrusive Rocks of Northern New Jersey and Southeastern New York.

Twenty-second Annual Meeting – 2005: Gates, Alexander E., ed., 2005, Geology of the Central Newark Basin - The View From the 21st Century.

Twenty-third Annual Meeting – 2006: Macaoay, Suzanne and Montgomery, William, eds., *Environmental Geology of the Highlands.*

Twenty-fourth Annual Meeting – 2007: Rainforth, Emma C., ed., 2007, *Contributions to the Paleontology of New Jersey (II).*

Twenty-fifth Annual Meeting – 2008: Gorring, Matthew L., ed., 2008, Environmental and Engineering Geology of Northeastern New Jersey.

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CONFERENCE SCHEDULE

FRIDAY, OCTOBER 9, 2009

The Lakeside Center at the Richard Stockton College of New Jersey

11:00-4:00 Registration

11:00-4:00 Posters

Determination of Variability in Hydraulic Conductivity of the Kirkwood-Cohansey Aquifer System Using Geophysical and Boring Logs of Wells in Cumberland County and Vicinity, New Jersey Coastal Plain
Alison D. Gordon, Richard L. Walker, Susan A. Collarullo, U.S. Geological Survey, New Jersey Water Science Center, West Trenton, New Jersey

Water-Level Conditions in Selected Confined Aquifers of the New Jersey and Delaware Coastal Plain
Vincent T. DePaul, Robert Rosman, and Pierre J. Lacombe, U.S. Geological Survey

11:30-1:00 **Teacher Workshop**
Salt Marsh Dynamics - An Endangered Coastal Ecosystem in a Second Life's NMC Virtual Space
Martha B Schoene, Marian Glenn, and Heidi Trotta, Seton Hall University

1:15-1:30 **Welcoming Remarks**
Deborah Freile, New Jersey City University, GANJ President

1:30-1:50 Hydrostratigraphy of the New Jersey Coastal Plain: Sequences and Facies Predict Continuity of Aquifers and Confining Units
Peter J. Sugarman[1], Kenneth F. Miller[2], James V. Browning[2], and Donald H. Monteverde,[1] [1]New Jersey Geological Survey, [2]Rutgers University - Department of Earth and Planetary Sciences.

1:50-2:10 An Iterative Shallow Hydrogeologic Investigation of Elevated Mercury Concentrations, Atlantic County, New Jersey
Ralph Costa, Dyna L. Krumich, Ryan H. Brown, Weston Solutions, Inc

2:10-2:30 Late Cretaceous Dinosaurs and Fossil Vertebrate Concentrations in the New Jersey Coastal Plain: Taphonomy, Stratigraphic Occurrence and Paleoenvironments
William Gallagher, Rider University

2:30-2:50 Detailed Temporal Measurement of Salt Marsh Edges Using GIS
James P. Browne, Stony Brook University & Department of Conservation and Waterways, Town of Hempstead, NY

2:50-3:10 Quantifying Alterations in Marshland Area within the South Shore Estuary Reserve, Long Island, NY Throughout the Past Century
Jonathan Ciappetta[1], James P. Browne[2], Beth Christensen[1], [1]Environmental Studies, Adelphi University, [2]Conservation and Waterways, Town of Hempstead, Point Lookout, NY,

3:10-3:30 Paleotempestology of Long Island: Does Grain Size Indicate Past Hurricane Activity?
E. Christa Farmer[1], Beth Christensen[2], Deborah Freile[3], James Browne[4], Jon Ciappetta[2,4], Matt Jensen[1], Angela Rosiello[3], Stephen Haslbauer[2], and Mark Zdziarski[3], [1]Hofstra University, [2]Adelphi University, [3]New Jersey City University, [4]Department of Conservation and Waterways, Town of Hempstead, NY

3:30-4:00 New Jersey Coastal Plain Reveals Global Sea-Level Changes in the Cretaceous Greenhouse
Svetlana F. Mizintseva, James V. Browning, and Kenneth G. Miller, Rutgers University

4:00-4:45 On-Campus Tour - Two Innovative Underground Thermal Energy Stores for Heating and Cooling Buildings at Richard Stockton College
Lynn Stiles, Richard Stockton College

5:00-6:00 **Keynote Speaker**
Kenneth G. Miller, Ph.D., Chairman of the Department of Earth and Planetary Sciences of Rutgers University and Chief Scientist for the New Jersey Coastal Plain Drilling Project Integrated Sequence Stratigraphy and Global Seal-Level: Should I Sell My Shore

6:30 Dinner and Business Meeting

SATURDAY, OCTOBER 10, 2009

8:00-11:30 Field Trip Departs- Part I- Coastal Processes (Morning)
Stops at Strathmere, Avalon and North Wildwood

11:30-12:30 Lunch-

12:30-1:30 Travel to Sewell, NJ and Inversand Pit (read field Trip Part II- Roadside Geology of Cape May County)

1:30-4:00 Field Trip- Part III- Stratigraphy and Paleontology of the Marl Mines (Afternoon)

4:00-5:00 Return to Richard Stockton College

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DETERMINATION OF VARIABILITY IN HYDRAULIC CONDUCTIVITY OF THE KIRKWOOD-COHANSEY AQUIFER SYSTEM USING GEOPHYSICAL AND BORING LOGS OF WELLS IN CUMBERLAND COUNTY AND VICINITY, NEW JERSEY COASTAL PLAIN

Alison D. Gordon, Richard L. Walker, Susan A. Collarullo

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agordon@usgs.gov

The U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, is developing a groundwater flow model of the Kirkwood-Cohansey aquifer system in Cumberland County. A hydrostratigraphic framework was developed for a fully 3-dimensional groundwater flow model using approximately 200 geophysical logs and boring logs. Stratigraphic cross-sections were prepared based on the interpretations of the geophysical logs and boring logs using RockWorks™ 2002 software. Hydraulic conductivity for the Kirkwood-Cohansey aquifer system was determined by assigning values for various depth intervals that represent the range of sediment textures typically encountered in the Coastal Plain. These hydraulic conductivity values were determined from geologic sediment textures interpreted from geophysical logs, and boring logs of wells and boreholes in the Cumberland County area.

The established relation of grain size distribution to hydraulic conductivity was used to estimate hydraulic conductivity for the various sediment textures typical of the Kirkwood-Cohansey aquifer system. Hydraulic conductivity for wells in the study area was determined from aquifer test data from the New Jersey Geological Survey Hydroparameter database, specific capacity data, or from a literature review of investigations conducted in wells or at sites in the Cumberland County vicinity. Estimated sediment textures were compared to hydraulic conductivities determined by these methods to determine a numerical relationship between these parameters.

The Kirkwood-Cohansey aquifer system contains sediment textures ranging from clay to coarse sand and gravel. The spatial variability of these sediment textures was expressed as a percentage of sand content, referred to as percent sand. These percent sand values were modeled in three dimensions in RockWorks™ to develop a spatial distribution of percent sand. The percent sand values were converted to representative hydraulic conductivity values based on the relationship established by comparing well-test data and estimated sediment textures to yield a spatial distribution of hydraulic conductivity that can be assigned to a 3-dimensional grid for use in the groundwater flow model.

WATER-LEVEL CONDITIONS IN SELECTED CONFINED AQUIFERS OF THE NEW JERSEY AND DELAWARE COASTAL PLAIN

Vincent T. dePaul, Robert Rosman, and Pierre J. Lacombe
U.S. Geological Survey, New Jersey Water Science Center, West Trenton, New Jersey
placombe@usgs.gov

The Coastal Plain aquifers of New Jersey provide an important source of water for more than 2 million people. Steadily increasing withdrawals from the late 1800s to the early 1990s resulted in declining water levels and the formation of regional cones of depression. In addition to decreasing water supplies, declining water levels in the confined aquifers have led to reversals in natural hydraulic gradients that have, in some areas, induced the flow of saline water from surface-water bodies and adjacent aquifers to freshwater aquifers. In 1978, the U.S. Geological Survey began mapping the potentiometric surfaces of the major confined aquifers of New Jersey every 5 years in order to provide a regional assessment of ground-water conditions in multiple Coastal Plain aquifers concurrently. In 1988, mapping of selected potentiometric surfaces was extended into Delaware.

During the fall of 2003, water levels measured in 967 wells in New Jersey, Pennsylvania, northeastern Delaware, and northwestern Maryland were used to estimate the potentiometric surface of the principal confined aquifers in the Coastal Plain of New Jersey and five equivalent aquifers in Delaware. Potentiometric-surface maps and hydrogeologic sections were prepared for the confined Cohansey aquifer of Cape May County, the Rio Grande water-bearing zone, the Atlantic City 800-foot sand, the Vincentown aquifer, and the Englishtown aquifer system in New Jersey, as well as for the Piney Point aquifer, the Wenonah-Mount Laurel aquifer, and the Upper Potomac-Raritan-Magothy, the Middle and undifferentiated Potomac-Raritan-Magothy, and the Lower Potomac-Raritan-Magothy aquifers in New Jersey and their equivalents in Delaware.

From 1998 to 2003, water levels in many Coastal Plain aquifers in New Jersey remained stable or had recovered, but in some areas, water levels continued to decline as a result of pumping. In the Cohansey aquifer in Cape May County, water levels near the center of the cone of depression underlying the southern part of the peninsula remained about the same as in 1998. To the south, recoveries up to 8 feet were observed in southern Lower Township as withdrawals had decreased since 1998. In the northern part of Cape May County, water levels had not changed substantially from historic conditions. In the Rio Grande water-bearing zone, water levels rose by as much as 13 ft at the Rio Grande well field; elsewhere across the aquifer, little change had occurred.

In the Atlantic City 800-foot sand, water-level changes were greatest in southern Cape May County; at the Cape May desalination wells, water levels were as much as 32 ft lower in 2003 than in 1998. In contrast, water levels at the center of a regional cone of depression near Atlantic City rose by as much as 10 ft. Within the Piney Point aquifer water levels rose by 46 ft near Seaside Park. Similarly, water levels increased by more than 30 ft in and around the major cone of depression underlying Dover, Delaware. In the Vincentown aquifer, water levels stabilized or recovered by 2 ft to 6 ft from 1998 to 2003 in most of the wells measured; the exception is near Adelphia in Monmouth County, where water levels rose by as much as 18 ft.

From 1998 to 2003, water levels near the center of a large cone of depression that extends from Monmouth to Ocean County recovered by as much as 20 ft in the Wenonah-Mount Laurel aquifer. Concurrently, ground-water levels within the Englishtown aquifer system declined by as much as 13 ft in the same area. Water levels across much of the Upper Potomac-Raritan-Magothy aquifer in the northern Coastal Plain remained about the same as 5 years previous, except in northern Ocean County where ground-water levels declined 10 ft to 33 ft. Water levels in the Middle Potomac-Raritan-Magothy aquifer declined from 5 to 9 ft along the border between Monmouth and Middlesex County. Elsewhere, across the northern part of the Coastal Plain, water levels stabilized within the Cretaceous-age aquifers.

In southern New Jersey, regional cones of depression persist in the Potomac-Raritan-Magothy aquifer system in Burlington, Camden, and Gloucester Counties. From 1998 to 2003, water levels in these large cones were generally stable or recovering across much of southern New Jersey; recoveries from 5 ft to 10 ft occurred in all three aquifers, and exceeded 20 ft in places within the Lower aquifer. In contrast, water levels declined near the center of the cone of depression within the Lower aquifer in central Camden County. Water levels in the Middle Potomac-Raritan-Magothy aquifer declined by as much 7 ft in central New Castle County, Delaware; however, those within the major cone of depression in the Lower aquifer stabilized from 1998 to 2003. In general, water levels across the Wenonah-Mount Laurel aquifer recovered in Burlington, Camden, and Gloucester Counties from 1998 to 2003; rises of nearly 30 ft were observed in central Gloucester County.

Reference

dePaul, V.T., Rosman, Robert, and Lacombe, P.J., 2009, Water-level conditions in selected confined aquifers of the New Jersey and Delaware Coastal Plain, 2003: U.S. Geological Survey Scientific Investigations Report 2008-5145, 123 p., 9 pl.

SALT MARSH DYNAMICS - AN ENDANGERED COASTAL ECOSYSTEM IN A SECOND LIFE'S NMC VIRTUAL SPACE

Martha B Schoene -Physics Department, Marian Glenn-Biology Department and Heidi Trotta- Department of Information Technology,

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Abstract

This workshop will take participants on a field trip within Second Life, a multi-user virtual environment. The dynamic Salt Marsh is a simulated coastal environment designed for use in Earth Science, Ecology, Environmental Science and Geology courses for High School and undergraduates.

This virtual environment is based on the salt-water marsh ecosystem, at Horseshoe Cove, Sandy Hook, NJ, a popular site for educational field trips. The simulated marsh presents a variety of real world challenges in coastal zone management that are best addressed using systems thinking and collaborative data-sharing. Student activities focus on collaborative inquiry-based exploration and synthesis.

The workshop will demonstrate how to gather, interpret and analyze data to solve a real-world problem - - a mysterious fish kill. No experience with Second Life is necessary, but participants who have Second Life avatars are invited to bring their laptops and join the explorations "in person."

Overall Project Objectives:
NJ State Core Curriculum Content Standards/Science-
http://education.state.nj.us/cccs/?_standard_matrix;c=5
5.1, 5.2, 5.4, 5.5, 5.8, and 5.10

- Identify and describe species of fauna and microfauna (plant and animal) found in a healthy marsh to include appearance, abundance, demography, and diversity.
- Relate water quality to the health of an ecosystem (temperature, nitrogen, phosphorus, chlorophyll, pH, turbidity, clarity, salinity, dissolved oxygen, fecal coliform).
- Provide geological perspective on marsh formation past and present.
- Relate watershed land use decisions to the ecological conditions in the marsh.
- Explain the process of ecological restoration, and propose techniques to restore the simulated marsh to a healthy state.
- Gather, analyze, manage, and evaluate data from numerous sources to include historical and physical data, environmental observations, and outside resources to gain clues to what is possibly occurring in the marsh, and substantiate and support arguments (i.e. weather reports, newspaper articles, interviews, core samples, water quality measurements, web resources).
- Apply scientific principles and concepts (i.e. food web, cause and effect, accumulation of small perturbations, effects of synergistic stressors, and dynamic nature of ecosystem function) to real-world contexts.
- Work collaboratively to exchange ideas, information and perspectives.
- Debate, discuss and arrive at a group consensus, identifying and evaluating possible causes and solutions (scientific and/or environmental) for the occurrences at the marsh..
- Demonstrate the acquisition of “ways of thinking” found in scientific and research
- communities.

Overview of the Exercise: Secrets of the Salt Marsh

Students will work in groups to investigate a fish kill in the marsh. By interacting with the virtual environment students will obtain clues and data to determine the ecological status of the marsh. Students will prepare a report on the probable causes of the fish kill and share their recommendations for prevention of further such occurrences.

Virtual World Characters

Hydrologist and Park Interpreter
Fish Biologist and Grandpa
Environmental Scientist and Citizen Activist
Microbiologist and Reporter

Workshop Topics:

- Explore the virtual marsh topography (i.e. shallow estuarine waters, sandy beaches, inlet ocean and bay)
- View plants and animals (microscopic and macroscopic-terrestrial and aquatic life)
- Visit structures and objects (i.e. man-made and natural to include physical elements such, visitor center, research building, osprey nests, seining nets)
- Discover clue objects and supporting artifacts
- Demonstrate a student guided question and assessments
- Use links to outside supporting documentation, references, images and multimedia
- Discuss plans for the future

Background Information

In 2006, Seton Hall entered into a development partnership with the New Media Consortium to develop plans for the creation of environmental learning spaces inspired by actual endangered eco-regions found both locally and around the world, within the online, virtual world of Second Life. In 2008 Heidi Trotta, Instructional designer for the Teaching, Learning and Technology Center at Seton Hall University was awarded a New Media Consortium Virtual Learning Prize to create a companion application, ***Salt Marsh Dynamics*** that developed this environment even further into a problem-based learning platform, allowing students to further develop "ways of thinking" found in the scientific research community.. When paired together, this project allows the achievement of multilevel learning objectives while offering the educational community the opportunity to study how the use of virtual world technologies can encourage and support teaching and learning in the sciences.

Workshop Information

For the web link to the Dynamic Marsh email M Schoene at schoenma@shu.edu

Requirements for interactive participation in the workshop (**optional)**

Lap top with wireless capability
Power cord or full charged battery

If you are interested in exploring Second Life marsh, you can do so by making a Second Life account before the workshop:

Download Software -http://secondlife.com/support/downloads.php
Create a Second Life Account:
http://tltc.shu.edu/virtualworlds/mediawiki/images/c/c0/NMC_SL_Account.pdf
http://sl.nmc.org/create.php

Tutorials on Getting Started in Second Life ….

Getting Started in Second Life
http://sl.nmc.org/wiki/Getting_Started

Virtual Worlds at Seton Hall

http://tltc.shu.edu/virtualworlds/mediawiki/index.php/Main_Page

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Dieterle, E., & Clarke, J. (in press). Multi-user virtual environments for teaching and learning. In M. Pagani (Ed.*),* Encyclopedia of multimedia technology and networking (2nd ed). Hershey, PA: Idea Group (2006)

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Fish and Wildlife Service, Species profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) Coastal Ecology

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Ketelhut, D. J.). The impact of student self-efficacy on scientific inquiry skills: An exploratory investigation of River City, a multi-user virtual environment. Journal of Science Education and Technology, *16*(1), 99-111. (2007)

Shaffer, D. W. How, Computer Games Help Children Learn. New York: Palgrave Macmillan. . (2006b)

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Supporting-Websites

(1) The New Jersey Marine Sciences Consortium (NJMSC) at Sandy Hook: www.njmsc.org/
(2) Marine Academy of Science and Technology- Blue Seas Trawl Data -Sandy Hook Bay / Raritan River area: www.mcmast.net/mast.html
(3) NOAA at Sandy Hook, NJ - http://sh.nefsc.noaa.gov/
(4) The Ocean Institute - part of the Community Development Division of Brookdale Community College.- Plankton Bloom –
http://ux.brookdalecc.edu/staff/sandyhook/plankton/index.htm
(5) Marine Sciences Research Center at Stony Brook University and New York Sea Grant: http://www.oar.noaa.gov/spotlite/archive/spot_saltmarsh.html

HYDROSTRATIGRAPHY OF THE NEW JERSEY COASTAL PLAIN: SEQUENCES AND FACIES PREDICT CONTINUITY OF AQUIFERS AND CONFINING UNITS

Peter J. Sugarman1, Kenneth F. Miller2, James V. Browning2, and Donald H. Monteverde1

[1] *New Jersey Geological Survey*

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The regional extent and connectivity of Cretaceous to Miocene aquifer sands in the New Jersey Coastal Plain are evaluated using detailed facies analysis within a sequence stratigraphic framework. We correlate sequences from continuous coreholes using well logs to trace strike and dip sections throughout this region, allowing us to predict the continuity of confining units and aquifer sands.

Marine sequences follow a predictable shallowing upward pattern: fine-grained shelf and prodelta sediments grade upward into delta front and shallow-marine sands, corresponding to confining unit-aquifer couplets. Aquifer sands deposited in marine shelf environments tend to be continuous on the 10+ km (6.2 mi) scale and are traceable for >60 km (37.3 mi) along strike and >25 km (15.5 mi) along dip. Confining units for these marine sequences are typically shelf or prodelta silty clays that are even more laterally continuous than their associated aquifer sands. Marginal marine to non-marine sequences are more difficult to predict due to a lack of continuous marine marker beds, difficulty in interpreting paleoenvironments of thick sand beds, and lack of fossil material except pollen for biostratigraphy. Marginal to non-marine sequences are generally less continuous, though some show surprising lateral continuity along strike (>60 km [37.3 mi]), reflecting the widespread extent of delta front environments.

We conclude that sequence stratigraphy provides a predictive framework for aquifers and confining units, but that regional and local differences in sediment supply and tectonics affect the development of the hydrostratigraphic framework.

AN ITERATIVE SHALLOW HYDROGEOLOGIC INVESTIGATION OF ELEVATED MERCURY CONCENTRATIONS, ATLANTIC COUNTY, NEW JERSEY

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ABSTRACT

An investigation of elevated mercury concentrations detected in surface waters and sediments was conducted in an undeveloped area of Atlantic County, New Jersey. An iterative investigative approach was used to reduce the size of the shallow investigation area by two orders of magnitude. Ultimately, a focused study area was identified primarily through the use of shallow groundwater observation well and seepage meter paired couplets. The easily obtained piezometric levels, groundwater flux, and total and filtered mercury data from within the identified focus study used to develop a powerful hydrogeologic conceptual model are presented.

The undeveloped focus study area is demonstrated to be an area of constant groundwater discharge to surface water and elevated mercury concentrations in surface water, pore water, and shallow groundwater. Although the highest mercury concentrations generally corresponded to the seepage meter location with the highest groundwater flux, the data did not demonstrate a consistent positive correlation between mercury concentrations and groundwater flux. Furthermore, the results of the focus study do not show any consistent correlation of mercury concentrations within an area with precipitation, pH, Eh, conductivity, dissolved oxygen, temperature, turbidity, or organic carbon.

Mercury was determined to be portioned approximately 1:1 between the particulate (>0.45 μm) and the non-particulate size (<0.45 μm) fractions in the shallow groundwater. However, within the pore water, there is a 3:1 ratio of mercury associated with particulate versus non-particulate fractions.

The Eh-pH stability diagrams suggest the shallow groundwater and pore water are unique, but commingled, zones. Geochemical modeling predicts that the negatively charged mercuric sulfite complex is the predominant aqueous mercury species expected within the shallow groundwater (85%) and pore water (92%) within the focus study area.

INTRODUCTION

Background

At room temperature, elemental mercury occurs as a liquid. Naturally occurring mercury compounds can be found in nearly 100 minerals, most notably cinnabar (HgS).

Historically, mercury has been used in batteries, the manufacture of chlorine and caustic soda, fluorescent vapor lamps, electronic and scientific equipment, fungicides, paints and pigments, dental amalgams, munitions, and the gold concentration process.

Anthropogenic mercury emissions are deposited to the surface via dry deposition and precipitation. Mercury concentrations in the undisturbed A-horizon of southern New Jersey forest soils are typically 50-150 μg/kg (Barringer et al., 2005). Historic use of mercury-based pesticides, septic-system effluent, landfills, and abandoned munitions remain potential anthropogenic sources of low level mercury concentrations. Natural sediments potentially contribute up to 0.01 μg/L of mercury to groundwater and therefore have not been identified as a likely source of elevated mercury in the Kirkwood-Cohansey aquifer (Dooley, 1992).

Mercury is a toxic contaminant which occurs in both inorganic and organic forms. In its organic form, methyl mercury bioaccumulates in the food web, particularly in fish. Because of its toxicity, mercury has strict regulatory criteria. The New Jersey Department of Environmental Protection (NJDEP) human health Surface Water Quality Criteria (SWQC) for freshwater is 0.05 μg/L . The United States Environmental Protection Agency (USEPA) drinking water maximum contaminant level (MCL) and the NJDEP Ground Water Quality Standard (GWQS) for Class IIA aquifers are both 0.2 μg/L .

Widespread elevated mercury concentrations within the Kirkwood-Cohansey aquifer system of southern New Jersey have been reported since the early 1980s (Barringer et al., 2005). The maximum reported mercury concentrations in uncontaminated water from the Kirkwood-Cohansey aquifer system is 0.042 μg/L (Murphy et al., 1994). For contaminated sites in Atlantic County, mercury concentrations ranged from <0.01 to 34.5 μg/L, the median mercury concentration was 0.28 μg/L , and 13% of the 1,543 samples exceeded 2.0 μg/L mercury (Barringer et al., 1995).

In 2002, the NJDEP Private Well Testing Act (PWTA) program began the mandatory testing of private drinking water wells prior to a property sale. Between 2002 and 2007 the PWTA program identified 35 out of 2,850 Atlantic County private drinking water wells (1.4%) which exceeded the NJDEP GWQS (NJDEP, 2008).

Collaboration between the NJDEP and the United States Geological Survey (USGS) has concluded that the elevated mercury concentrations are representative of an environmental issue, and are not a function of water sampling or analytical techniques (Barringer et al., 1997). Available manufacturers' data indicate mercury is not being derived from well materials or pumps (Barringer et al., 1995). To date, extensive investigations have not conclusively identified specific mercury source areas or defined distinct mercury plumes (Barringer et al., 2005).

Based on the work of Barringer et al. (1997, 2005), mercury contamination in southern New Jersey is heterogeneous on the local and regional scale, and does not demonstrate mercury distribution along flow paths. However, data do suggest mercury concentrations are generally higher in developed areas than in undeveloped areas. In residential and agricultural areas, elevated mercury is present where water quality is degraded by elevated concentrations of major cations and anions (e.g. sodium, chloride, nitrates).

Site Description

The study area is located in eastern Atlantic County, New Jersey (Fig. 1). Locally, the upper 150 feet of sands and gravels belong to the Miocene age Cohansey Formation (Newell et al., 2000). The primary clay mineral in the Kirkwood-Cohansey aquifer is kaolinite, with leser amounts of illite and smectite (Barringer and Szabo, 2006). Iron hydroxide coatings are found on sand grains surfaces (Barringer and Szabo, 2006). Study area soil borings indicate the upper 25 feet of the formation consist primarily of fine to medium quartz sand and gravel, with varying amounts of silt. The sands are predominantly yellow and gray; however, a wide variant in color (white, light gray, gray, dark grayish brown, pale yellow, olive and reddish yellow, yellowish red, and red) has been noted. Occasional clayey sand lenses up to approximately 1 foot are encountered, but these lenses are generally not horizontally continuous between borings.

Groundwater at the site is part of the unconfined Kirkwood-Cohansey aquifer system. The Kirkwood-Cohansey aquifer underlies an area of approximately 3,000 square miles of New Jersey's Coastal Plain physiographic province. Locally, the Kirkwood-Cohansey aquifer is a water-table aquifer, approximately 250 feet thick, which includes lower to middle Miocene light colored quartz sand mixtures of the Kirkwood Formation and overlying Cohansey sand (Zapecza, 1989).

Normal annual precipitation for Atlantic County, New Jersey is approximately 40 inches. Regionally and locally, surface water and shallow groundwater flow is generally towards the southeast and the Atlantic Ocean. At the study site, the shallow groundwater horizontal hydraulic gradient is approximately 0.001 ft/ft towards the southeast. However within the focus study area the horizontal hydraulic gradient increases to approximately 0.01 ft/ft towards the southwest and northeast where it discharges to the southeast-flowing creek.

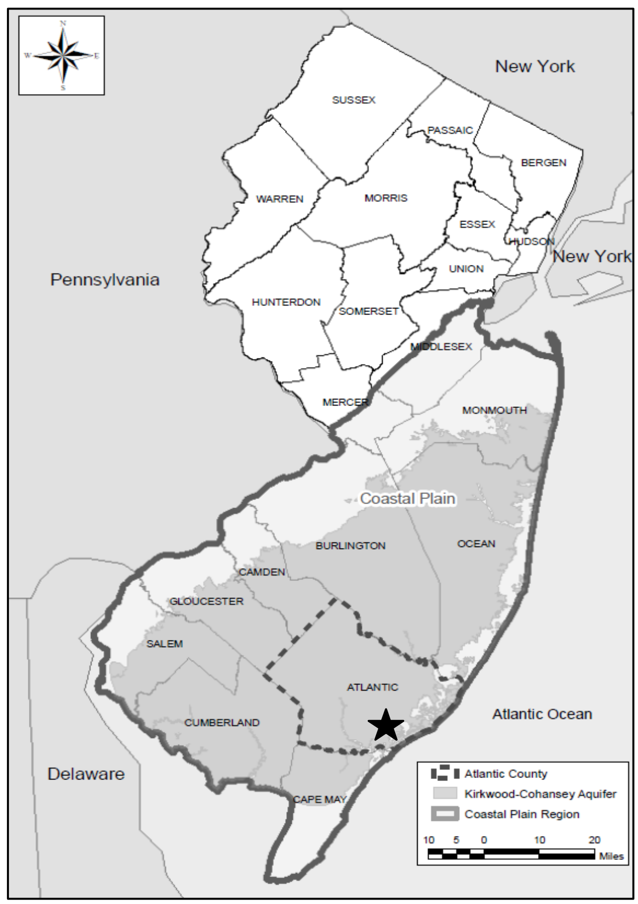

Figure 1: Study area location map. The approximate location of study area (filled star) in eastern Atlantic County, New Jersey (Sources: Herman et al., 1999; NJDEP, 2002, NJDEP, 2003).

The absence of headwaters, and the constant low temperatures of the creek during warm months strongly suggest that substantial groundwater discharge to the creek is occurring. During soil boring activities, the presence of running sands encountered at depths greater than approximately 3-4 feet below the creek bed also suggests ongoing groundwater discharge to the creek.

Estimated horizontal and vertical hydraulic conductivity values for the Kirkwood-Cohansey aquifer in southwestern New Jersey range from approximately 100-200 ft/day and 4-9 ft/day, respectively (Szabo et al., 1996).

Objectives

The primary objective of this study was to use iterative field methods to better define the geographic extent of the investigation (i.e. identify a focus area) for a creek which contains elevated concentrations of mercury. Within the identified focus area (Fig. 2), the objectives were to: 1) characterize the hydrologic relationships between the shallow groundwater, pore water, and surface water; 2) evaluate the spatio-temporal variability of aqueous mercury; and 3) provide a geochemical evaluation of the mercury speciation within the shallow groundwater and pore water.

The authors are not aware of any previously published reports, which synoptically evaluate mercury concentrations in the shallow groundwater, interstitial water, and surface water over time. Previous local mercury in groundwater studies have been performed using wells and data from depths greater than 50 feet (Barringer, et al., 2005). This study recognizes and evaluates for the first time mercury contamination in undeveloped forested area at depths shallower than 25 feet and, in particular, depths less than 5 feet. To the authors' knowledge, a comparison of the inorganic mercury species in the shallow unconfined groundwater and paired interstitial water samples has not been previously reported.

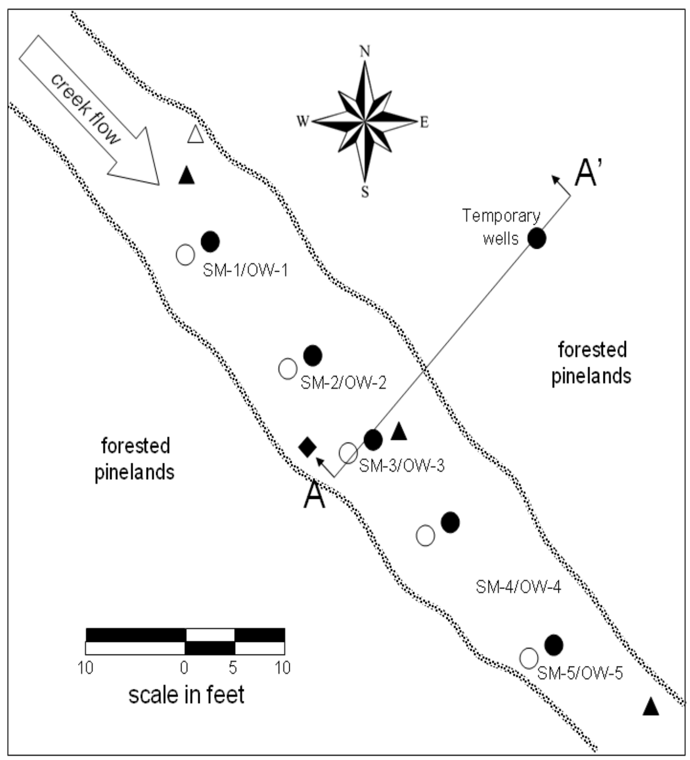

Figure 2: Focus study area map. Shallow wells (closed circles), seepage meters (open circles); surface water locations (closed triangles); bank seep (open triangle), and stilling well (closed diamond) are identified by type.

METHODS AND APPROACH

During previous investigations, high concentrations of mercury were detected over a greater than 2,500 foot segment of the creek containing the focus area. The prior investigations included collection of aquatic macro-invertebrate, forage fish, surface water, groundwater seep, sediment, soil and other biotic samples to determine if elevated mercury levels may have indicated a potential source or input of mercury into the focus study area.

Initially, two species of aquatic macro-invertebrates; along with forage fish were collected upstream of, within, and downstream of the focus study area. Based on the results, surface water, groundwater seep, and corresponding seep location sediment samples were also collected from several locations upstream of, within and downstream of the focus study area, corresponding to where elevated mercury concentrations had been detected in aquatic macro-invertebrates and forage fish samples. Three rounds of progressively located sediment samples were subsequently collected from locations adjacent to several of the aquatic macro-invertebrate sampling locations to determine if mercury was present in creek sediments. Numerous sediment locations downstream of the focus study area were initially sampled, however, the investigation expanded to include sediment locations within and upstream of the focus study area as well. A series of soil samples were then collected adjacent to the study area where the highest mercury levels were detected in biota and sediment. This included sampling several upland areas, a nearby drainage swale, stream bank soils, dredge spoil soils and the surrounding floodplain. Finally, detritus, sphagnum moss, and tree leaf/needle samples were collected. All samples from the prior investigations were analyzed by either certified laboratories using pre-approved methods, or by on-site mercury analysis using an Ohio-Lumex RA-915+ mercury analyzer.

The combined results of prior investigations were used to reduce the creek study area from greater than 2,500 linear feet to a smaller study area of approximately 500 feet in length. Ultimately, this smaller study area was further reduced to a focus study area approximately 50 feet in length. The smaller study area and the focus study area investigations included installation of temporary well points, seepage meters, a stilling well, as well as iterative sampling of these devices as described below.

Observation Wells

One-inch diameter schedule 40 PVC shallow wells were manually installed using a bucket auger to a depth less than 10 feet within the creek bed. Running sands were typically encountered at approximately 3-4 feet below the creek bed. Therefore, temporary 4-inch diameter and/or 3-inch diameter schedule 40 PVC casing was used to prohibit surface water infiltration and borehole collapse. In all cases, the native formation served as the sandpack once the casing was removed. The lowermost 1-foot section of the well was screened. Five shallow wells were installed over a 50-foot focus area (Fig. 2). Sampling rounds were conducted approximately every four weeks.

In the forested upland adjacent to the creek, a track-mounted Geoprobe® 6620DT was used to collect groundwater samples at depths greater than 10 feet below ground surface. Continuous soil samples were collected, for logging purposes, to a depth of 25 feet below ground surface using a 5-foot, 1.5-inch diameter Macro-Core® soil sampler with disposable clear plastic sleeves. Groundwater samples were collected over 2-foot intervals between

24 feet and 12 feet bgs using a ¾-inch diameter stainless steel discrete groundwater sampler.

Seepage Meters

Each seepage meter cylinder was constructed from approximately a 1/3 section of a 55-gallon closed-top steel drum (Lee, 1977) (Fig. 3). Each seepage meter was fitted with a brass port and barbed fitting to which silicone discharge tubing was attached. Stainless steel hose clamps were used to attach the discharge hose to the barbed fitting. Plastic cable ties were used to attach polyethylene bags to the silicone tubing in order to directly measure groundwater seepage velocity/flux and collect pore-water water samples.

Seepage meters were installed in the creek bed by a combination of twisting and the application of downward pressure. In some instances, where excessive coarse material was present, a shovel was used to remove large gravel and cobbles which interfered with the setting of the seepage meter into the creek bed. The seepage meters were installed with the discharge tubing on the downstream side of the seepage meter. To minimize the accumulation of gases, the seepage meter discharge was positioned at the highest elevation (Fig. 3).

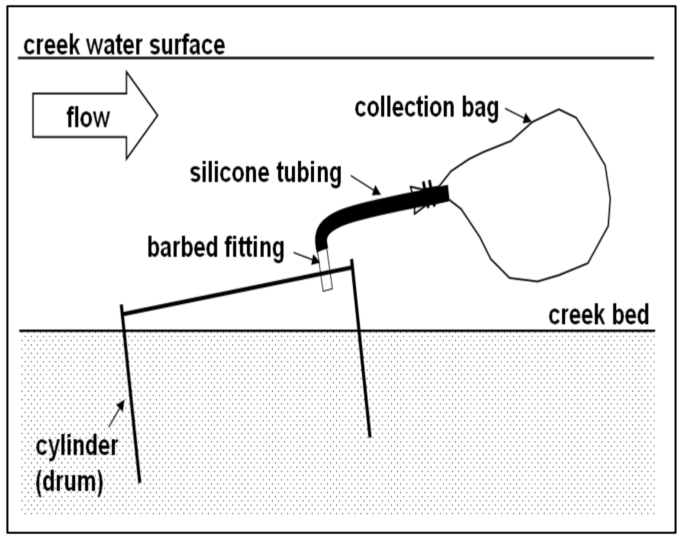

Figure 3: Cross-sectional view of installed seepage meter construction (after Lee, 1977). Not to scale.

Interstitial water samples were collected in a clear polyethylene bag. After passively filling at the natural flux rate, the sample collection bag was disconnected from the seepage meter discharge tube for transfer into the sample bottles. The sample was transferred via peristaltic pump equipped with silicone tubing. For the filtered aliquot, a single-use disposable 0.45 um cartridge filter was attached to the end of the silicone tubing; and the sample was pumped through the filter and into the sample container.

Stilling Well

A stilling well was constructed in the focus study area (Fig. 2). The stilling well was constructed of a 6-inch diameter schedule 40 PVC with a length of 5-ft. It was held in place by fence posts that were installed in the creek bed using a sledgehammer. Stainless steel bands were used to secure the fence posts to the PVC. The bottom of the PVC was submerged in the stream but not in the creek bed. A wireless Micro-Diver DI601 and wireless Baro-Diver DI-100 were placed inside the stilling well and into the water. Both divers were set to record the levels every two minutes. Between May and August continuous water level, barometric pressure and temperature data downloaded monthly into a portable field computer (data not shown).

Sample Collection

During all mercury sample collection, the clean hands/dirty hands sampling protocol (USEPA method 1669) was followed on the basis of sample integrity for analysis of trace levels of mercury. One member of the sampling team, designated as the "dirty hands", was responsible for all sample activities that did not directly involve any contact with the sample, (i.e. operation of pumps and grab sample devices, documentation, etc.). Another team member, the "clean hands", performed all operations that involved direct contact with the sample container. This includes opening and closing of the container and the inner protective plastic bag surrounding the sample container as well as the transfer of the sample from the collection device to the container.

Laboratory Analysis

Total and field filtered samples were analyzed for low-level mercury by modified EPA Method 1631. For filtered samples, a single-use disposable 0.45 μm cartridge filter was attached to the end of the silicone tubing. All total organic carbon (TOC) samples were analyzed by Standard Method 5310.

General chemistry parameters used for geochemical modeling were analyzed in the laboratory and in the field. All metals were analyzed using EPA Method 200.7, Rev 4.4. Anions were analyzed by EPA-600/4-79-020. Sulfate was determined in the laboratory by SW846. Alkalinity was measured using Standard Method 2320B. Standard Method 4500 was used for the laboratory determination of carbon dioxide, chloride, cyanide, nitrite, nitrate, orthophosphate, and sulfide. Commercial field test kits were used for the field determination of silica, carbon dioxide, ferrous iron, sulfite, and iodine.

Aqueous Sampling

Aqueous samples included shallow groundwater, pore water, and surface water. Methods used to collect groundwater samples during all phases were based on the NJDEP Alternative Methods for Groundwater Collection (NJDEP, 1994). Groundwater samples were analyzed for total mercury and/or non-particulate mercury. All groundwater samples were collected using a peristaltic pump equipped with silicone tubing in the pump head and polyethylene tubing down the well. The tubing was set mid-screen for all samples. A minimum of three well volumes were purged from each well prior to sampling. Purge rates ranged from approximately 150-375 ml/min. Water Quality Indicator Parameters (WQIPs) including temperature, pH, conductivity, dissolved oxygen, redox potential, and turbidity were measured using a YSI Model 6920. WQIPs were typically measured and recorded at the beginning of well purging, after groundwater samples were collected, and after a field filtered (0.45 μm) groundwater sample was collected. In addition, turbidity was measured using a LaMotte 2020e turbidity meter. All samples were collected in 250-ml mercury-free polyethylene containers.

Seepage meters were sampled by fastening a plastic bag to the tubing installed in the seepage meter and allowing the pore water to discharge over time. The collected pore water was then sampled by directly pouring from the plastic bag for laboratory-filtered samples, or pumping from the plastic bag and through a 0.45-micron dedicated and disposable capsule filter for field-filtered samples. WQIPs were collected after the sampling process was complete.

Water quality parameters were collected prior to sample collection at each surface water sample. The surface water samples were collected in a clear polyethylene plastic bag. Sample bags were slowly lowered into the creek upstream of the sampler. The bag was not permitted to come in contact with the bottom of the creek or create any turbidity. Samples were then transferred into dedicated sample containers. Samples were collected by facing upstream in either the main channel or meander. Sampling proceeded in a downstream to upstream order to minimize any potential effects from disturbance of the creek bottom may have had during sample collection.

Groundwater Seepage Velocity Measurements

Groundwater seepage velocity and flux were directly calculated by measuring the volume of pore-water water collected in the sample bag over a known time interval using the following formula (Lee, 1977).

$$v = 1.075\frac{V}{t}$$

Where, v is the macroscopic seepage velocity (µm sec^{-1}) or seepage flux (ml m^{-2} s^{-1}), V is the volume of water entering/exiting bag (liters), t is elapsed time (hours), and 1.075 is a conversion factor for volume, time, and area covered by cylinder (55-gallon drum; 0.255 m^2) to equivalent units of velocity.

Water Levels

Water levels were measured for surface water, shallow groundwater, and the seepage meters. At each location within the focus study area the surface water and seepage meter levels were measured relative to a wooden stake; and the shallow groundwater was measured relative to the top of the well. The piezometric level of the seepage meters was measured at the height above the surface water where discharge began. Because of potential disturbance of the reference elevations, a level survey was conducted during each monthly sampling event. For each event, the level survey was used to produce a piezometric profile within the focus area.

Precipitation Data

Throughout the focus study area investigation, daily precipitation was obtained from the National Weather Service. The precipitation data was used to evaluate a potential relationship between total mercury and groundwater flux.

Geochemical Model

Visual MINTEQ (Gustafsson, 2009) was used to calculate equilibrium compositions and predict the mercury species present in unfiltered pore-water and shallow groundwater at the OW-3/SM-3 pair. The OW-3/SM-3 couplet was selected because it is at the center of the focus study area, and has the highest median total mercury concentrations. The model also provided a saturation index which was used to determine the degree of saturation for mineral forms. The unfiltered chemical data used as model input parameters were obtained during July and August (Table 1). All non-detect components were entered into the model as zero values.

TABLE 1: PREDICTIVE MODEL INPUT DATA

Input components	Units	Pore water (SM-3)	Groundwater (OW-3)
Al^{3+}	µg/L	102	150
Ca^{2+}	µg/L	918	1110
Fe^{2+}	µg/L	250	< 100
Fe^{3+}	µg/L	51	153
$Hg(OH)_2$	µg/L	10.2	10.5
K^+	µg/L	1190	1230
Mg^{2+}	µg/L	1960	2200
Mn^{2+}	µg/L	13.8	13.3
Na^+	µg/L	10400	9500
NH_4^+	mg/L	< 0.10	< 0.10
Br^-	mg/L	0.082	0.074
Cl^-	mg/L	15.1	14.3
CN^-	mg/L	< 0.010	< 0.010
CO_3^{2-}	mg/L*	119.3	150.0
F^-	mg/L	< 0.020	< 0.020
I^-	mg/L*	< 0.5	< 0.5
NO_3^-	mg/L	< 0.10	< 0.10
NO_2^-	mg/L	< 0.10	< 0.10
PO_4^{-3}	mg/L	< 0.030	< 0.030
SO_4^{-2}	mg/L	10.4	12.2
SO_3^{-2}	mg/L*	0.64	0.64
HS^-	mg/L	< 1.0	< 1.0
H_4SiO_4	mg/L*	9.0	10.0
DOC (Gaussian)	mg/L	1.20	1.18
Temperature	˚C†	15.2	15.2
pH	pH units†	4.73	4.52

Note:
*Data by field measured test kit.
† Field WQIP data.

RESULTS AND DISCUSSION

Results of the previous investigations which included aquatic macro-invertebrate, forage fish, surface water, groundwater seep, sediment, soil and other biotic samples indicated that there was a defined area of elevated mercury levels within the creek. The upstream extent of the highest mercury levels and the general downstream bounds were used to reduce the size of the study area and ultimately define the focus study area. Analyses of the aquatic macro-invertebrate and forage fish samples indicate that the highest levels were observed within the focus study area. The concentrations then decreased at the upstream location. The mercury concentrations in three surface water samples collected downstream of the focus study area were 0.010 µg/L or less, while the six groundwater seep samples all resulted in mercury concentrations less than the method detection limit. Sediment samples collected in association with the groundwater seep samples had low mercury levels (ranging from 0.020 and 0.13 µg/kg). Sediment sample results helped to confirm that an area of elevated mercury levels, with field-screened concentrations ranging from 1,530 to 8,260 µg/kg, exists within the focus study area sediments. Soils that were sampled all had relatively low mercury concentrations. However, the highest mercury concentrations, in both the bank and spoil soils, were detected within the focus study area which were consistent with the sediment samples.

Later, during a smaller scale study conducted during 2008, seepage meter SM-3 was identified and confirmed as the location having the highest dissolved mercury concentrations. The data from September 2008 was used to construct a hydrogeologic cross section which includes the OW-3/SM-3 couplet that was also constructed to evaluate the groundwater flow lines (Fig. 4). This cross section was used in an attempt to attempt to track mercury concentrations from a confirmed high mercury discharge location in the creek backwards to a possible local source.

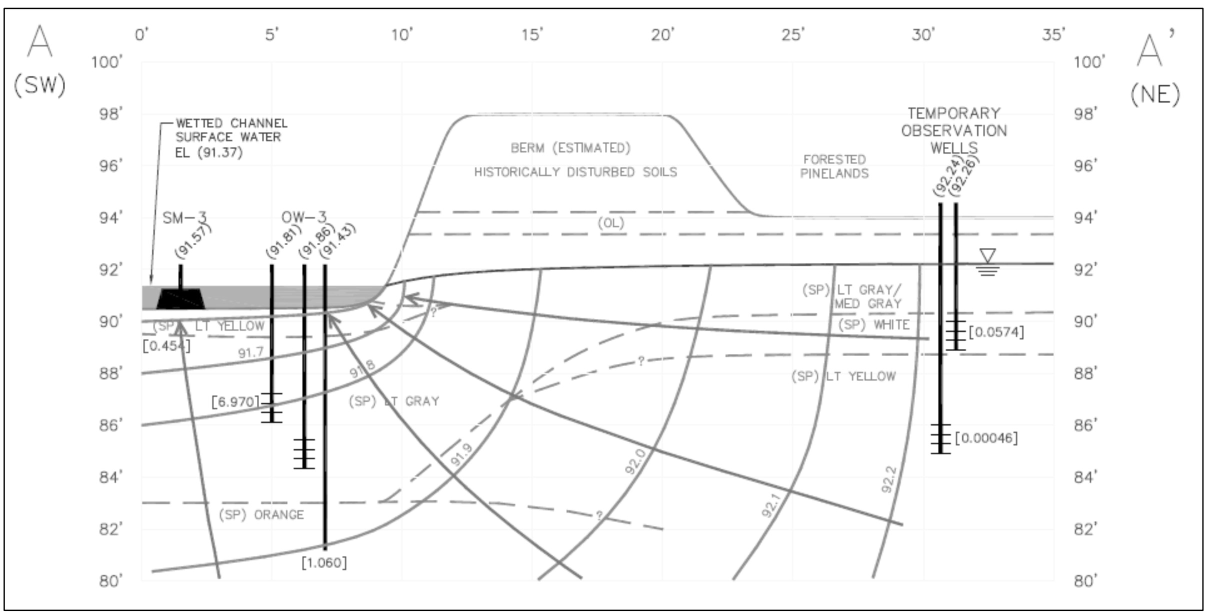

Figure 4: Hydrogeologic cross section A-A' constructed perpendicular to creek flow. Surface water flow is out of the page. All elevations are relative to an arbitrary 100' datum. Piezometric head values are given in parenthesis. Filtered mercury concentrations (µg/L) are given in square brackets. Arrows indicate groundwater flow direction and discharge to creek.

The September 2008 groundwater flow paths were projected backwards into the forested pinelands northeast of the creek. In November 2008, seven groundwater samples were collected between 12 feet and 24 feet below the ground surface. The results of the two-dimensional vertical profiling effort did not trace elevated mercury concentrations backwards along groundwater flow lines to projected depths (Fig. 5). Expanding this approach (i.e. a three dimensional approach) may potentially reveal elevated mercury associated with traceable groundwater flow lines. As a result, a fifty foot long focus study area centered on SM-3 was established as the focus area study. Within the focus area the hydrogeochemical relationships between shallow groundwater and pore water were studied over a six month period, one round per month.

Seepage Meter and Groundwater Mercury Results

The seepage meter and groundwater sample results are provided only for the focus study area. Total and dissolved mercury concentrations results are presented in Table 2 for each round of sampling. A maximum total mercury concentration of 10.2 µg/L was identified in the groundwater collected from observation well OW-3 during July 2009. The maximum mercury concentration of 10.5 µg/L for pore-water was found in the paired seepage meter SM-3 during the same sampling event.

Correlations between filtered mercury and other groundwater constituents, where present, have been reported as positive up to mercury concentrations of approximately 0.1 µg/L ; however, above 0.1 µg/L , there are no apparent correlations, or the correlations are negative (Barringer et al., 2005). Within the focus study area, there were no apparent correlations between precipitation or WQIPs. In addition, no seasonal pattern was observed.

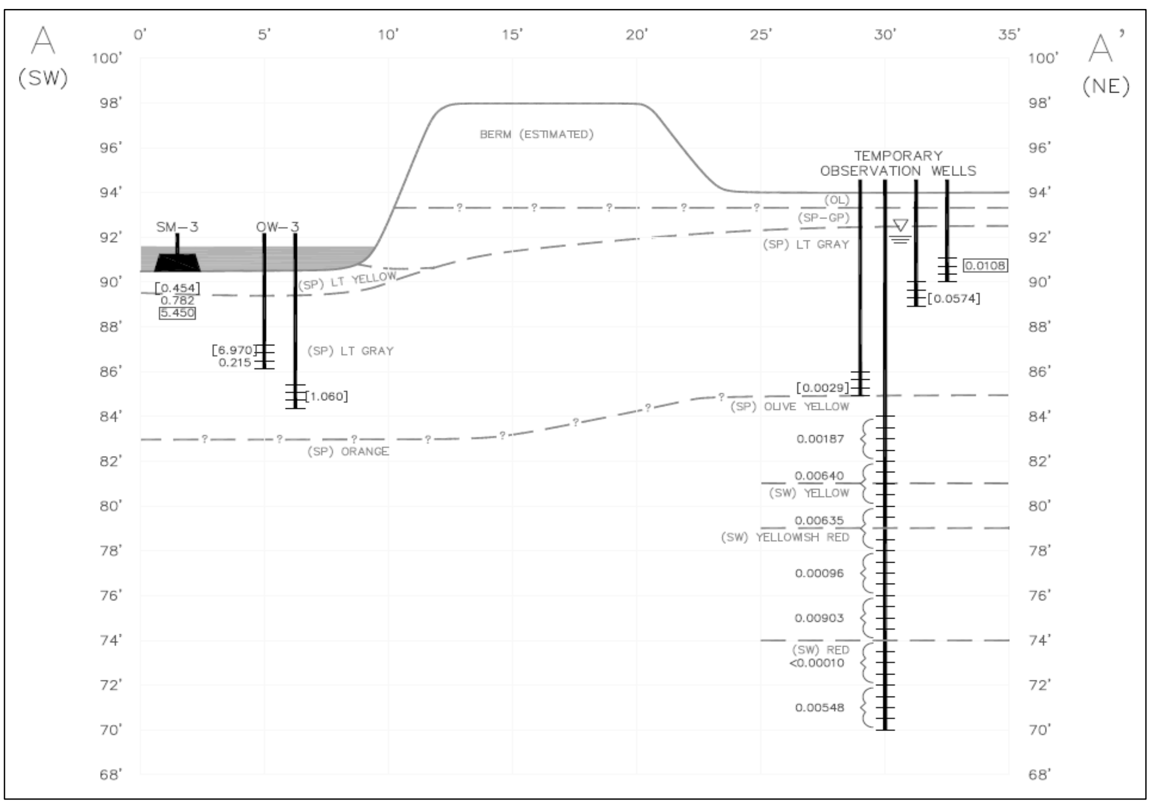

Figure 5: Hydrogeologic cross section A-A' depicting filtered mercury concentrations collected in June (in boxes), September (in square brackets), and November 2008.

Although an affinity of mercury to organic carbon was expected, the results did not demonstrate a correlation. Total organic carbon concentrations are low and ranged from approximately 1.0 mg/L to 2.0 mg/L, and appear to be almost exclusively associated with the non-particulate size fraction. Positive correlations between organic carbon and mercury have been suggested only to be present at low mercury-to-dissolved organic carbon ratios (Haitzer et al., 2002).

TABLE 2: TOTAL AND FILTERED MERCURY RESULTS

Sample Location	Mar-09		Apr-09		May-09		Jun-09		Jul-09		Aug-09	
	Total Hg (µg/L)	Filtered Hg (µg/L)	Total Hg (µg/L)	Filtered Hg (µg/L)	Total Hg (µg/L)	Filtered Hg (µg/L)	Total Hg (µg/L)	Filtered Hg (µg/L)	Total Hg (µg/L)	Filtered Hg (µg/L)	Total Hg (µg/L)	Filtered Hg (µg/L)
Observation Wells – Shallow Groundwater												
OW-1	8.01	4.53	8.85	5.58	7.07	1.77	6.68	6.75	N.D.*	N.D.*	N.D.*	N.D.*
OW-2	7.50	0.14	7.63	0.45	9.70	2.74	7.85	6.32	N.D.*	N.D.*	N.D.*	N.D.*
OW-3	8.34	0.63	9.12	4.62	8.48	6.07	9.36	6.87	10.2	4.76	7.62	1.71
OW-4	7.28	5.27	8.21	7.68	6.46	6.25	9.99	3.62	N.D.*	N.D.*	N.D.*	N.D.*
OW-5	7.85	4.79	6.96	5.27	6.77	5.75	5.31	4.60	N.D.*	N.D.*	N.D.*	N.D.*
Seepage meters - Pore water												
SM-1	8.25	1.48	8.01	1.14	8.74	1.10	6.18	1.86	N.D.*	N.D.*	N.D.*	N.D.*
SM-2	7.05	0.55	7.04	0.14	7.88	0.34	8.02	2.42	N.D.*	N.D.*	N.D.*	N.D.*
SM-3	7.95	0.54	8.16	5.06	7.19	5.74	9.31	4.10	10.5	2.51	10.5	2.4
SM-4	7.27	2.52	8.06	4.81	7.31	4.23	9.63	1.94	N.D.*	N.D.*	N.D.*	N.D.*
SM-5	6.52	3.99	7.55	2.05	6.63	1.94	10.90	1.75	N.D.*	N.D.*	N.D.*	N.D.*

Note:
* N.D. indicates samples were not collected during this event in order to narrow down the focus area.

Pore Water Results

Monthly water level measurements between March and August demonstrated the average piezometric head of the seepage meters and the shallow wells are typically 0.2 ft and 0.8 ft higher than the surface water, respectively. The center of the focus area has the lowest shallow well (OW-3), and the highest seepage meter (SM-3) average piezometric heads (Fig. 6). The data does not demonstrate seasonal variability or a correlation with precipitation.

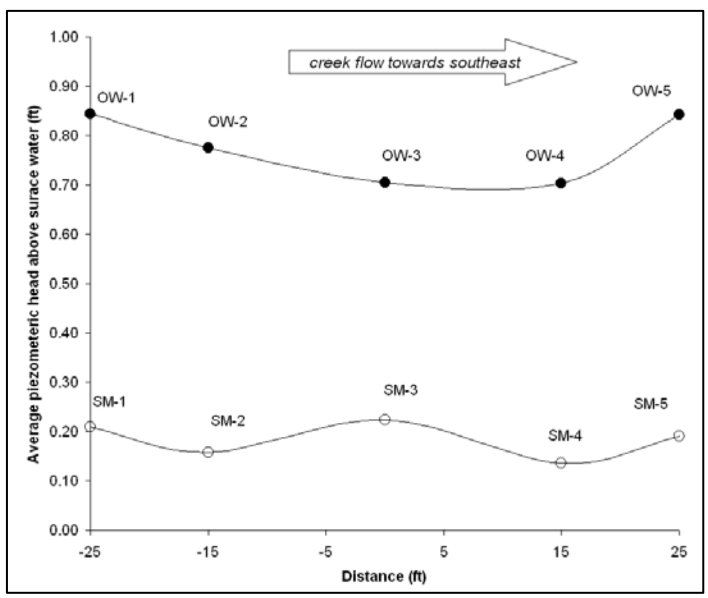

Figure 6: Focus study area piezometric profile created using the average of monthly piezometric head measurements for individual seepage meters and shallow wells relative to surface water.

The combined average vertical gradient between all shallow well and seepage meter paired couplets was 0.16 ft/ft. The average vertical gradient at individual paired couplets ranged from 0.13 ft/ft to 0.17 ft/ft.

The Atlantic County average precipitation data indicate the study was conducted over a period which was approximately 1.3 times the normal observed rainfall (MARFC, 2009). The rainfall total for the seven days preceding the March event was 1.3 inch. Approximately 0.4 inch of precipitation was recorded for the seven days prior to the April, June, and July events. Approximately 0.1 in. and 0.5 in. rainfall was recorded for the seven days preceding the May and August events, respectively. For each event, precipitation totals for the previous one, two, three, four, five, seven, 15, and 30 days were evaluated for correlation with piezometric heads and mercury concentrations. There was no discernable correlation between precipitation amounts and measured piezometric heads (data not shown).

Within the focus study area, the highest total mercury concentration corresponded to the highest groundwater seepage velocity (Fig. 7). However, there was not a direct correlation demonstrated between these two parameters across all seepage meters.

Filtered mercury concentrations in groundwater have been previously reported to range

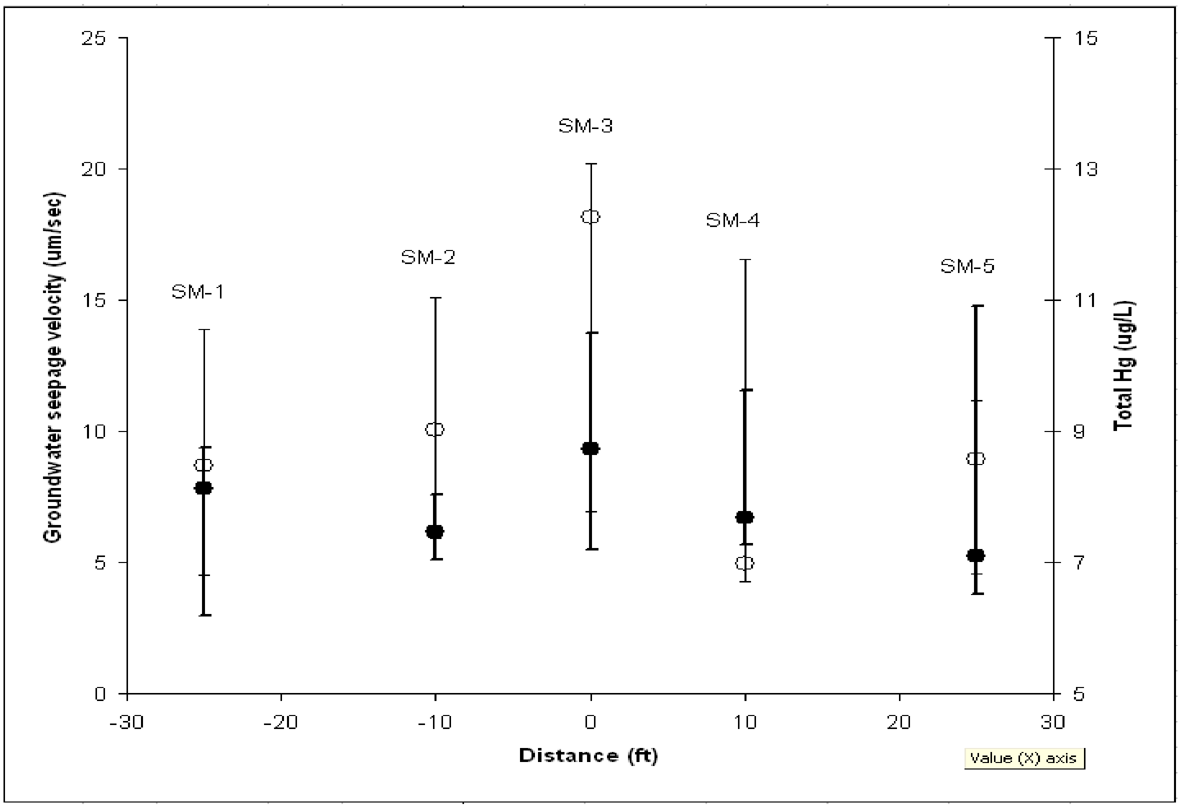

Figure 7: Median seepage meter groundwater seepage velocity (open circles) and total mercury concentrations (closed circles). Whiskers (total mercury, bolded) depict the range of values measured March to August 2009.

from about 0% (Barringer et al., 2005) to 50% (Barringer et al., 1997; Barringer and

MacLeod, 2001) in a non-filtered paired sample. Overall, the shallow groundwater from this focus area study, demonstrate the filtered mercury concentration represents from 2%-100% of the total mercury. At individual shallow wells within the focus study area the average monthly filtered mercury concentrations were 18%-86% of the total mercury. The geometric mean of the average monthly filtered mercury concentrations for individual wells indicate the filtered mercury is approximately 49% of the total mercury in shallow groundwater. In pore water, the filtered mercury concentrations ranged from 2%-80% of the total mercury. At individual seepage meters the average monthly filtered mercury concentrations were 9%-46% of the total mercury. The geometric mean of the average monthly filtered mercury concentrations for individual seepage meters indicate the filtered mercury is approximately 25% in pore water. The filtered mercury concentration relationship in shallow groundwater (49%) and pore water (25%) is approximately a 2:1 ratio. The filtered mercury concentrations represent mercury associated with the colloidal and dissolved fractions; whereas, the unfiltered mercury concentration also includes the particulate fraction (> 0.45μm). The focus study area data suggest that mercury is more likely associated with the particulate size fraction within the hyporheic zone.

Geochemical Modeling Results

Within the focus area, the major cations and anions indicate the shallow groundwater and pore water are within the sodium-bicarbonate hydrochemical facies (Fig. 8).

Divalent mercury in surface freshwater is expected to be primarily complexed with hydroxide and chloride ions (Morel et al, 1998). Previously, mercuric chloride ($HgCl_2^0$) was determined as the most prominent mercury species in the low pH groundwater of the Kirkwood-Cohansey aquifer, whereas volatile and methyl mercury together constituted less than 10% of the mercury (Murphy et al, 1994). Prior to geochemical modeling, the monthly unfiltered March through August 2009 focus area data were plotted on a mercury Eh-pH stability diagram (Fig. 9A). All field Eh readings were corrected to the standard hydrogen electrode by adding 0.244 V to obtain true Eh values used for the stability diagrams.

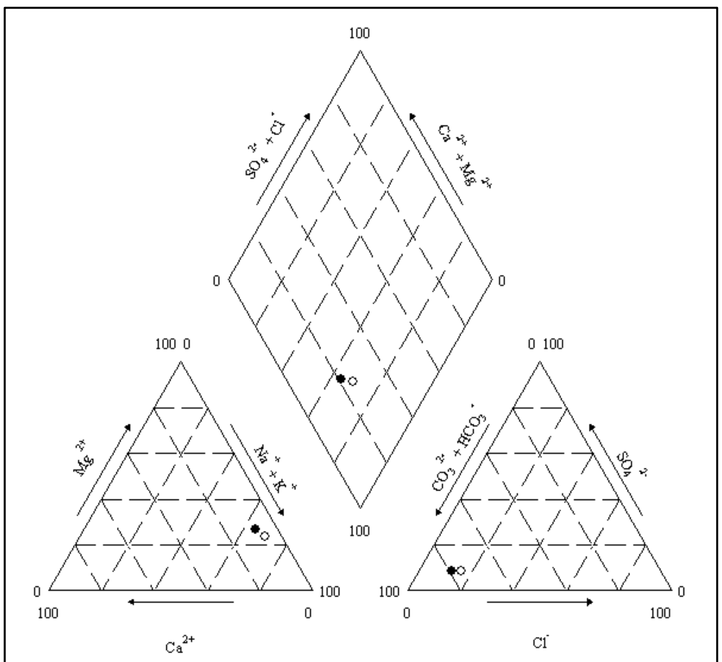

Figure 8: Piper plot of shallow groundwater (OW-3; closed circles) and pore water (SM-3; open circles). Plot created using USGS software (Winston, 2000).

The stability field diagram from the focus area indicates that $HgCl_2^0$ (aq) is the most anticipated species within the shallow groundwater and surface water (Fig. 9B). The predominance of $HgCl_2^0$ (aq) in the shallow groundwater of the focus area is consistent with deep groundwater results in the Kirkwood-Cohansey aquifer (Murphy et al., 1994). However, the pore water mercury within the focus area plots as $HgCl_2^0$ (aq), Hg^{2+}, and Hg^0 (aq), and suggests the hyporheic zone provides a unique transitional and dynamic environment for mercury speciation.

The Visual MINTEQ model was performed only for the July 2009 shallow groundwater and pore water paired couplet OW-3/SM-3. The Eh-pH for the OW-3/SM-3 samples plot in the $HgCl_2^0$ (aq) stability field (Fig. 9B). When only the species present on the Eh-pH stability diagram are used for a model run (data not shown), the results predict 100% of the mercury is present as $HgCl_2$ (aq). To this extent the model data agree with the stability field data; and the shallow groundwater and pore water data from the focus area agree with previous deep groundwater mercury speciation determined by Murphy et al. (1994). However, the Visual MINTEQ model effort provides additional insight to species potentially present in the focus area.

The Visual MINTEQ model predicted the most prominent species in the shallow groundwater and the pore water is the mercuric sulfite complex [$Hg(SO_3)_2^{-2}$] at their respective field pH values (Table 3).

TABLE 3: VISUAL MINTEQ MODEL OUTPUT AT 15.2˚C

Predicted species	Concentration (µmol L-1)		Percentage of total	
	Pore water (SM-3)	Groundwater (OW-3)	Pore water (SM-3)	Groundwater (OW-3)
HgCl2 (aq)	2.32E-09	4.56E-09	5.33	10.20
HgCl3-1	9.80E-12	1.83E-11	0.02	0.04
HgClOH (aq)	2.61E-11	3.43E-11	0.06	0.08
HgBr2 (aq)	2.77E-10	4.94E-10	0.64	1.10
HgBrCl (aq)	7.45E-10	1.40E-09	1.71	3.12
Hg(SO3)2-2	4.01E-08	1.83E-11	92.44	85.45
Hg(OH)2	6.36E-14	5.57E-14	0.00	0.00
Hg2+	1.00E-16	1.00E-16	0.00	0.00

Note:
Groundwater pH = 4.5; pore water pH = 4.7

At field conditions, the model predicted the total percent concentration of negatively charged mercury species is greater in shallow groundwater than in pore water.

The modeled shallow groundwater results for the four most prominent mercury species between pH 2 and pH 12 are shown in Figure 10. Within the expected field pH range of the focus area, $Hg(SO_3)_2^{-2}$ is the most dominant mercury species predicted in shallow groundwater (Fig. 11). The model predictions

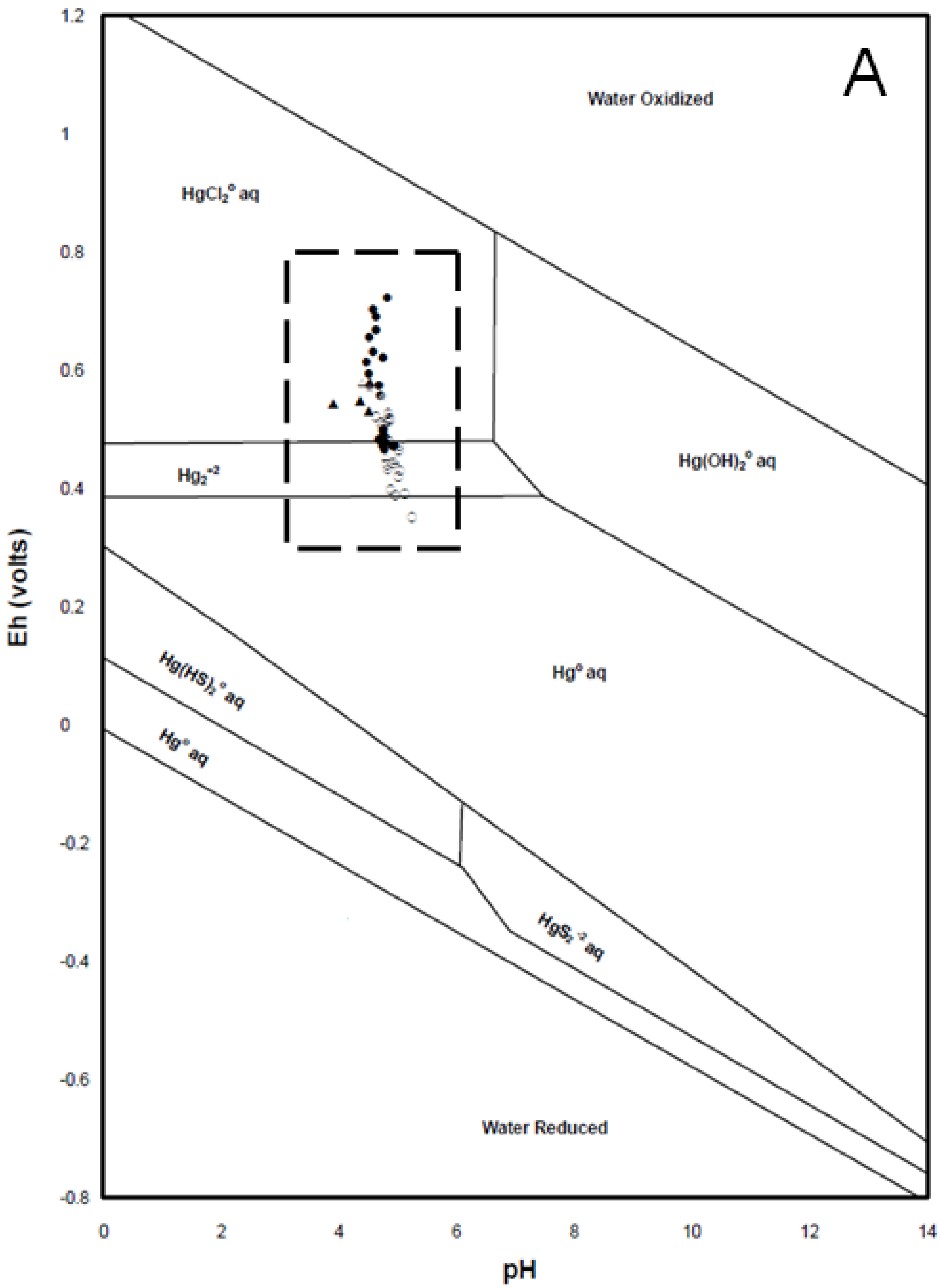

Figure 9A: March to August 2009 focus area monthly data plotted on Eh-pH stability field diagram for mercury species at 25°C and 1 atmosphere (after Hem, 1970). Dashed box indicates area of Figure 9B.

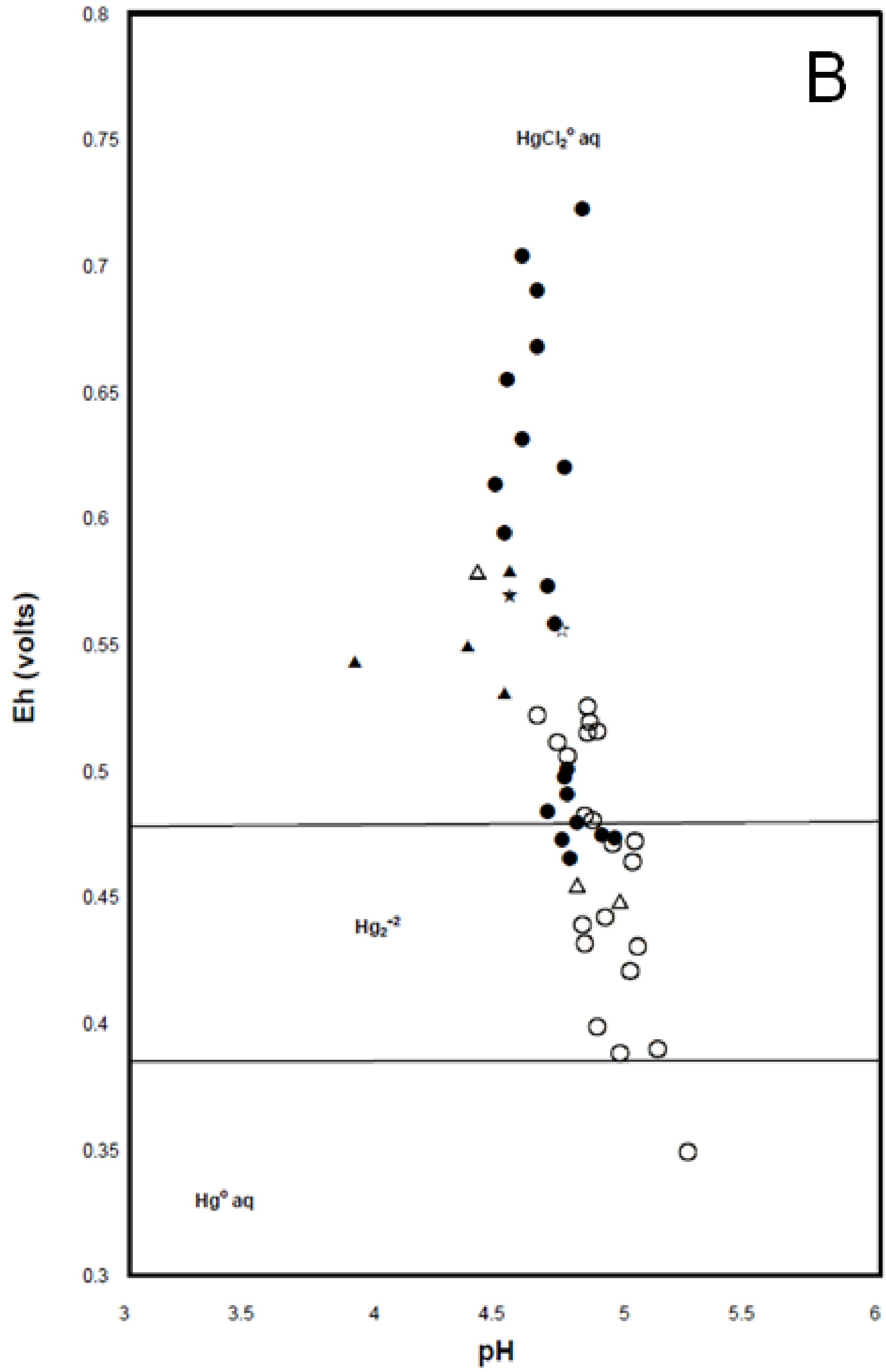

Figure 9B: Eh-pH stability field diagram (after Hem, 1970) showing focus area shallow groundwater (closed circles), pore water (open circles), surface water (closed triangles), and bank seep (open triangles) data distribution. The shallow groundwater (solid star) and pore water (open star) samples used for Visual MINTEQ model are also shown.

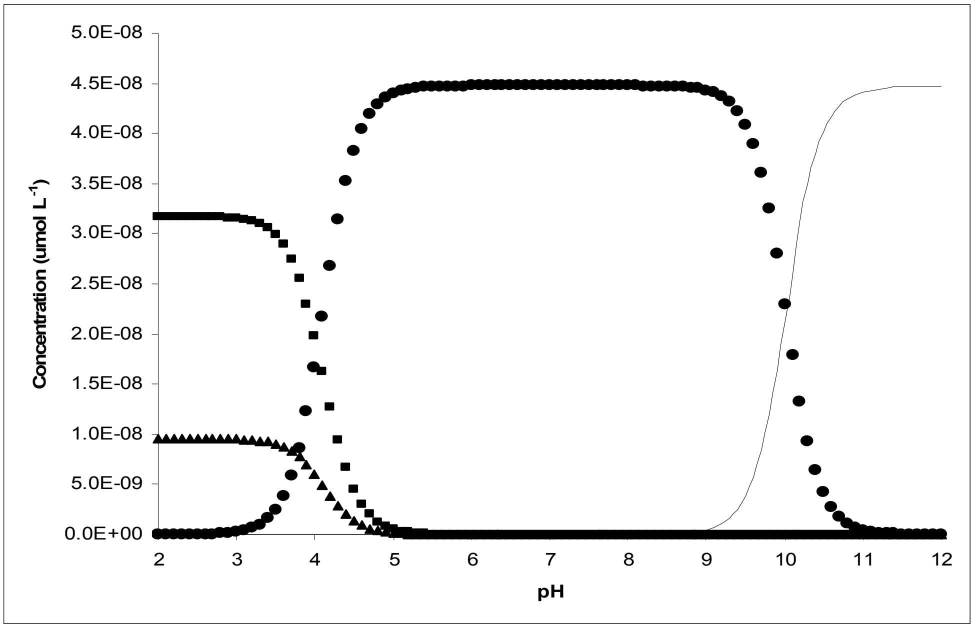

Figure 10: Most prominent focus area shallow groundwater predicted mercury species by Visual MINTEQ, pH 2-12 sweep. $Hg(SO_3)_2^{-2}$ (closed circles), $HgCl_2$ (aq) (closed squares), HgBrCl (aq) (closed triangles, and $Hg(OH)_2$ (solid line).

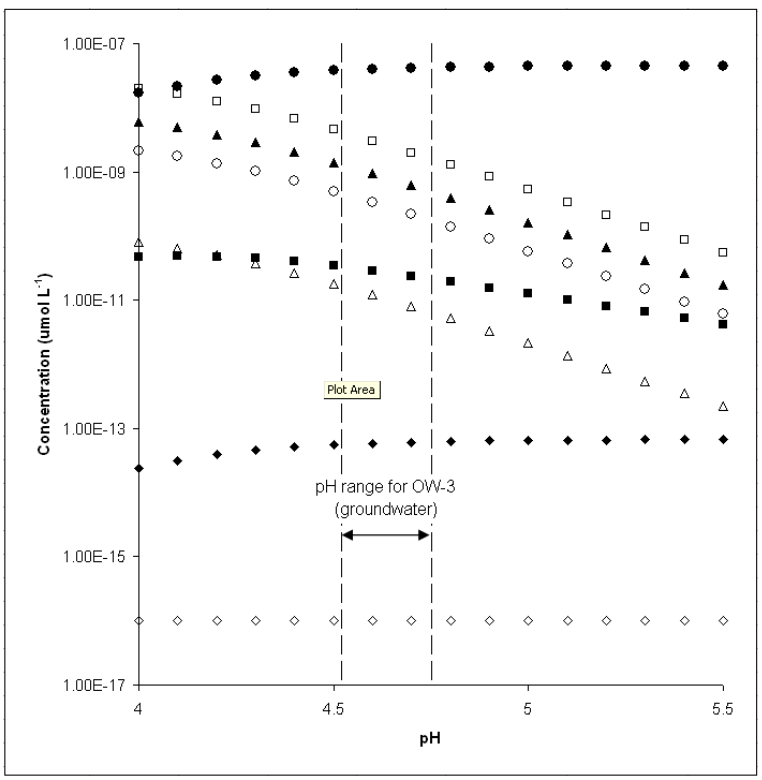

Figure 11: Focus area shallow groundwater predicted mercury species by Visual MINTEQ, pH range 4-5.5. $Hg(SO_3)_2^{-2}$ (closed circles), $HgBr_2$(aq) (open circles), HgClOH (aq) (closed squares), $HgCl_2$ (aq) (open squares), HgBrCl (aq) (closed triangles), $HgCl_3^{-1}$ (open triangles), and $Hg(OH)_2$ (closed diamonds), and Hg_2^{2+} (open diamonds).

were similar for the pore water (data not shown). The predicted percent of total mercury for the three most prominent mercury species are approximately the same for the shallow groundwater and pore water within the range of expected pH values (Fig. 12). The Visual MINTEQ model data suggests that the pore water and shallow groundwater inorganic mercury speciation is different from the deep groundwater species (Murphy et al., 1994); and that due to the relative higher pH value, the pore water is potentially more reactive than the lower pH shallow groundwater.

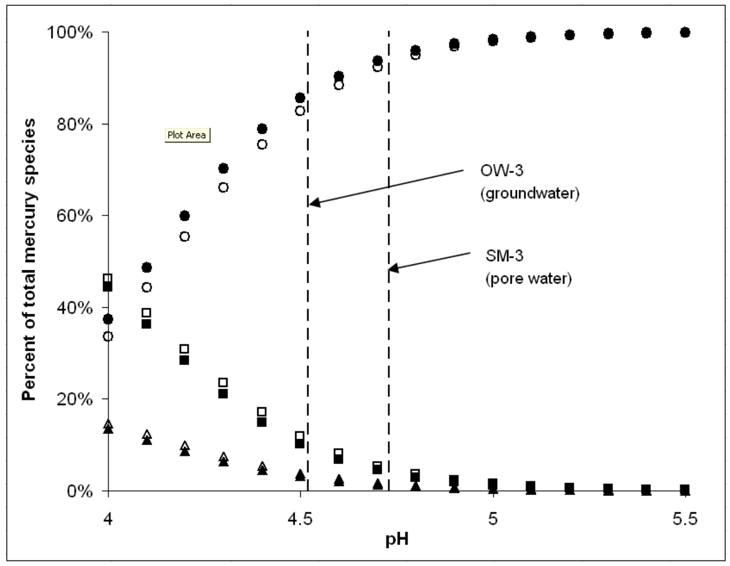

Figure 12: Most prominent mercury species predicted for focus area shallow groundwater (closed symbols) and pore water (open symbols) mercury species by Visual MINTEQ, pH 4-5.5. $Hg(SO_3)_2^{-2}$ (circles), $HgCl_2$ (aq) (squares), and HgBrCl (aq) (triangles).

If, as the model predicted, the mercury in the pore water and shallow groundwater are primarily present as a negatively charged complex, then adsorption of the complex to positively charged mineral surfaces is possible. Based on published point of zero charge (PZC) values (i.e. the pH value at which a mineral surface has a zero charge), aluminum and iron oxide, hydroxide, and oxyhydroxide minerals would have net positively charged surfaces (Sparks, 2003), and therefore could act as an adsorbent for a negatively charged mercury complex. The model output indicated diaspore (γ-AlOOH) is oversaturated in the shallow groundwater and pore water. The adsorption to quartz or feldspars would not be expected because the PZCs are less than approximately 2.4 (Sparks, 2003). The net surface charge of kaolinite (PZC = 4.6; Sparks, 2003), may fluctuate over time and space within the focus area, and therefore, have a variable affinity for adsorption of a charged mercury complex. Generally, the shallow groundwater has a lower pH than the pore water. As a result, adsorption of a negatively charged mercury complex to kaolinite in the shallow groundwater may be expected; however, in the hyporheic zone, a slightly higher pH may render the kaolinite surface negatively charged and the mercury complex more reactive or available. The fate and transport of mercury in this shallow aqueous environment needs to consider the adsorption of inorganic mercury by particulate and colloidal kaolinite, as well as aluminum and iron mineral phases. However, additional mineral phase characterization and adsorption modeling is necessary.

CONCLUSIONS

Within a large study area, seepage meters and shallow groundwater wells can be used to quickly reduce the size of the investigation area by 1-2 orders of magnitude, and identify a

focus study area. In this case, piezometric levels, groundwater flux, total and filtered mercury data obtained from within the identified focus study area were used to greatly enhance the hydrogeologic conceptual model. Additional geochemical modeling provided insight to the potential fate and transport mechanisms for mercury.
The piezometric head data confirmed the focus area is a continuous zone of groundwater discharge to surface water.

Although the highest groundwater flux did correspond to the highest mercury concentrations, there was no demonstration of a proportional relationship between the two parameters. The total mercury concentrations within the study area were not found to correlate with any of the WQIPs, precipitation amounts, or total organic carbon.

Within the focus area, the data indicate that mercury concentration is predominantly associated with the particulate size fraction within the hyporheic zone. Within the shallow groundwater, the mercury was nearly equally partitioned between the particulate and non-particulate fractions. The difference in size partitioning of the mercury in these two zones may be important to the fate and transport of mercury in this environment.

The use of the seepage meters provided direct measurements of groundwater flux. The use of the Eh-pH stability diagram suggested the shallow groundwater and the pore water are unique, but overlapping, zones where the shallow groundwater pH is generally slightly less than the pore water. Furthermore, the lower pore water Eh values suggest that there may be more mercury species variability within the hyporheic zone.

Unlike previous studies of deep groundwater, the model predictions indicate the primary mercury species in the shallow groundwater and the pore water is $Hg(SO_3)_2^{-2}$. The predominance of this negatively charged mercury complex, the low pH conditions, and the presence of positively charged aluminum and iron mineral surfaces would promote adsorption. The net surface charge of kaolinite may reverse due to minor variations in pH over time and space. As a result, the fate and transport of the prominent mercury complex could be complicated greatly.

Additional mineral phase characterization and adsorption modeling could be conducted to enhance the understanding of inorganic mercury fate and transport in this shallow aqueous environment.

ACKNOWLEDGEMENTS

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LATE CRETACEOUS DINOSAURS AND FOSSIL VERTEBRATE CONCENTRATIONS IN THE NEW JERSEY COASTAL PLAIN: TAPHONOMY, STRATIGRAPHIC OCCURRENCE AND PALEOENVIRONMENTS

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Some of the first dinosaur specimens from North America came out of the marl mines of the New Jersey Coastal Plain. Dinosaur specimens in this area typically occur in several taphonomic modes: 1) as single partial skeletons ; 2) as one to several isolated bones; 3) as single disarticulated elements within concentrations of other vertebrate fossils.

Vertebrate fossils including dinosaurs usually are found in shallow nearshore marine or parallic coastal deposits. A half-dozen stratigraphic units have produced dinosaur fossils in the New Jersey Coastal Plain. The Campanian Woodbury Formation has produced the type specimen of *Hadrosaurus foulkii* found in 1858 in Haddonfield, NJ and still the most complete dinosaur specimen from New Jersey . Stable strontium age estimation from original shell material yields an age estimate of 79.5 to 80.5 million years for the fossil shellbed associated with *H. foulkii*.

The overlying Englishtown Formation has yielded some interesting scraps, including a tooth of a possible east coast dromaeosaur. The Marshalltown Formation at the Ellisdale site is an important source of dinosaur and many other vertebrate specimens; this is an estuarine deposit with a very thin well-defined vertebrate fossil concentration that may be a storm deposit. The Wenonah and Mount Laurel Formations are a consistent source of dinosaur and other vertebrate fossils, usually from well-defined layers and pockets of fossil remains. The Navesink- New Egypt stratigraphic interval is Maastrichtian in age and has yielded the youngest (last) dinosaur specimens from New Jersey, including partial skeletons of *Hadrosaurus minor* and the tyrannosauroid *Dryptosaurus aquilunguis*.

DETAILED TEMPORAL MEASUREMENT OF SALT MARSH EDGES USING GIS

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An ongoing effort to explore the causes of salt marsh edge erosion is being carried out using Geographic Information System. Salt marshes on the east coast of North America, and Long Island, New York in particular, are typically reported to be losing area. However, it is highly unlikely that this loss is proceeding at an even rate in all locations within a given estuary, or even within a given marsh location. It is also unlikely that there is a single cause influencing the marsh. The use of area as the only measurement for a trend is uninformative as to both the rate of local edge change and the potential local causal influences.

Over eighty years of change are being measured though referencing aerial photography dating to 1926. The effort is not aimed as trends in area change, but in distinguishing between erosion rates of different points along the marsh edge. The intent is to compare the local changes with local historical conditions so that possible causes can be distinguished, even between parts of the same section of marsh.

QUANTIFYING ALTERATIONS IN MARSHLAND AREA WITHIN THE SOUTH SHORE ESTUARY RESERVE, LONG ISLAND, NY THROUGHOUT THE PAST CENTURY

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Coastal areas are affected by natural and anthropomorphic changes. The western portion of the South Shore Estuary Reserve, located on Long Island, NY, has been subject to such changes for over a century. The Jamaica Bay Estuary, similar but separate from the South Shore Estuary Reserve, has reported losses of over 50% from 1900 through 1994. This study will quantify how much of the western South Shore Estuary Reserve has been lost throughout the past century by utilizing aerial photography. It will represent a more comprehensive comparison of how South Shore Estuary Reserve marshland areas have changed over time than previously completed. Data sets are created from compiled aerial photographs and are available in approximate 20 year intervals. Comparing total areas of marshland between data sets will establish how much change has occurred, and where rates have been most drastic. Each photo was digitized, geo-referenced, and added into ESRI Arcmap 9.3 as layers that could then be measured for marshland area. This method will be repeated for up to seven data sets for a statistically viable interval. Results will reflect approximately 100 years of change and are to be visualized using ESRI Arcmap 9.3. This will effectively highlight local trends for areas where the most severe alterations have been incurred.

PALEOTEMPESTOLOGY OF LONG ISLAND: DOES GRAIN SIZE INDICATE PAST HURRICANE ACTIVITY?

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Introduction

The satellite record of hurricane activity only extends a few decades into the past, too short to enable true study of decadal to centennial trends. In the last few decades, techniques have been developed, largely on the coast of the Gulf of Mexico, to infer hurricane landfall events from grain size in coastal sediments. Storm surge and wind associated with a landfalling hurricane have been documented to have pushed beach sand over the dunes into the largely estuarine environment of coastal lakes adjacent to the shore (Liu and Fearn, 1993). Interpretations of sediment cores from several of these lakes led Liu and Fearn (2000) to propose that tropical Atlantic hurricane activity behaves in a "see-saw" pattern on centennial scales over the past several thousand years, such that when storm tracks into the Gulf of Mexico are frequent, storm tracks into the Northeast are rare, and vice versa. They based the mechanism for this hypothesis on the North-South placement of the Bermuda high and its affect on atmospheric circulation.

These "paleotempestology" techniques have since been adapted for other areas, including the Northeast. Most recently, Scileppi & Donnelly (2007) collected sediment cores from several barrier beach marsh locations around Lido Beach, NY and Long Beach, NY on western Long Island and identified sand layers that appeared to be somewhat synchronous with storm deposits on the coast of the Gulf of Mexico, thus contradicting Liu & Fearn's (2000) hypothesis.

Since the linear distance along the shore over which a particular landfalling hurricane might send beach sand over the dune crest is not likely to be more than some fraction of the width of the storm itself, it seems important to "sew up" the coast with sediment cores in order to capture as many storm deposits as possible. We therefore set out to find other locations further East on Long Island that might bear paleotempestological records. Unfortunately, our initial attempts at identifying marsh sites at Jones Beach (the next barrier beach island to the East of Long Beach) appropriate for collecting these types of records did not meet with success. Using a soil borer to penetrate the top meter or so of sediment in a few seemingly likely locations, we found sites that were entirely sandy and sites that were entirely marshy, but none that contained both marsh sediments and sand layers. Our project, therefore, evolved into simply trying to replicate the records published by Scileppi and Donnelly (2007) to make sure we were doing it right.

Methods

Seven sediment cores were collected with a vibracore system, and two with a slide-hammer soil borer from several locations around the Lido Beach Nature Preserve, NY (Fig. 1). Cores ranged from 110cm to 235cm in length. Sediment type and Munsell color was described by eye for all cores, and grain sizes of the sediment layers were measured with a Ro-Tap sieve system for most of the cores. Trace metal concentrations were measured in Core 1 using X-Ray Flourescence (XRF). Aerial photographs of the sites over the past several decades were inspected to detect recent changes.

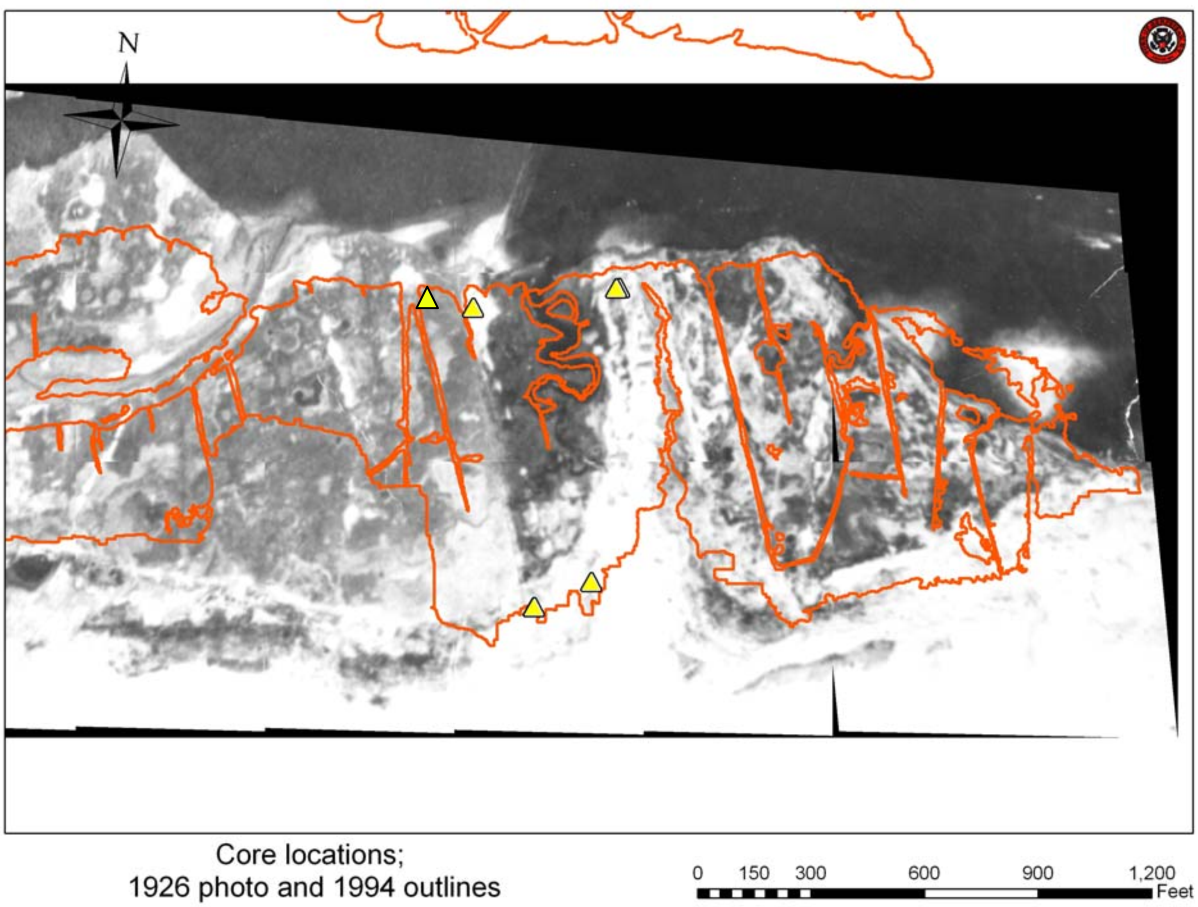

Figure 1. Lido Beach Nature Preserve study site, triangles show location of cores. Note sand on marsh, a probable consequence of dredging activities (aerial photo commissioned by Town of Hempstead, NY)

Results

Grain size varied in all cores; however, no coherent sand layers were identified that could be correlated between all cores. Cu, Pb, and Zn concentrations in Core 1 never show a significant upward shift, which would correspond with an increase in industrial pollution. Aerial photographs from 1926 indicate the active presence of dredging operations in the nearby channel, with light-colored (presumably sandy) dredge spoil being pumped onto the marsh surface, obscuring the naturally darker vegetation (Fig. 1).

Conclusions

The lack of an increase in trace metal concentrations in one of our cores implies that the sediments in at least some of our cores are younger than the pre-industrial era, indicating a high rate of sediment accumulation. We wonder how much the dredging activity has disturbed the sediment record in this area. This motivates even more strongly future efforts to collect cores from further East on Long Island's barrier beaches to confirm conclusions about basin-wide changes in hurricane patterns drawn from this area.

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NEW JERSEY COASTAL PLAIN REVEALS GLOBAL SEA-LEVEL CHANGES IN THE CRETACEOUS GREENHOUSE

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The New Jersey continental margin provides a most detailed record of millions of years of sea-level change. Recent Late Cretaceous studies on the New Jersey Coastal Plain (Miller et al., 2004, 2005, Kominz et al., 2008, Mizintseva et al., 2009) reveal evidence of large and rapid (> 25m in << 1myr) sea-level changes during the past 100 millions years. Detailed studies of the Merchantville Formation (late Santonian-early Campanian) revealed a link between sequence boundaries and deep-sea benthic foraminifera oxygen isotope increases suggesting that small and ephemeral polar ice sheets may have formed during the Late Cretaceous. Here we present our results that indicate close correlation of the sea-level events and the oxygen isotope increases. We consider glacio-eustasy as the most rational explanation for late Santonian-early Campanian sea-level fluctuations.

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INTEGRATED SEQUENCE STRATIGRAPHY AND GLOBAL SEA-LEVEL: SHOULD I SELL MY SHORE HOUSE?

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We present an estimate of sea-level change over the past 180 million years derived from backstripped Russian Platform/Siberian records (180-90 Ma; Sahagian et al., 1996), backstripped New Jersey coastal plain records (100-7 Ma; Miller et al., 2005), and scaling of $\delta^{18}O$ estimates (9-0 Ma; Miller et al., 2005). Long-term (10^7-10^8 y) sea-level changes during this period were smaller than previously inferred, with a Late Cretaceous peak of 100±50 m implying small, but nonzero, changes in seafloor spreading rates.

On the 10^6 y scale, the tempo (~1-3 million year cyclicity) and amplitude (30-80 m) of global sea-level changes are remarkably similar from the supposedly ice-free Jurassic-Cretaceous Greenhouse into the Oligocene-Holocene Icehouse. It is only with the advent of large Northern Hemisphere ice sheets (NHIS) at ca. 2.6 Ma that amplitude of sea-level changes increases significantly, albeit on the Milankovitch (10^4-10^5 y) scale.

Our record compares favorably with the Exxon Production Research (EPR) eustatic record over the past 100 million years in the number and timing of sea-level events. However, the EPR amplitudes are 2.5 times or greater than ours on both the 10^7-10^8 and 10^6 scales.

Glacioeustasy is the only known mechanism that can account for Late Cretaceous to early Eocene rapid eustatic changes (i.e., 30-80 m on 10^6 y scale) because other hypothesized mechanisms (steric effects, water storage in lakes, deep-water changes, groundwater, or sea ice) are too slow or too small. In contrast to this evidence for glacioeustasy, ample geological evidence points to warm high-latitude temperatures at this time. We reconcile records of warm high latitudes with glacioeustasy by proposing that Late Cretaceous-early Eocene ice sheets generally reached maximum volumes of 8-12 x 10^6 km^3 (20-30 m glacioeustatic equivalent), but did not reach the Antarctic coast; hence, coastal Antarctica (hence deep water) remained relatively warm even though there were significant changes in sea level as the result of glaciation. Unlike the Oligocene and younger icehouse world, these ice sheets only existed during short intervals of peak Milankovitch insolation, leaving Antarctica ice-free during much of the Greenhouse Late Cretaceous to middle Eocene. Ice-volume variations controlled sea-level changes of ~30-80 m on the 10^6 scale over at least the past 180 million years and changes of 30-120+ m on the "Milankovitch" scale for the past 2.6 million years. Over the past 180 million years, sea-level changes reflect global climate evolution from a time of ephemeral Antarctic ice sheets (180-33 Ma), through a time of large and variable Antarctic ice sheets (33-2.5 Ma), to a world with large Antarctic and large, variable NHIS (2.5-0 Ma).

Sea-level changes mirror $\delta^{18}O$ variations on various scales. Such covariance can be explained by ice-volume changes in concert with temperature changes on the 10^6 y and Milankovitch scales, but a long-term $\delta^{18}O$ increase of ~4-5‰ since 50 Ma must be primarily attributed to deep-water cooling (~13-15°C overall), rather than to ice storage. The link between sea level and temperature on the 10^7-10^8 y scale cannot be due to cooling alone because this steric effect would explain only ~15 m of eustatic fall since 50 Ma. The link between $\delta^{18}O$ and sea-level variations on the 10^7-10^8 y scale must be due to tectonics through carbon dioxide, as indicated by a covariance of long-term sea level, $\delta^{18}O$, and CO_2 proxies. This suggests that ocean ridge variations controlled greenhouse gases, causing global temperature changes. Though long-term thermal evolution generally follows CO_2 and parallels sea-level changes, sharp changes to cooler climatic states occurred in the earliest Maastrichtian, across the Eocene/Oligocene boundary, in the middle Miocene, and in the mid-Pliocene.

Rising sea level poses a threat to coastal communities, yet the extent of this threat is often exaggerated in the media, from an "Inconvenient Truth" to the New York Times, scaring citizens into thoughts of a real estate exodus. Recent studies have documented that sea level is rising today at 3.3±0.4 mm/y, accelerating from a 20th century rise of 1.8±0.3 mm/y. We show that the maximum global rate of rise prior to 1850 was 0.5-1.0 mm/y and thus can attribute <<30% of the modern rise to natural causes. By 2100, the IPPC best estimate is that global sea level will rise by at least 40 cm (1.2 ft). However, this is not a reason to flee the beaches in panic; Atlantic City saw 40 cm of rise in the 20th century. Most regions will also see additional relative rise due to subsidence, ranging from 10-20 cm along the U.S. east coast to over a meter in southern Louisiana and Bangladesh. In the latter cases, regionally high subsidence rates are the prime concern, not global rise due to warming. The most important effects of sea-level rise in the next century will continue to be its exacerbating influence on coastal storms, the loss of marshlands, and the continued costs to fight the inexorable march back of the beaches. But we note the following concern: Rahmsdorf et al. (2007) show that we are tracking at the high end of the IPCC estimates and conclude that 80 cm (2.4 ft) is the most likely global rise by 2100. This higher rate of rise is a major concern: it will result in loss of land (1-3% of the U.S. east coast), loss of marshland, higher beach erosion, and high costs to society. A major unknown is that the upper limit of 80 cm of rise by 2100 is not well constrained. If the rate of Greenland melting continues to increase, it is possible that the global rise by 2100 will exceed 80 cm. In that case, higher ground is preferred.

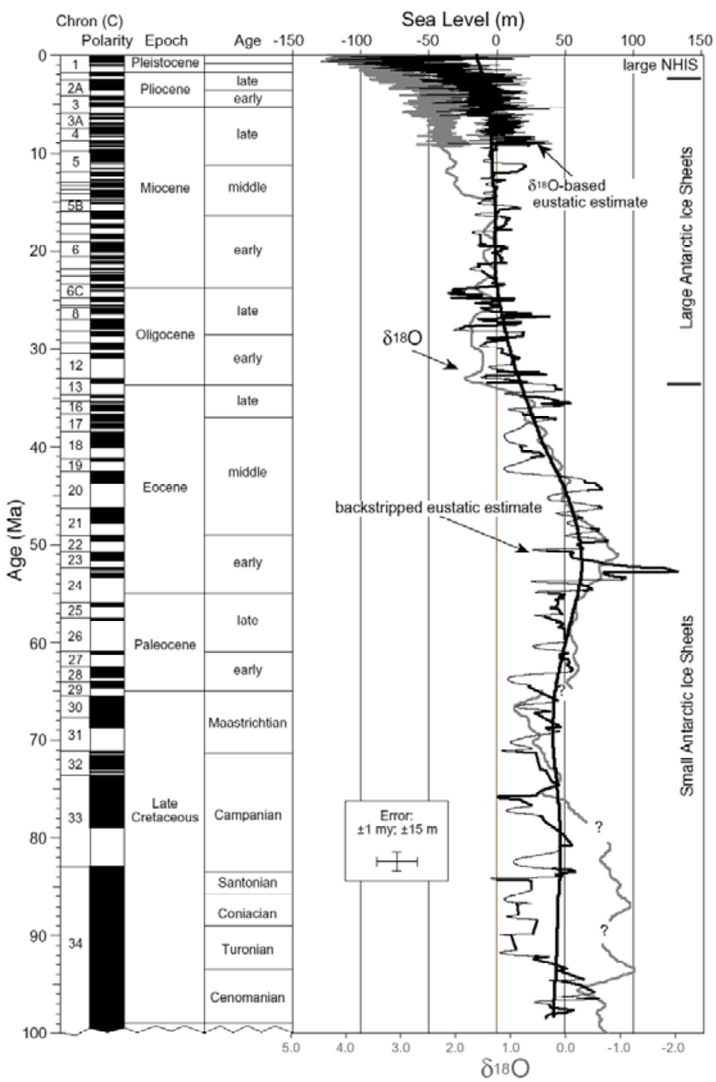

Figure 1. Global sea level (thin black line) derived by backstripping (7-100 Ma) and $\delta^{18}O$ (0-9 Ma). Shown for comparison is a benthic foraminiferal $\delta^{18}O$ synthesis from 0-100 Ma (gray) with scale on bottom axis in ‰ (reported to *Cibicidoides* values. Heavy black line is the long-term fit to backstripped curve. After Miller et al, 2005.

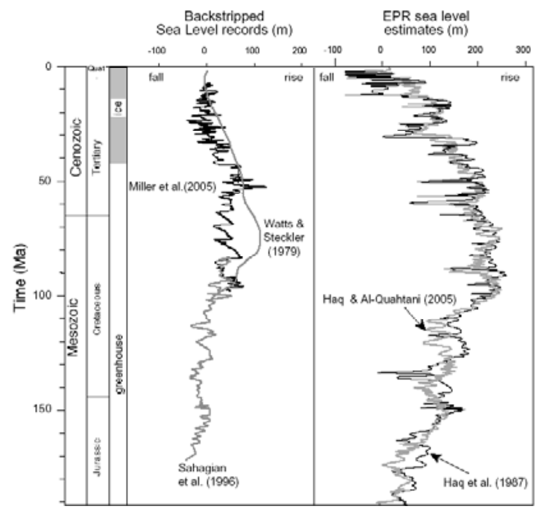

Figure 2. Comparison of backstripped and EPR records. After Miller et al, 2005

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FIELD GUIDE

PART I

BEACH NOURISHMENT IN NEW JERSEY FOR 2009: CURRENT WORK IN STRATHMERE, SEA ISLE CITY, STONE HARBOR & NORTH WILDWOOD

Dr. Stewart Farrell
Richard Stockton College, Coastal Research Center

INTRODUCTION

Beach restoration or nourishment is the deliberate attempt to add new sand to an eroded shoreline to improve the storm protection or recreational opportunities for the local residents and tourists. This new sand may come from the mainland (delivered by truck), from nearby tidal inlet deposits or from offshore deposits (derived by hydraulic dredge and pumped to the shoreline). All forms of this process require both NJ State and Federal permits to proceed. All methods require the finding and moving of hundreds of thousands of cubic yards of sand from one place to the erosional segment of the coast. Project planning and execution are extensive and need a large segment of the affected population to concur that this is the proper strategy for best success in preserving the beach. Finally, the cost is driven by two major factors; the expense and time of mobilizing the equipment and personnel needed to undertake the project ($500,000 and up) and the cost per cubic yard for the sand pumping (between $6.50 to $12.00 per cubic yard). The cost factor for a half million cubic yard project is between $4,250,000 and $6,500,000.

Beach management has evolved in New Jersey since popular resorts developed in Cape May City and Atlantic City, plus several Monmouth County communities in the years following the Civil War. By 1900 all these municipalities were extensively developed and were finding that there were some drawbacks to building permanent structures on a sand barrier island. Initially the dunes were viewed as a source of sand for filling in the marsh areas on the island, to the point where Atlantic City passed ordinances in 1906 to curtail the mining of the dunes and beach for "FILL". They also passed an ordinance to prohibit the depositing of winter furnace ash from coal-fired heating systems onto the beach (these clinker fragments are still present under a microscope examination of AC beach sand).

The first episode in shore protection revolved around timber bulkheads parallel to the shoreline and groins perpendicular to the beach. These started small in the last third of the 19^{th} Century and expanded greatly as both rail and truck transport developed to handle large stone used for rock structures in place of timber. The "hard structure" solution remained the engineering choice between 1900 and 1970 in New Jersey. Many communities have groins spaced every three or four city blocks and all but three of the eleven NJ inlets have hard structure jetties guarding the channel.

Beach nourishment commenced with a 2.52 million cubic yard project in Ocean City, NJ in 1952. The sand used was too fine and the project did not last nearly as long as expected causing the continuation of the idea to stop for two decades. The City did operate a dredge for 15 years, largely to clear boat slips and maintain navigation channels on the bay side of the island, but putting the sand on the beach. This helped, but the quantities moved were small in comparison to the need, and the bay sand was too fine to remain on the beach very long. In the late 1970's the State Division of Engineering and Construction tried nourishment again following a very well advertised and successful project conducted by the US Army Corps of Engineers on North Miami Beach in 1978. The State used bond funds to provide the money to conduct several projects in NJ Coastal communities. Bond funding proved too limited in terms of the future debt load and new funding streams were sought.

In the mid-1980's the US Army Corps of Engineers (ACOE) again entered the coastal preservation arena using their congressional funding to first study the existing array of problems and then propose solutions using beach sand restoration. The initial two projects were in Ocean City and Cape May City in 1989. The former was a "Navigation Project" to clear the sand from Great Egg Inlet using the dredged material as beach fill rather than discharge it into deep water, and the latter was an outcome of litigation over the loss of beach attributed to the 1911 construction of two long jetties at Cold Springs Inlet by the US Navy. Here the US Army Corps paid 90% of the project cost. The Ocean City project introduced the concept of Federal funding of "Shore Protection Projects" with 65% Federal funding IF the local interests would fund the remaining 35% (any combination of community, county, or state participation). In 1994, the legislature passed PL 93 providing $25 million dollars every year for coastal protection projects, administered by the Construction and Engineering division of the NJDEP. The project costs would be split 75% State money and 25% local funding. This money was derived from the NJ Real Estate Transfer Tax levied on every property sale in NJ and paid by the seller. The fund is permanent and not subject to political sapping for other purposes. The State recognized that application for a Federal project was a dramatic leveraging of State money and for the local communities the prospect of the State paying 75% of the 35% local costs of a Federal project means that for every million dollars of project cost the community's share would be $87,500.

The process begins with a Congressional authorization of a project based on a 100% ACOE funded Reconnaissance Study of the problem beach to define the issues and examine the potential solutions. The reconnaissance study is followed with a Feasibility Study were the State and Federal agencies share an extensive study of the problem, potential engineering solutions, and generate an extensive report detailing the costs and effectiveness for a variety of potential solutions. A recommended course of action is also recommended. Finally a Design and Engineering Memorandum is generated based on the recommended Feasibility Study solution to the point of creating construction plans and documents. The local partners are responsible for their funding share and local real estate issues regarding the project operating on the selected beach. The State signs agreements with both the ACOE and with the local community spelling out the responsibilities and costs associated with each partner. When both NJ State and Federal permits are in place the construction can begin. Time from concept to construction is about 8 – 10 years.

TO DATE, the State of New Jersey has completed the following projects in partnership with the Federal ACOE:

1. Monmouth County	21 miles	$210,000,000	1994 – 2000
2. Long Beach Island	4 miles	$ 79,000,000	2007 –
3. Brigantine Island	2 miles	$ 6,000,000	2006
4. Absecon Island	4 miles	$ 24,000,000	2003 – 2004
5. Ocean City	6 miles	$ 70,000,000	1992 – 2004
6. 7-Mile Island	4 miles	$ 7,000,000	2004 – 2005
7 Cape May City	6 miles	$ 34,000,000	1989 – 2005
8. Cape May Meadows	4 miles	$ 6,500,000	2005

These are only the NJ State partnered Federal projects and do not include multiple NJ State and local projects funded under the State formula. The Monmouth County project is the largest such efforts and took six years to complete. The Ocean City and Cape May City projects have seen multiple maintenance work between the initial start and today. Each Federal project comes with a promise to monitor the beach and provide maintenance fill for a 50-year time IF Congress provides the money. That promise went un-fulfilled in 2007 and 2008, so work has backed up and efforts are underway to gain those maintenance projects by the State and local interested parties.

As a result of the political difficulty getting the Federal projects funded in new locations and the slow rate of maintenance dollars coming to existing projects, the State and local governments agreed to a series of projects for the 2009 season that covers the communities of Strathmere in Upper Township, Sea Isle City, Stone Harbor and the City of North Wildwood. This $18,000,000, 4-community project was awarded to Great Lakes Dredge and Dock Co. and work started at the unincorporated segment of Ludlam Island called Strathmere in the Township of Upper.

Strathmere occupies the northern end of the barrier island and Corson's Inlet was used as the source of sand. This inlet is one of three NJ inlets without hard structures confining the channel flow. The consequence is that the inlet has a tendency to migrate north to south over a 9 to 11 year cycle. When the meandering carries the tidal channel south toward the development in Strathmere, the citizens grow concerned. This concern grew into panic as the winter of 2008 commenced. Even in the absence of northeast storms the beach between the development and the State park land at the tip of the island diminished every day. Finally, in spite of planning underway for a nourishment action, the locals were forced to install a steel bulkhead along the north boundary of the properties at the inlet and support the bulkhead with a rock toe. Storm waves still topped the structure and potential loss was so obvious that the beach nourishment became urgent in the extreme. Below (Fig. 1) are a pair of vertical air photographs showing the previous cycle of advance and retreat of this shoreline between 1991 and 1999 (US ACOE photos).

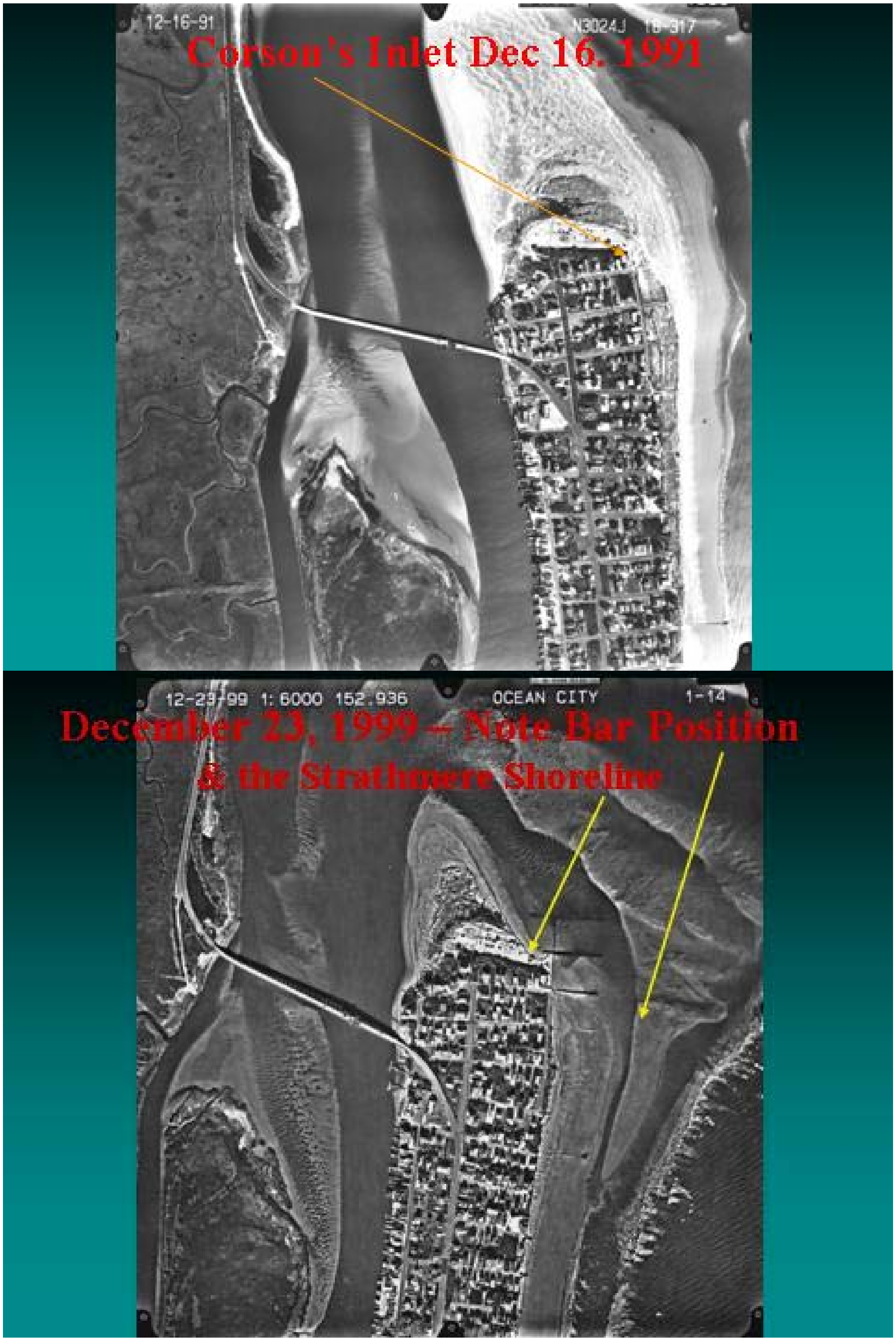


Figure 1. Pair of vertical aerial photographs of Strathmere showing the past cycle of inlet change that lead to the 2001 NJ State and locally sponsored beach restoration (courtesy of ACOE).

STOP 1. Seaview Avenue, Strathmere, Upper Township, NJ.

Exit 17 from the Garden State Parkway, travel east to Sea Isle City Ocean Avenue, turn left (north) and go north until you can go no further (do not cross the toll bridge off Ludlam Island). The last street in Strathmere is Seaview Avenue, turn left and go to the beach. The project extends around this street end to the inlet and along the properties at the north side of Seaview Avenue. It also extends south for 2.5 miles into Sea Isle City. This spring the low tide line was at the bulkhead and no dry beach existed beyond the bulkhead. Almost a million cubic yards of sand were mined from the ebb-tidal delta of Corson's Inlet and applied to the beach. This was the third in a series of projects completed on this beach starting in 1984, again in 2001. The first two fills were smaller and only covered the oceanfront shoreline over a third of the Strathmere shoreline. This project provides new sand to the entire municipal oceanfront.

Pumping started in early July 2009 and moved into Sea Isle City by the end of August. When completed, along with the two segments of Sea Isle City will have taken almost a million and an half cubic yards from the inlet ebb-tidal deposit. This particular variation in the south inlet shoreline was particularly problematic because without the initial hard structural response in late 2008, the six homes at the inlet would have been lost before the sand would have been pumped. Air photographs (Fig. 1) show that Corson's Inlet has migrated almost a mile south since 1920 when two inlets to the bay between Ocean City and Strathmere coalesced into one and eliminated a short barrier segment called Sand Island in the late 19th Century. Ironically, it was beach nourishment in Ocean City between 1995 and the present which added to the propensity for the Corson's Inlet southwesterly migration by allowing thousands of cubic yards of sand to pout south to the southern tip of Pecks Beach pushing the main tidal channel to the south. Using this knowledge, the dredging design plan called for taking most of the sand for this project from the northeast side of the tidal deposit allowing the inlet to stabilize in a more northeasterly position to extend the time to the next cycle of strong push toward the Strathmere side.

From here we will move south toward where the work proceeds at this moment in time. This will likely be North Wildwood, but if bad weather intervenes, the dredge may still be working in the Borough of Stone Harbor. For the record, Stone Harbor conducted a State and locally sponsored project in 1998 following a pair of minor northeast storms in early 1998. All of Seven-Mile Island became a Federal project in 2003 with the Stone Harbor beach being completed in 2004. In the absence of Federal maintenance money, the State and Borough have cooperated to use State funds to maintain a little less than half the municipal beach.

STOP 2. Stone Harbor and North Wildwood Shore Protection Projects.

Leaving the Strathmere beach, we drive south along the length of Ludlam Island, cross Townsends Inlet and head south along the Avalon and Stone Harbor shoreline. If the dredge is still working in Stone Harbor, we will stop where the sand is being pumped onto the beach and allow you all to observe the process in action. The Borough of Stone Harbor initially conducted a State/locally sponsored project in 1998 following a pair of modest northeast storms that cut the beach back to the bulkhead. In 2003 – 2004 the entire barrier island was the subject of an Army Corps Shore Protection project covering Avalon and Stone Harbor. This project is designed to fill in areas that have retreated to the point where any storm activity would negatively impact the dune system. If the work has shifted to North Wildwood, we will continue through Stone Harbor, cross Hereford Inlet and go to the beachfront in the City of North Wildwood (Fig. 2). The pair of photographs (Fig. 2 & 3) showing the dramatic shift in sand distribution in the City of North Wildwood leading to this project is below. The graphic taken from the 2008 NJ Beach Profile Network report on the 15th Street survey site is also provided.

Figure 2. The beach at the City of North Wildwood in 2004 as changes to the Hereford Inlet ebb-tidal geometry were changing to produce a loss of sand from the bulge in the beach above to move material south into Wildwood and north into Hereford Inlet.

As of September 15th the contractor was commencing the pumping of sand onto the North Wildwood beach, so it will depend on the progress made which municipal shoreline the trip will visit.

In either case, a word of caution: This is a major construction project with heavy equipment and a large volume discharge of slurry water onto the beach. The project closes the beach to non-project personnel within a thousand feet of the work, but arrangements have been made with the contractor for this visit, so please follow the project operator's instructions and DO NOT WANDER AWAY FOR THAT EXCLUSIVE PHOTOGRAPH. This project is being supplied with sand derived from the Hereford Inlet ebb-tidal delta.

North Wildwood started the 21st Century with over a 1,000-foot wide ocean beach. Major shifts in the inlet main ebb-tidal channel produced an extraordinary movement of sand from the northeast corner of the oceanfront into the inlet along the North Wildwood side and south into Wildwood. The total retreat amounted to 1,054 feet between 1998 and 2006 (NJ Coastal Monitoring program) (Fig. 3). The contractor's representative will provide the specific details on sand quantity, placement details and dredge productivity rates. The time will be spent going to vantage points on the beach and in the dunes to view the progress and the process.

Figure 3. North Wildwood in 2008. Note that the bulge is gone, the shoreline has retreated, but massive quantities of sand have moved to the Hereford Inlet shoreline. This is a 25 to 30 year cycle that last occurred in 1962 to 1970.

FIELD GUIDE-
PART II

ROADSIDE GEOLOGY OF CAPE MAY COUNTY

Pierre J. Lacombe

The surface geology of most of Cape May County is composed of barrier islands and back bay deposits and the deposits made under the ocean in about 5 to 150 ft of sea water (near shore neritic zone). The barrier islands and back bays that form the eastern half of Cape May County (Fig. 1) are made up of Recent sand, muck, clay, and silt. These sediments were deposited during the past 10,000 years. The surface geology of the peninsular mainland and much of the northern mainland is made up of Sangamonian age barrier islands, back bays, and neritic deposits. Deposition occurred when sea level was about 15 to 20 ft higher during the last interglacial period. The spine of the county, which consists of a flat broad sandy high ground along Route 9, and west of the Garden State Parkway was a former series of barrier islands. This high ground consists of beach sand and dune deposits. Swamps, west of Route 9, such as the Great Cedar Swamp, Turkey and Beaver Swamp, Lizard Swamp, Bennett's Bog were former back bays and were underlain by sand, clay, silt, and muck deposits.

Owens and others (1999) show the strata that are exposed in the northern mainland or immediately below the surficial deposits are the Belleplain Member of the Kirkwood Formation (Tkb), Cohansey Formation (Tch) , Bridgeton Formation (Tbr) and the Unnamed Unit Beneath the Cape May Peninsula (Tu) (Fig. 2 and 3). Abridged strata descriptions from Owens and others (1999) and Newell and others (2000) follow:

Belleplain Member (Tkb) (Miocene) forms extensive massive gray to dark brown silt to clay beds with characteristic micaceous partings and local lignite.

Cohansey Formation (Tch) (Miocene) consists of sand, gravel, silt, clay, peat, and lignite. The sand consists of white, pale-yellow, and grey, fine- medium-grained, well rounded, well sorted, unweathered quartz and siliceous rock fragments. The gravel consists of well rounded quartz. Clay is predominately kaolinite and illite. In southern New Jersey are assemblages of trough cross beds interspersed with gently dipping, attenuated sets of planar beds (interpreted as marine beaches deposits). Thickness ranges from 2 to 6 m; beds consist of well rounded, cross bedded sand and sparse pebbles, cemented molds and casts of shell hash (including clam *Spisula* sp.), and deep penetrating, nodded, clay-line burrows (*Ophiomorpha nodosa*). Alternating trough cross beds and planar beds were created in the surf zone and represent rising and falling tidal deposition and storms-surge events. Overlying beach facies are meandering channels filled with silt and clay and small-scale (10 to 20 cm) ripples, cross beds, and planar beds indicative of tidal channel and back-barrier and lagoonal environments. In many places, the top of the Cohansey Fm. is truncated and is overlain by the Bridgeton Formation. Miocene age deposits—the

Cohansey (Tch) and the Bridgeton (Tbr and Tbrg) outcrop in northern Cape May County and are mined extensively east of Woodbine.

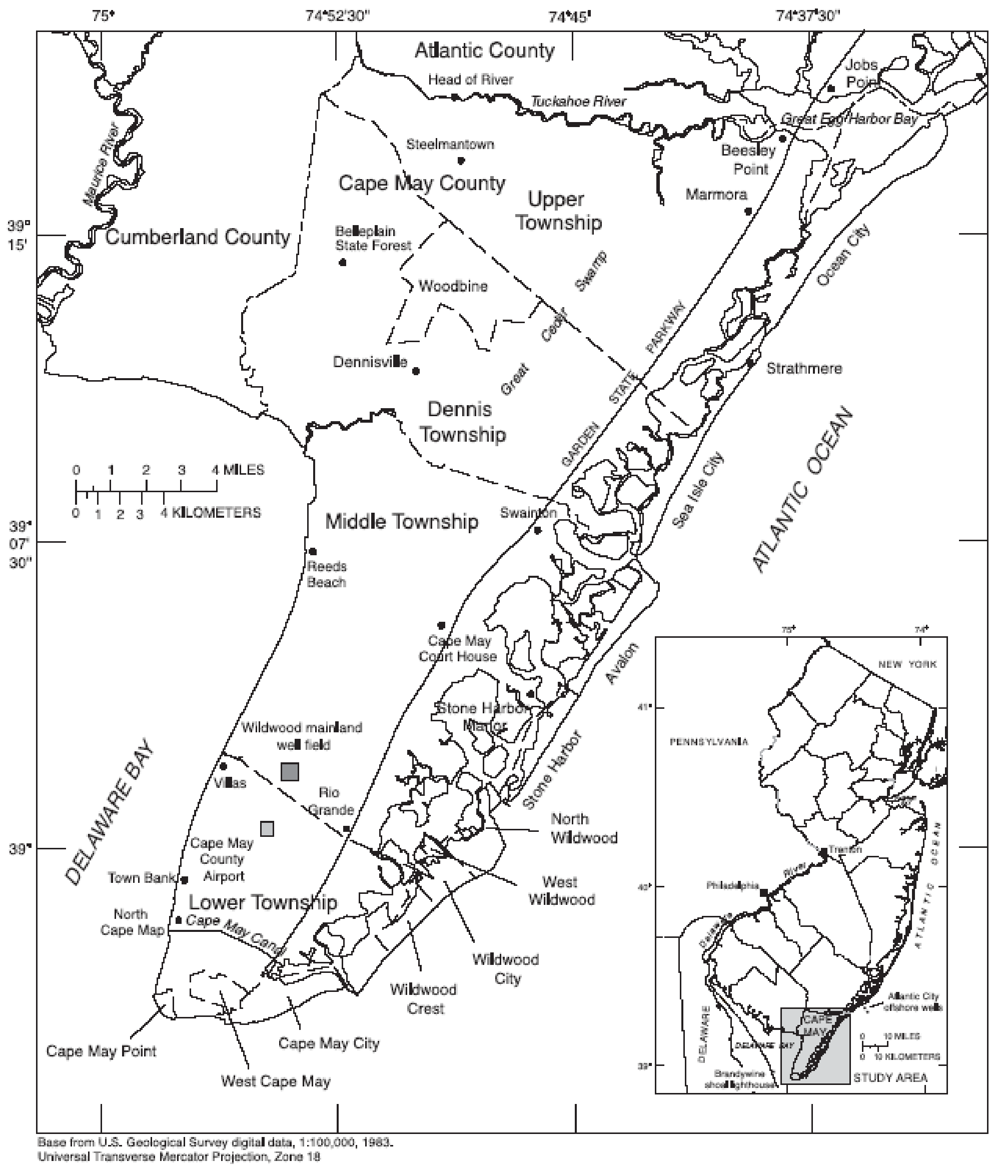


Figure 1. Map of Cape May County showing townships and major towns

Bedrock Strata
Miocene and Pliocene Sands and Clays generally under veneer of Pleistocene deposits

Bridgeton Formation (Tbr) (Miocene) consists of sand, gravel, silt, and clay. Sand is arkosic, angular to poorly rounded grains of quartz, weathered feldspar, mica and an immature suite of unstable and resistant heavy minerals. Many lithic clasts are completely weathered. Clay is predominately kaolin from in-place weathering of feldspar rich sediments. Reddish to orange hues are common in weathered outcrop.

Unnamed Unit Beneath the Cape May Peninsula (Tu) (upper Pliocene) is a gray to greenish gray, black, thin to thick bedded sand, clayey silty, glauconitic, pebbly sand, and woody, clayey silt. Found only in the subsurface on the Cape May Peninsula (the estuarine sand and clay strata of Gill (1962). It is a sequence of ascending fluvial estuarine and marine deposits bounded by unconformities. Basal unconformity marked by gravely sand overlying well sorted silty and fine sand with diatoms from the Tkb member.

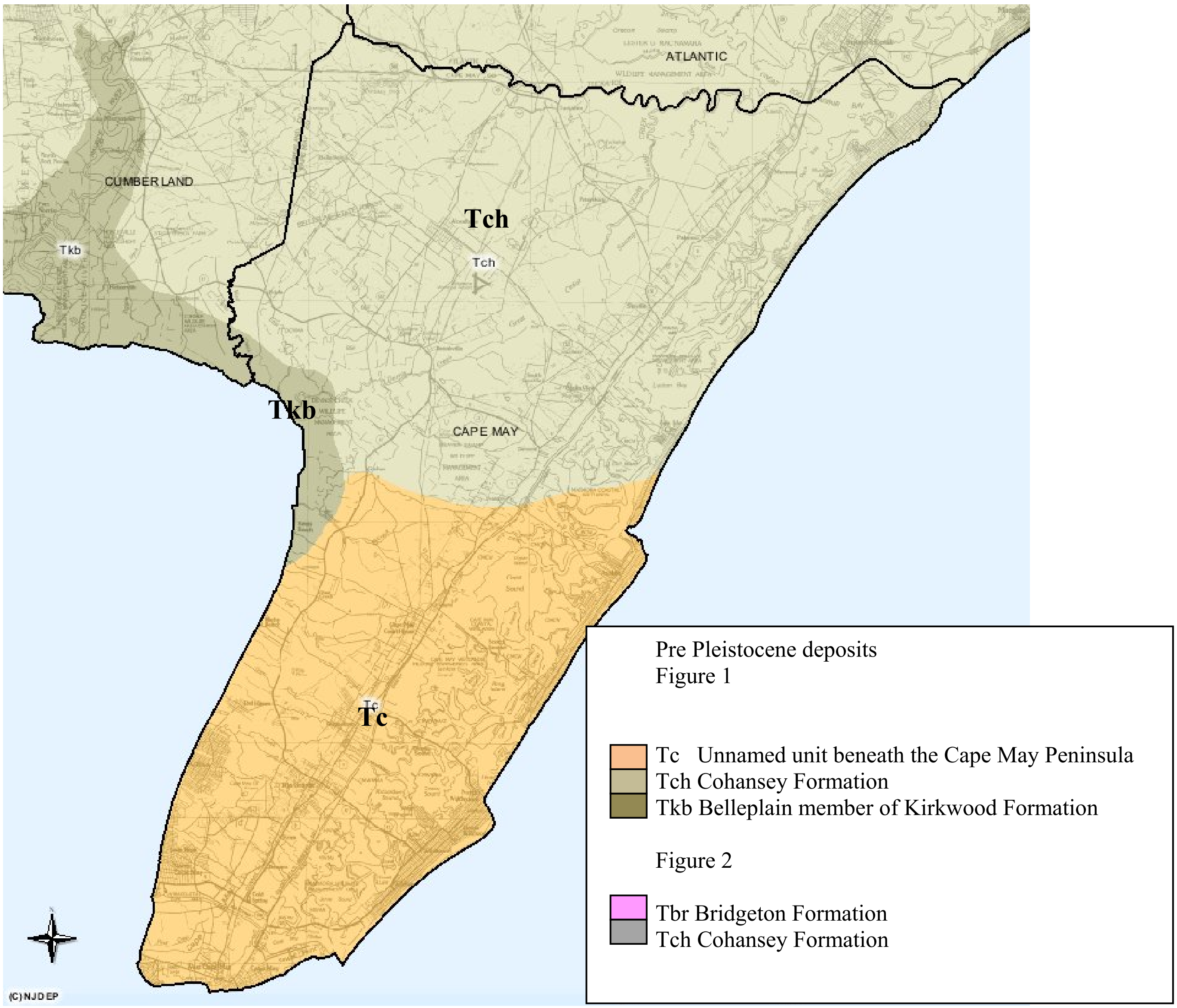


Figure 2. Bedrock strata immediately below the surficial deposits of Cape May County. (from Owens and others, 1999)

Pre Miocene deposits

All pre Miocene strata in Cape May County have only been observed via drilling (Fig 3). The deepest holed drilled in Cape May County is the Anchor Gas Well. It was drilled to a depth of 6388 ft. Metagabbro and gneiss rocks were recovered. This is likely the deepest well drilled in New Jersey.

Miller and others (1996) drilled three wells in Cape May County as part of the Coastal Plain Drilling Project (Fig. 3). The Cape May County core holes are part of the onshore portion of the Ocean Drilling Program/Integrated Ocean Drilling Program (ODP/IODP) New Jersey sea level/Mid-Atlantic Transect. The Transect focuses on reconstructing global sea-level variations during the past 100 m.y. and global events in Earth History. Eleven onshore core-holes have been continuously cored and logged as part of the Transect.

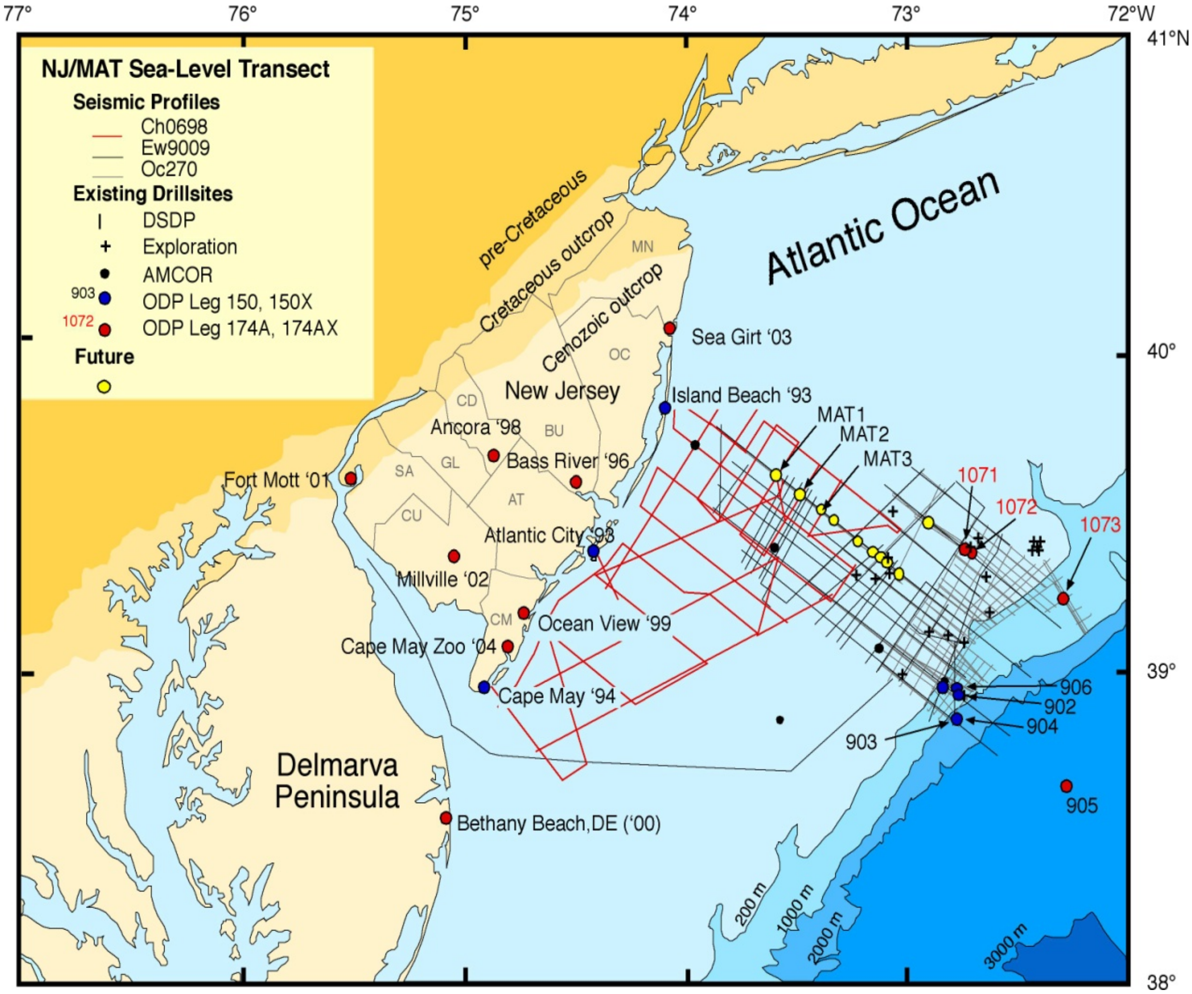
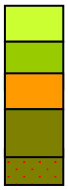


Figure 3. Map showing the location of drill sites in Cape May County and elsewhere as part of the Coastal Plain drilling project. (From Ken Miller http://geology.rutgers.edu/cpcores.shtml access Sept 2 2009)

Surficial Deposits
Sands and Clays that form veneer of Pleistocene deposits

The surficial deposits of the mainland peninsula and lowlands of northern Cape May County are of the Cape May Formation (Qcm) (Pleistocene) and are divided into five units. (Fig. 4)



Unit 1 (Qcm1) (early Wisconsin? to late Sangamonian)-
Unit 2 (Qcm2) (late Sangamonian) and
(Qcmbl) (late Sangamonian
Unit 3 (Qcm3) (early Sangamonian)
(Qcmb) (early Sangamonian)

The deposits are predominately quartz rich sand with variable mix of heavy minerals and variegated gravel, silt, clay, and peat. Sorting, clasts shapes and bed forms indicate deposition in a marginal marine to estuarine environment. Beach deposits are distinguished by well rounded disc and rod shaped pebbles. The low angle planar beds dip seaward.

During the highest sea level of the early Sangamonian (Fig. 5) the barrier islands extended from Marmora to South Seaville and are represented by units Qcm3 and Qcmb (Fig. 4). An early Sangamonian back bay occupied the present Great Cedar Swamp.

Sea level declined and the barrier islands migrated southward and eastward. Gravel and sand ridges through Clairmont and Swainton reflect the new shoreline and barrier islands as sea level declined. The back bay behind these newer barrier islands are today occupied by Beaver and Timber Swamp.

In late Sangamonian, the barrier islands formed the spine of the peninsula. These islands extended from 2 miles north of Cape May Court House to Cape May Point and likely into present Delaware Bay where the Cape May Point shoals are located. West of the Qcm2 barrier islands were the back bay deposits (Qcmbl). Today these are headwater areas of Fishing Creek, Dias Creek, Green Creek, and others.

Sea level continued to drop as the Wisconsin glacial event progressed. The barrier islands again shifted eastward forming Qcm1. Variations in the type of sediments for each of these deposits are minimal. The elevation of the sand, silt, clay deposits as marginal marine deposits dictates the age difference.

During the early Wisconsin ice age the barrier islands continued to shift eastward forming barrier islands on the shore of the receding Atlantic Ocean. Delaware Bay became dry and formed an upland region much like all of southern New Jersey, but the vegetation on the land was like tundra.

At the maximum advance of the Wisconsin glaciation (glaciers covered all of northern New Jersey) sea level was 250 to 300 ft lower than today and the eastern most barrier island were near the continental shelf. Today these series of barrier islands (Qcm1) (Fig. 6) are covered with the Holocene barrier island deposits (Qb).

With the onset of the Holocene (Recent) interglacial cycle, the glaciers melted, sea level rose, and crated a series of barrier islands parallel with today's shoreline and on top of the barrier islands that formed during the recession. The submerged Holocene barrier islands are seen in bathymetric maps of the offshore region of Cape May County and stylized in section B-B' as offshore peaks in unit Qs (Fig. 6). The submerged barrier islands are mined with ocean going dredges and pumped to replenish the sand beaches on the coastal communities from Ocean City to Cape May City.

Today, the barrier island deposits (Qb) and the Back Bay deposits (Qm) are covered in many location with Artificial fill (Af) which is sand dredged from offshore or mined from the mainland.

Abridged descriptions of the Pleistocene deposits, as described by Newell and others (2000) include the following:

Units Qcm_3, Qcm_2, Qcm_1, Qcmbl and Qcmb comprise a beach facies that consist of quartz rich sand to pebble gravel with variable mix of heavy mineral and stable mineral. The top 1 to 2 meters is deeply weathered and locally includes frost wedges that formed during the Wisconsin glaciation and blanket of windblown sand.

Unit Qcm_3, filled the deep channels, which cut as much as 55 m below present sea level. These paleo rivers, including a proto-Delaware River. These channels formed as sea level dropped as much as 60 m below present sea level. Paleochannel shown in the Airport and North Wildwood area is referred to as the Rio Grande paleochannel by Gill 1962, and is shown in section A-A' of Newell and others (2000) (Fig. 7).

Abridged descriptions of the Holocene deposits as described by Newell and others (2000)

Beach Deposits (Qb) (Holocene) Yellow brown sand and gravel, include scatted windrows of whole, disarticulated, and broken mollusks shells and well rounded rod and disc shape pebbles of quartz, poly-crystalline quartz, quartzite, and Paleozoic chert. Reworked multicycle sediments of broad intertidal range occurring in alternating sets of bay or ocean facing attenuated coalescing strata. Include beds on landward facing small scale trough crossbeds. Thickness ranges from feather edge to as much as 15 m. Some beaches include scattered shell material, however most urban beaches have been replenished.

Salt Marsh Deposits (Qm) (Holocene) Organic muck and peat, silt, clay and sand; black brown and gray organic muck includes remains of salt tolerant grasses especially *Spartina*, silt and sand occur as levee and crevasses splays, silty deposits along tidal creek margins transported largely as suspended sediments in turbid bays of rivers during high tides generally 1 to 2 m thick up to 6 m thin along shoreline.

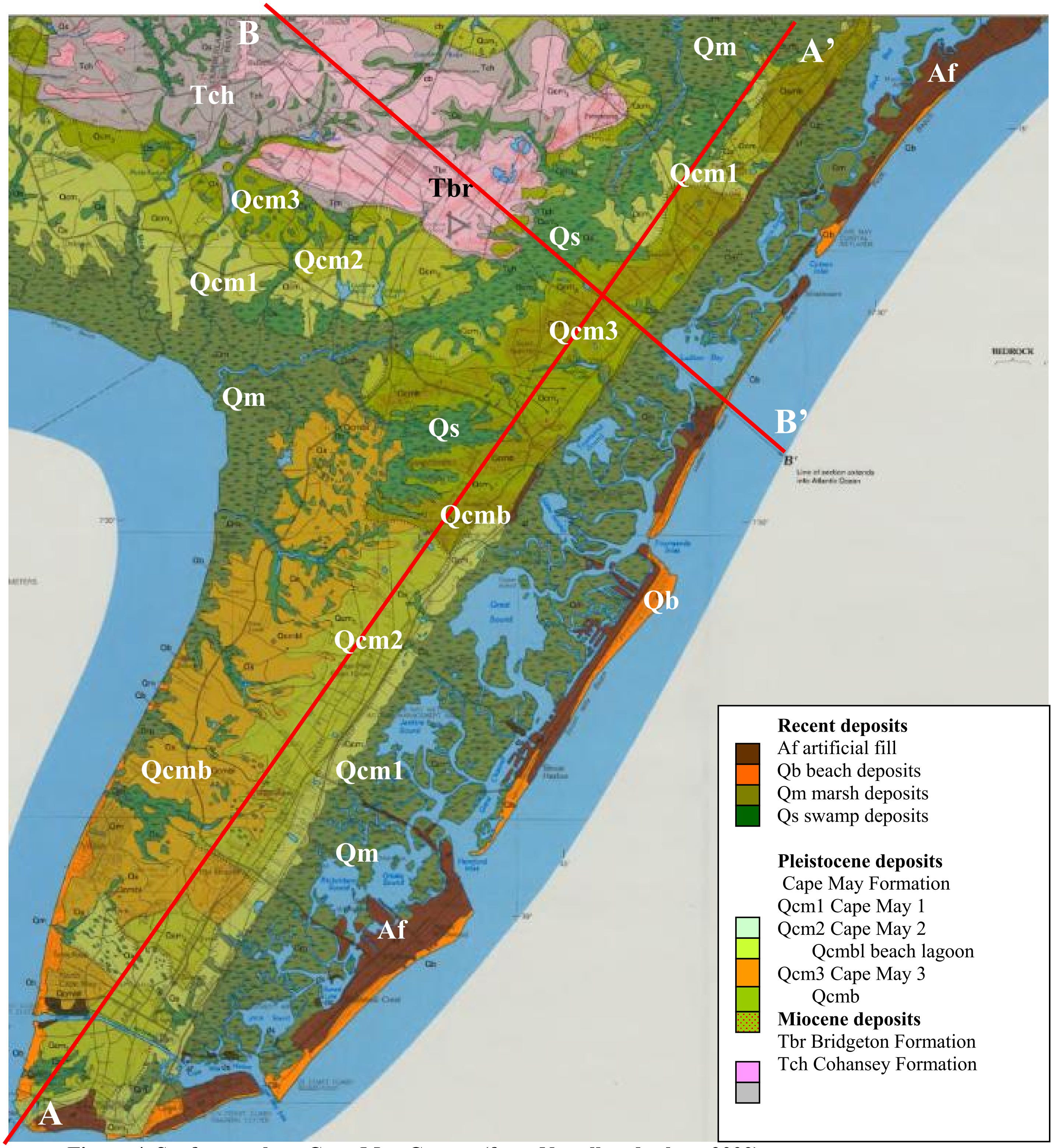


Figure 4. Surface geology Cape May County (from Newell and others 2000).

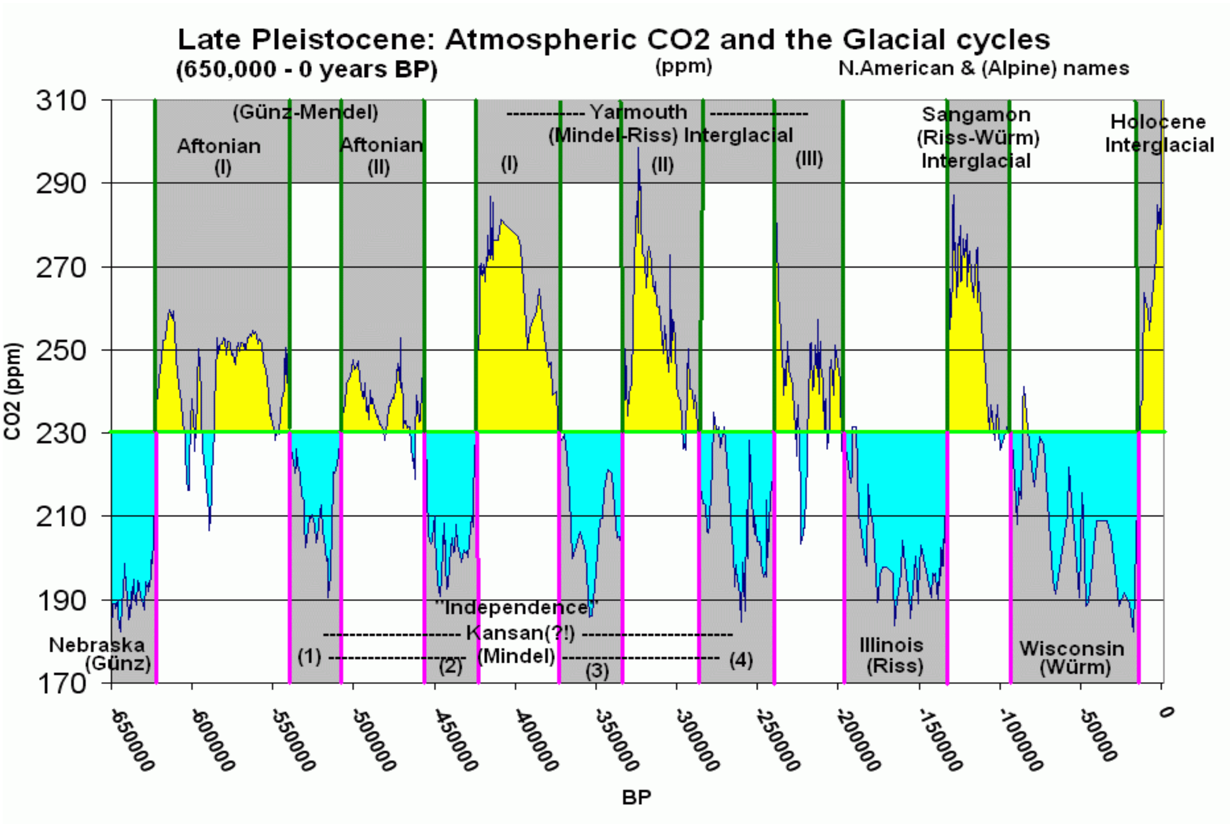


Figure 5. Glacial, interglacial cycles of the past 650,000 years. Strata exposed in Cape May county is from the Sangamon interglacial period, Wisconsin glacial period, and Holocene (recent) interglacial period.
(From: http:en.wikipedia.org/wiki/File:Atmoshepheric_CoO2_with_glaciers_cycles.gif)

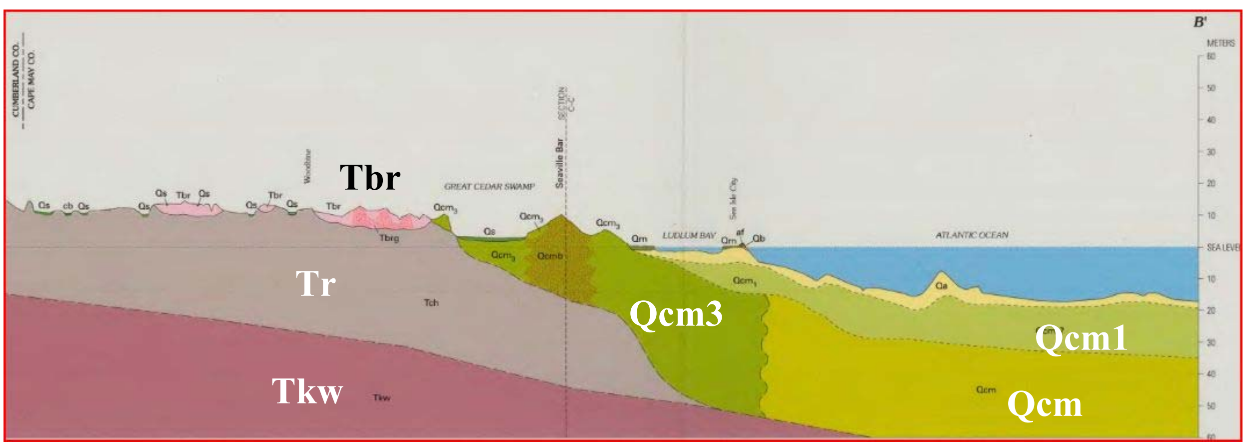


Figure 6. Section B-B' crossing northern Cape May County through Sea Isle City to offshore regions depicting offshore barrier islands (from Newell and others, 2000).

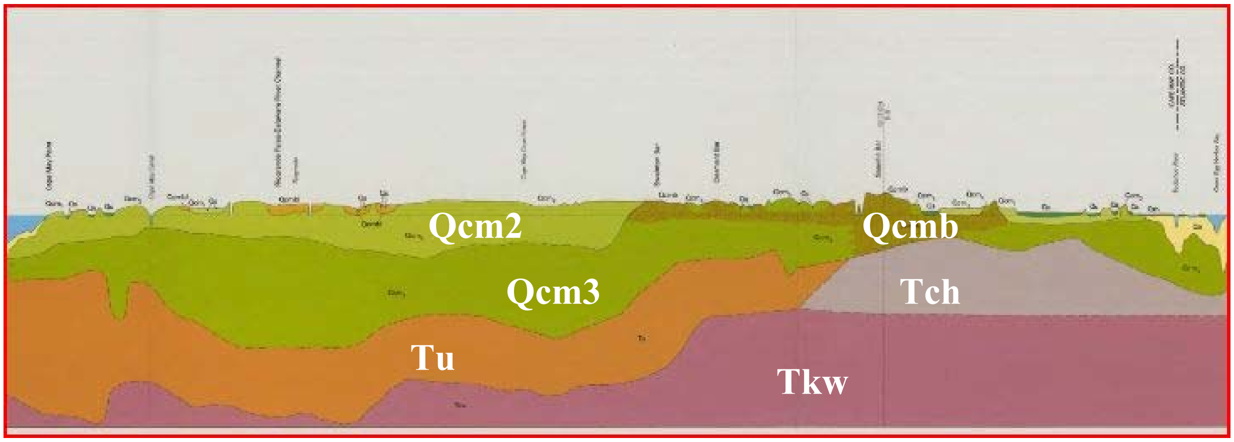


Figure 7. Section A-A'' crossing from northern Cape May County Cape May court House to Cape May Point and Delaware Bay. Proto Delaware River valley shown (from Newell and others, 2000).

PLACES OF GEOLOGIC AND HYDROLOGIC INTEREST IN CAPE MAY COUNTY

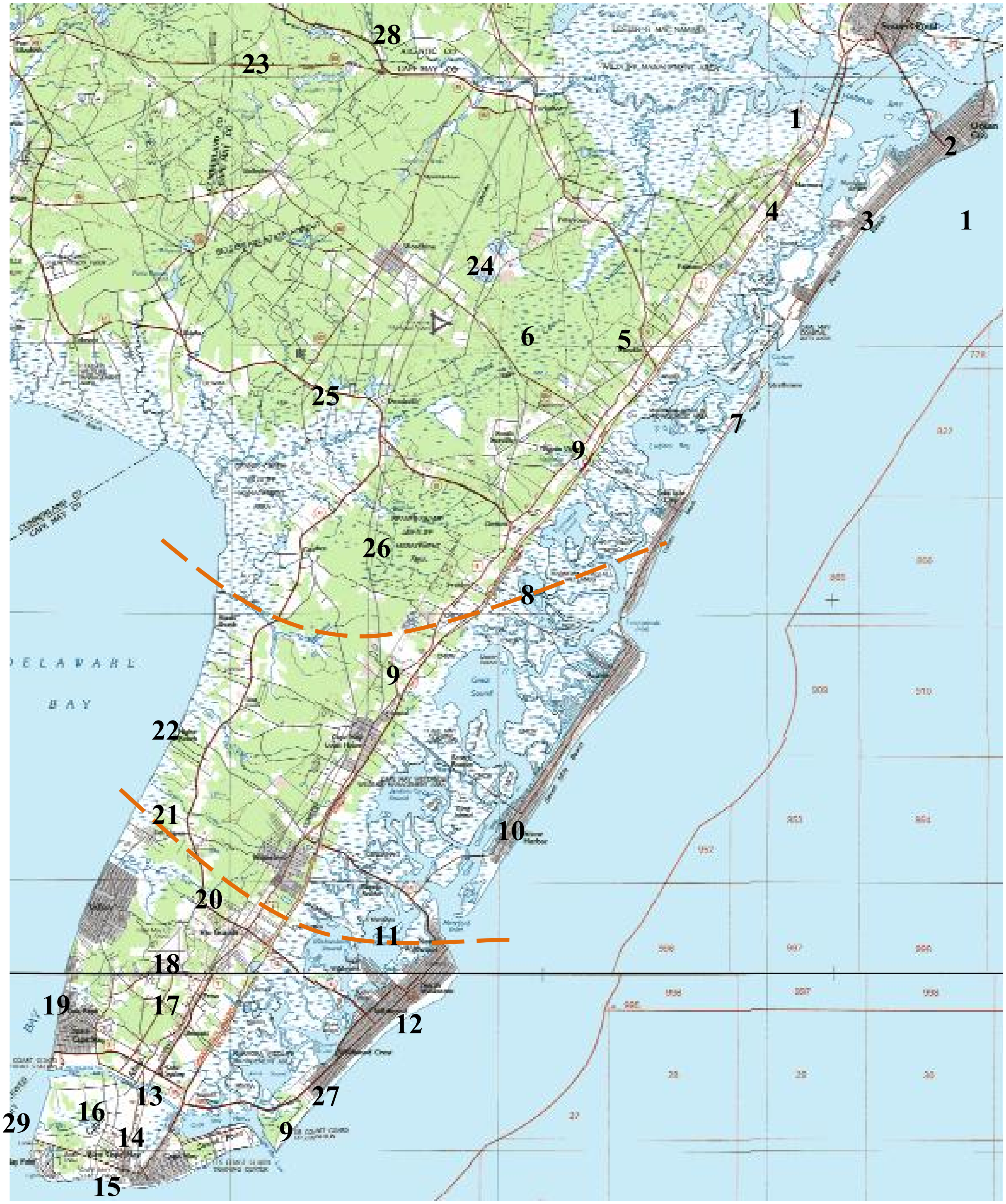


Figure 8. Map of Cape May County showing area of geologic or hydrologic interest.

1. **BL England Fossil Fuel Electric Generation Power Plant**. When first opened in the early 1960s the plant used the Cohansey aquifer for water supply but within months the chloride concentration rose to greater than 40 mg/L, scaling on the inside of the boiler was a problem. They drilled two wells into the Atlantic City 800-foot sand aquifer (AC800) and have used fresh water from it since then. During the drought of the 1960's they began to recharge the Cohansey well with water from the Atlantic City 800-foot sand aquifer. This is likely the first industrial aquifer storage and recovery (ASR) plant and likely the longest running industrial ASR plant in the nation. The stored water is used when the AC800 wells are shut down for repair.

2. **Ocean City** drilled its first well into the Atlantic City 800 foot sand in 1893 using a cable tool. The water was used for steam trains and potable water supply. The water from 720 ft below land surface flowed at 25 gpm and the static water level was 22 ft above sea level. In 2003 the static water level in the autumn is -73 ft and during the summer is -100 ft or deeper. Today Ocean City has 10 public supply wells and withdrawal is about 1.5 billion gallons of water per year. Water from the Cohansey aquifer is salty but was used in the past to cool the theaters during the summer. The boardwalk during the 1930-40 was about 500 ft west of the present boardwalk but as sand has accreted the town grew to the east.

3. **Hurricanes and northeasters** have over flooded all barrier islands and eroded the beach front extensively in Cape May County (Fig. 9).

Figure 9. Flooding in Ocean City in 1962 during the Ash Wednesday northeastern storm

4. **Former sand mines** just south of Marmora. Sand was mined and moved by train to Ocean City to help in the construction of tourist accommodations. All of the ponds along the Garden State Parkway are former sand mines for building the Parkway.

5. **Spine of Cape May County**. During the Sangamonian Interglacial warm period. The spine of Cape May (Route 9 runs on top of the spine) was a series of Barrier Islands when sea level was about 16 ft higher than it is today. Most of the golf courses are located on the spine because of the sandy and somewhat hilly terrain. Few of the farms are on the spine because of the sandy soil.

6. **Great Cedar Swamp.** This wide swamp was covered with old growth cedars in the early 1700's but was logged for its impressive rot resistant Cedar trees. Cook (1857) reported that stumps from some trees in the swamp that had been logged at the time had 1,000 to 1,200 tree rings. Downed cedar trees were mined for wood products. The trees were located using 10 foot long metal rods and then excavated. Once excavated, the log would roll over rapidly. The logs were sawed and used to make shingles. A hurricane in the 1700s went across Delaware Bay. Because the Great Cedar Swamp had been so heavily logged, it is reported that a boat could be rowed from Delaware Bay to Ocean City after the storm.

7. **Strathmere, Whales Beach.** This is one of the most eroded sand dune regions of the Atlantic Coast of Cape May County (Fig. 10) (for more information see Nordstrom and others,1986).

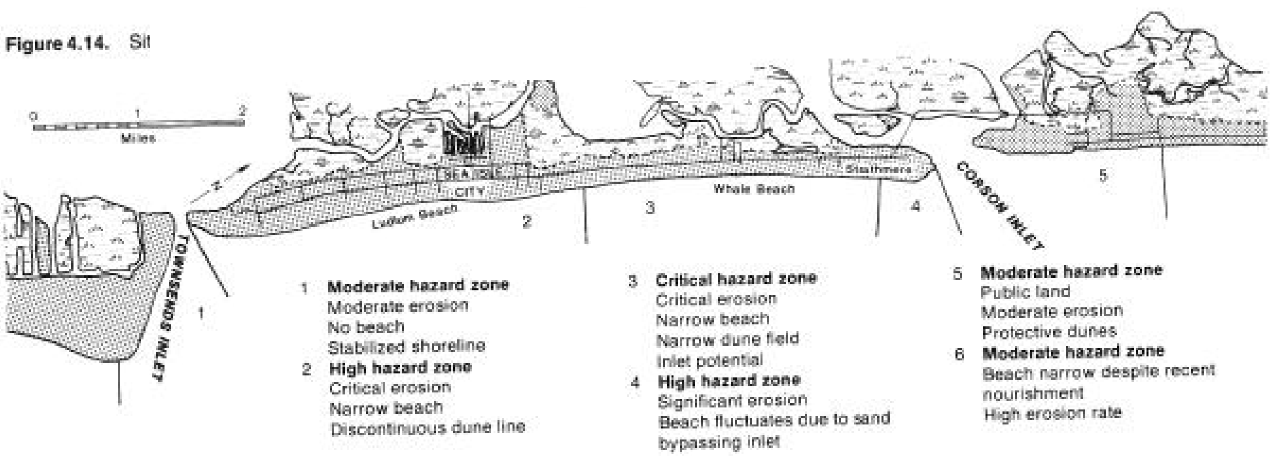


Figure 10. Analysis of the level of hazard for erosion of beaches from Townsends Inlet to Corson Inlet. (From: Nordstrom et al., 1986)

8. **50 mg/L sodium isoline in the Atlantic City 800 foot sand**. This likely is the result of saltwater flooding of the Atlantic City 800 foot sand during the Sangamonian interglacial period. Water from AC800 wells south of this line has high sodium concentrations. For more information see Lacombe and Carleton (2002).

9. **Coastal Plain Drilling Project** . Three core holes drilled by Ken Miller, Peter Sugarman and others to investigate the history of sea level rise of the New Jersey Coastal Plain. Log of shallow zone from Cape May borehole (Fig. 11) (from Miller and others 1996).

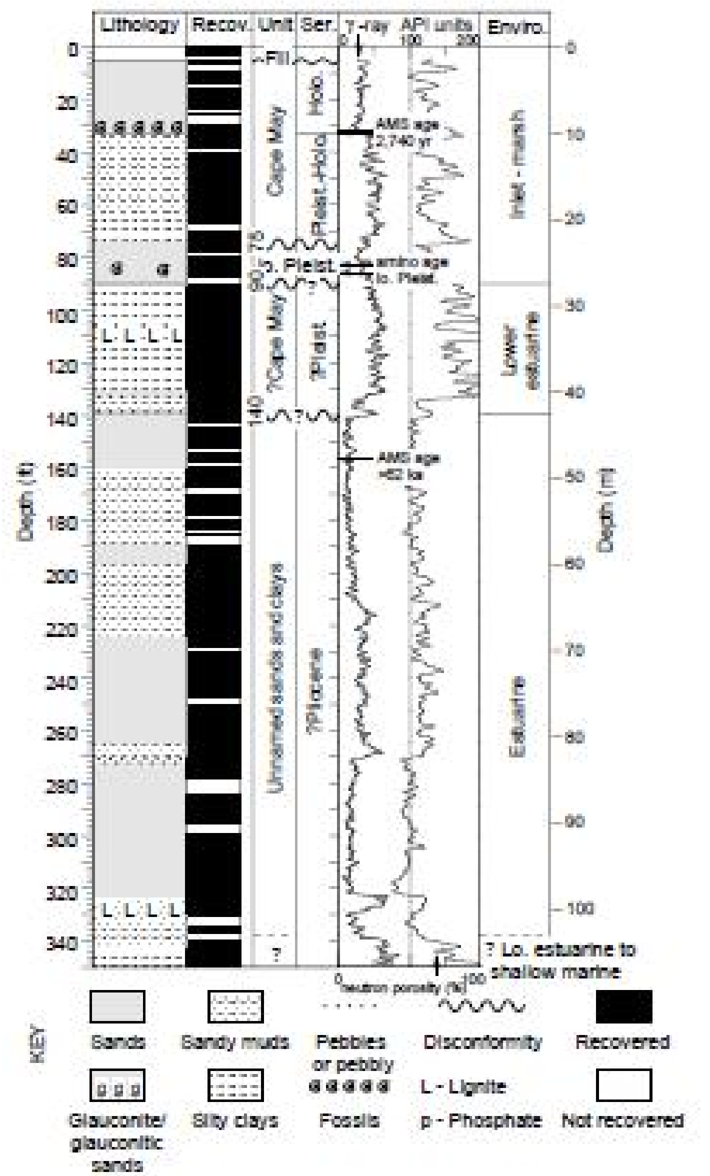


Figure 2. The Cape May (Pleistocene–Holocene) Formation and unnamed ?Pliocene sands and clays, Cape May borehole. Recovered intervals are shaded; unrecovered intervals are in white. Recov. = core recovery; Enviro. = environment of deposition.

Figure 11. The Cape May Pleistocene-Holocene formation and unnamed Pliocene sand and clays, Cape May borehole. Recovered intervals are shaded, unrecovered intervals are in white. Recov. = core recovery; Environ. = environment of deposition. (from Miller and others 1996).

10. **Southernmost fresh-water supply well in the Atlantic City 800-foot sand**. Ocean City has 10 wells in the aquifer, Strathmere has 2 wells, and Sea Isle, Avalon, and Stone Harbor each have about 5 wells. Cape May Court House has 2 wells. Most other major freshwater withdrawal for public supply is from the Cohansey aquifer.

11. **250 mg/L chloride isoline in the Atlantic City 800 foot sand**. Water from wells in the AC800 south of Stone Harbor have too much chloride to be used for potable supply unless it is desalinated.

12. **Wildwood** used to be two islands Five Mile Beach and Two Mile Beach (Fig 12a). Turtle Gut Inlet was filled in to accommodate the tourist industry and much of the back bay near the dunes were filled in for construction. The first wells drilled in Wildwood were hand dug. In 1894 the first well was drilled into the AC800. The water had a chloride concentration of 200 mg/L and it was used for many years. In 1910, Wildwood relocated its source of water to a swamp in Middle Township. They drilled 15 wells into the water-table aquifer near a preexisting dammed pond.

Figure 12 Maps of Wildwood area in (A) 1872 and (B) 1972 Map A from http://mapmaker.rutgers.edu/CAPE_MAY_COUNTY/CapeMayCounty_1872.jpg accessed Sept 2 2009 Map B from USGS Wildwood quadrangle

13. By 1926 the capability to drill to 300 ft using truck mounted drill rigs was available and so they and others drilled supply wells into the Cohansey aquifer. In 1959, the single water main from the mainland to the island broke. Soon after the main water line was fixed and a second pipe added to the system. Wildwood Water Utility experimented with ASR aquifer storage and recovery by injecting water into the

AC800 foot sand. Wildwood learned that they could not inject as much water in a given time as they could withdraw from the same well. During the drought of the early 1960s, Wildwood WU reevaluated ASR and began the first public-water supply ASR system in the nation. The system has been operating continuously since 1964. Each year Wildwood WU injects about 250 MGY and recovers about 90% of the water. The Wildwood withdrawal system consists of 1 estuarine sand well, 7 Cohansey wells, and 3 Rio Grande water-bearing zone wells. The injection wells are screened in the estuarine sand and Cohansey aquifer. In the past they also injected into the AC800 aquifer. This is one of the few conjunctive water withdrawal schemes in the County. Wildwood WU withdraws about 1.25 Bgal/yr.

14. **Cold Spring Harbor and Cape May Canals** were dug during WWII. The harbor and sea-level shipping canal were constructed by excavating Cold Spring Creek on the east side and New England Creek on the Delaware Bay side.

15. **Cape May City Water Supply system**. Cape May City first drilled 15 water-table wells in 1910 in the swamps of Cape Island Creek. By 1926 they installed their first well in the Cohansey aquifer. A well screened in the Cohansey aquifer was drilled in 1940 in the village of Cape May. The well was intruded with saltwater within 18 months. In 1942 they drilled a second well on the north side of town but it was intruded with salt water within 5 year. They drilled three more wells in Lower Township south of the canal. Wells 3 and 4 became salty by 1990. In 1998 Cape May City installed two saltwater supply wells and began desalination for water supply. They are capable of desalinating 2 Mgal/day (Fig. 13). This is the first desalination system in New Jersey.

Figure 13. Desalination units of the Cape May City desalination system (photo from Carl Behrens Cape May City Water Department)

16. **Cape May Point and Cape May City** have experience massive shoreline erosion in the past 50 years. A military bunker built near the light house was constructed about 500 ft north of the shore line during WWII. By the late 1990s, the bunker was more than 200 ft offshore as a result of erosion. The Army Corps of Engineers (ACOE) beach replenishment program has filled in the eroded beach. Now the bunker is 500 ft on shore again. Saltwater intrusion in the Cape May Point forced the sealing of 2 public-supply wells and two industrial-supply wells that tap the Cohansey aquifer.

17. **Anchor Gas-Dickinson Well** was drilled to a depth of 6,388 ft and is the deepest hole in Cape May County. It was drilled to find a storage location for natural gas. Samples remaining from the original well cuttings are of a fine-grained, grayish-black to greenish-black, gabbro containing plagioclase, hornblende, trace amount of biotite and sulfide with minor amounts of quartz. Data from this well has been used in many papers on the basement and deep subsurface geology of southern New Jersey.

18. **Bennets Bog a former back** bay deposit mined for the clay to make local bricks (Fig. 14). Clay for other brick buildings came from other local deposit

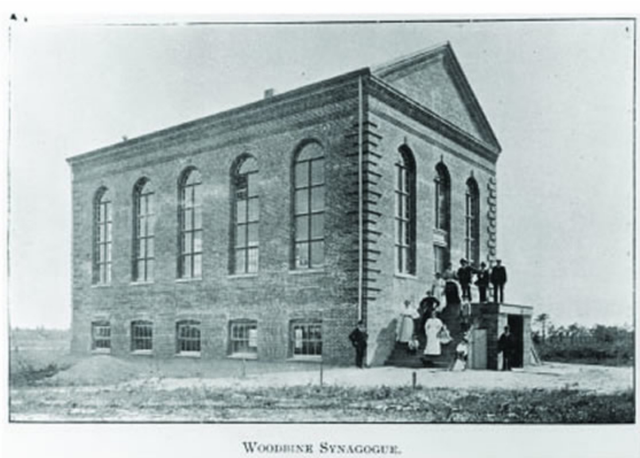


Figure 14. Woodbine Synagogue built 1895-6 Brick was made from nearby local clay deposits. (photo from http://www.thesam.org/bhoodsynagogue.htm accessed September 2, 2009

19. **Virginia Polytechnic Institute** and the US Dept of Energy investigated low-temperature geothermal terrestrial heat flow of the Atlantic Coastal Plain. A geothermal exploration hole was installed at the Cape May County Airport (Fig. 15). This was one of 5 geothermal wells installed in the NJ Coastal Plain. The well was 300 meters deep. Temperature and thermal gradient are plotted against depth in the following graph.

20. **Town Bank,** a former whaling/ fishing village in existence by 1690 is now 0.25 miles in Delaware Bay as a result of shore line recession.

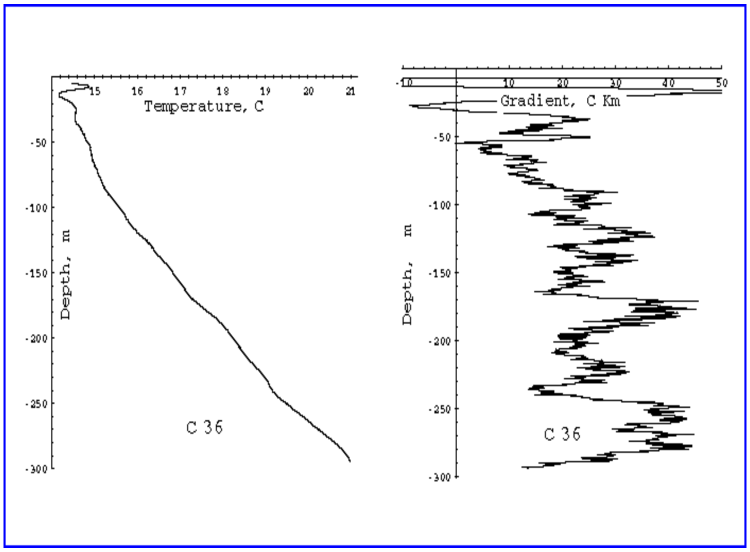


Figure 15. Plot of temperature and thermal gradient vs. depth at hole C36 Cape May County airport (from http://geothermal.geol.vt.edu/c36.html accessed September 13, 2009).

21. **Wildwood Water Utility** drilled two wells into the Rio Grande water-bearing zone in 2000 for water supply. In the drill cuttings pile, I found large chunks of coral (*Astrihelia palamata*) *Turritella sp*., and numerous sections of bivalves (Fig. 16). (David Parris of the NJ State Museum stated the coral is from the Choptank Formation and found at Calvert Beach. Calvert Co. Maryland (Miocene).

Figure 16. Photographs of (A) coral, *Astrihelia palamata* and (B) *Turritella* sp. and bivalves from drill cutting of wells for Wildwood WU Middle, Cape May County NJ.

22. **Green Creek:** During the early 1900s, the outlets that drained the saltwater wetlands adjacent to Delaware Bay were fitted with tide gates. The tide gates permitted freshwater to flow out of the wetland at low tide but did not permit saltwater to flow into the wetlands at high tide. With time the saltwater wetlands became freshwater wetlands and were used for farming. By the 1980s little farming took place in altered land and oaks maples and *Phragmites* replaced the native *Spartina* or salt marsh grass. In the late 1990s, the ACOE removed tide gates from some of the streams and for the

first time in over 70 year the sea flooded the land twice daily. This killed the freshwater flora that established themselves in the human made freshwater wetlands. The dead trees are evident just north of the village of Green Creek and the air photo shows the same for Pond Creek south of the canal (Fig. 17).

Figure 17. Pond Creek wetland showing (a) new tidal flooding after removal of tide gate and change from invasive freshwater *Phragmites* to make way for native saltwater *Spartina*. (b) New outlet of Pond creek making its way through the sand dunes of Delaware Bay in Lower south of the Canal

23. **Oyster Research Lab** of Rutgers University and commercial oyster growing beds. Shoreline exposures of middens and erosion of land under former cedar tree groves. Former buildings along the beach show evidence of sea level rise and shore line erosion. Sand tubes near the Research buildings protect them from beach erosion.

24. **Highest point in Cape May County** has an altitude of about 60 ft. The altitude of land surface at the Fire tower is +55 ft.

25. **Sand mines** use dredge pumps capable of pumping 3000 gallons per minute (Fig. 18). Much of the sand is exported to a limestone mine in PA and crushed rock from the limestone mine is imported to Cape May County. The sand and limestone are mixed to make cement and other products.

26. **Dammed pond**s. There are more than 10 small dams in Cape May County that were used for power supply in the 1700 and 1800s. East Creek Pond, Ludlams Pond, and Johnsons Pond are a few of the ponds that were formed. Diadromous fish are unable to get past the dams during their annual migration. The only fish ladder in the County is on the Tuckahoe River at Head of River. It is under the bridge near the stream gauging station.

Figure 18. Dredging operation and sand washing of Cohansey sand Cape May County.

27. **Vernal ponds.** There are more than 300 vernal ponds in Cape May County. Many are in former back bay depressions and many are in small mine excavations. Many of the vernal ponds were ditched during the depression for mosquito control or converted into farm pond for irrigation (Fig. 19).

Figure 19. Dry vernal pond that was ditched in the 1930s. Old sand quarry that has become a vernal pond.

28. **Cape May Diamonds:** Quartz pebbles. The gravel of the Cohansey, Bridgeton, and Cape May Formations are predominately quartz pebbles. Most of it is milky quartz but a small amount of it is clear quartz. The clear quartz when tumbled or faceted makes attractive jewelry. The pebbles can be found in any high energy part of the shore line and in any sand and gravel mine of Cape May, Cumberland, and Atlantic Counties. There are two stories about the origin of the diamonds. One story is that the Kechemeche Indians collected and used them for trade. The second is that a jeweler who vacationed in Cape May brought them home, faceted or tumbled them and sold them as Cape May diamonds.

29. **Flowing Wells.** Many wells along the Tuckahoe River flow year round. A good example of one flowing well is at Head of River Church. This is common of wells close to streams in many parts of the pine barrens. One well on a farm east of Head of River had a head of 14 ft above land surface.

30. **Concrete ship.** The US military built 12 concrete ships to transport troops and supplies from Europe at the end of WWI. The ship *S.S. Atlantus* was the second ship built. After the war it was used to transport coal. In 1926 this ship and 2 other ships were purchase to construct a dock for the proposed Cape May-Lewes Ferry (Fig. 20). The ship broke loose of it mooring and ran aground just north of Cape May Point. Storms have eroded the ship during the past 80 years.

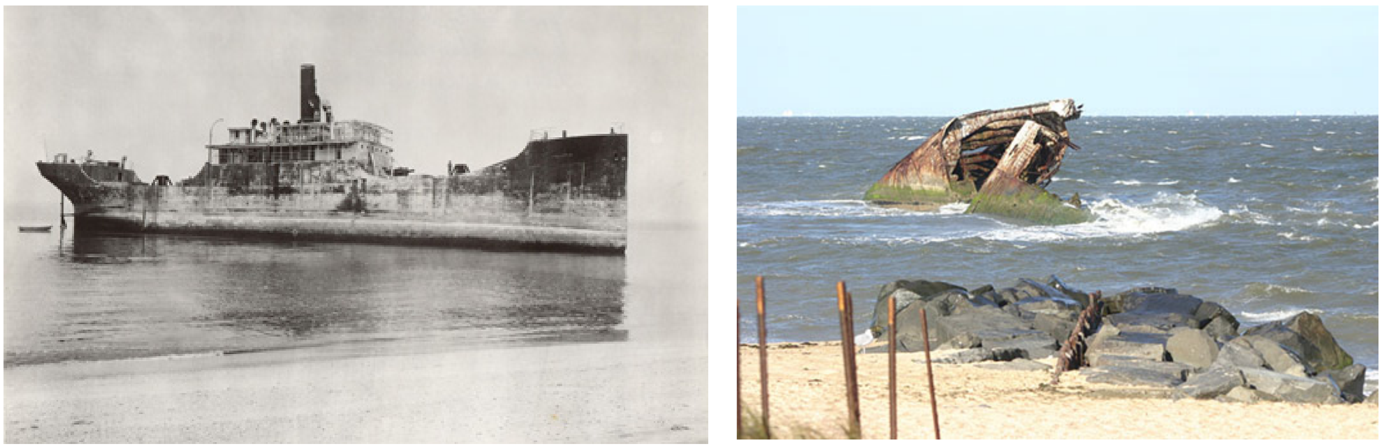


Figure 20. *SS Atlantus* in 1926 and at present.

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FIELD GUIDE-Part III Coastal Plain Stratigraphy

Last of the Marl Mines: Stratigraphy and Paleontology at the Inversand Pit

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Introduction

From the early part of the nineteenth century until the present time, the marl deposits of the New Jersey Coastal Plain have been an important source of fossil specimens and information about prehistoric life in this area during the Late Cretaceous- Early Paleogene time interval. Geologists associated with the early geological surveys of New Jersey such as Henry Darwin Rodgers of the University of Pennsylvania and George Cook of Rutgers extolled the benefits of marl as a soil conditioner and noted the fossil content of these beds. Marl mining boomed in southern New Jersey during the later half of the nineteenth century. The pioneers of vertebrate paleontology in North America obtained their first specimens of dinosaurs and other vertebrate fossils from these numerous pits, as recounted in Gallagher (1997).

Unfortunately, the marl mining industry declined during the twentieth century. By the 1960s, there were only three operating marl pits left, and today the last of these pits, the Inversand Company excavation at Sewell, NJ, is threatened with extinction. Today the greensand marl is mined as a water conditioner. There were several pits on this property; we will visit the active excavation, started in 2000.

Stratigraphic overview

At the base of the pit, the "chocolate marl" of the Navesink Formation is the lowest stratigraphic unit exposed here. On paleontological grounds, the Navesink is assigned a Maastrichtian age. It is a clayey glauconitic sand with a brownish olive color, hence the miner's old nickname, the chocolate marl. The unit is more fossiliferous at the base, which is not well exposed in the current excavation. The lower part of the unit in this excavation shows the top of an extensive shellbed composed mostly of fossil oyster shells. Many of these shells are in the process of being dissolved by the acidic groundwater, and so are very fragile. But they can be clearly seen in outcrop in crescentic cross-section.

The layer of primary economic interest here is the greensand marl of the Hornerstown Formation, the prominent green cliff in the pit. This green material is glauconite, a complex potassium iron aluminum silicate mineral in the mica family. Most models of glauconite deposition hypothesize a prolonged period of authigenic geochemical alteration

in the production of glauconite from kaolinite and mica predecessors, in this region possibly derived from Piedmont metamorphic sources.
Various estimates derived from different methods (for example, foramniferal zone ages) yield an estimate of approximately three million years for deposition of the six meter thick formation (Gallagher, 1993). The Hornertown contains several fossil concentrations which are instructive in terms of the aftermath of the Cretaceous-Paleogene mass extinction.

The Vincentown Formative lies above the Hornerstown Formation. This unit is characterized by increasing quartz content, with more glauconite at the base and less at the top. The Vincentown is fossiliferous primarily at the basal contact with the underlying Hornerstown. But upward in the formation rare intermittent fossils of marine invertebrates are found. It is usually assigned a Thanetian age.

The Miocene Kirkwood Formation overlies the Vincentown, and above it the Cohansey Formation. Neither one produces fossils at this site. Capping the section is the Pennsauken gravel, an alluvial formation usually given a Plio-Pleistocene age. The only fossils in this unit are rounded weathered chert pebbles containing Paleozoic marine invertebrates (tabulate and rugose corals, crinoid columnals, brachiopods, bryozoans, trilobite fragments) derived from Appalachian sources.

Navesink Formation Paleontology

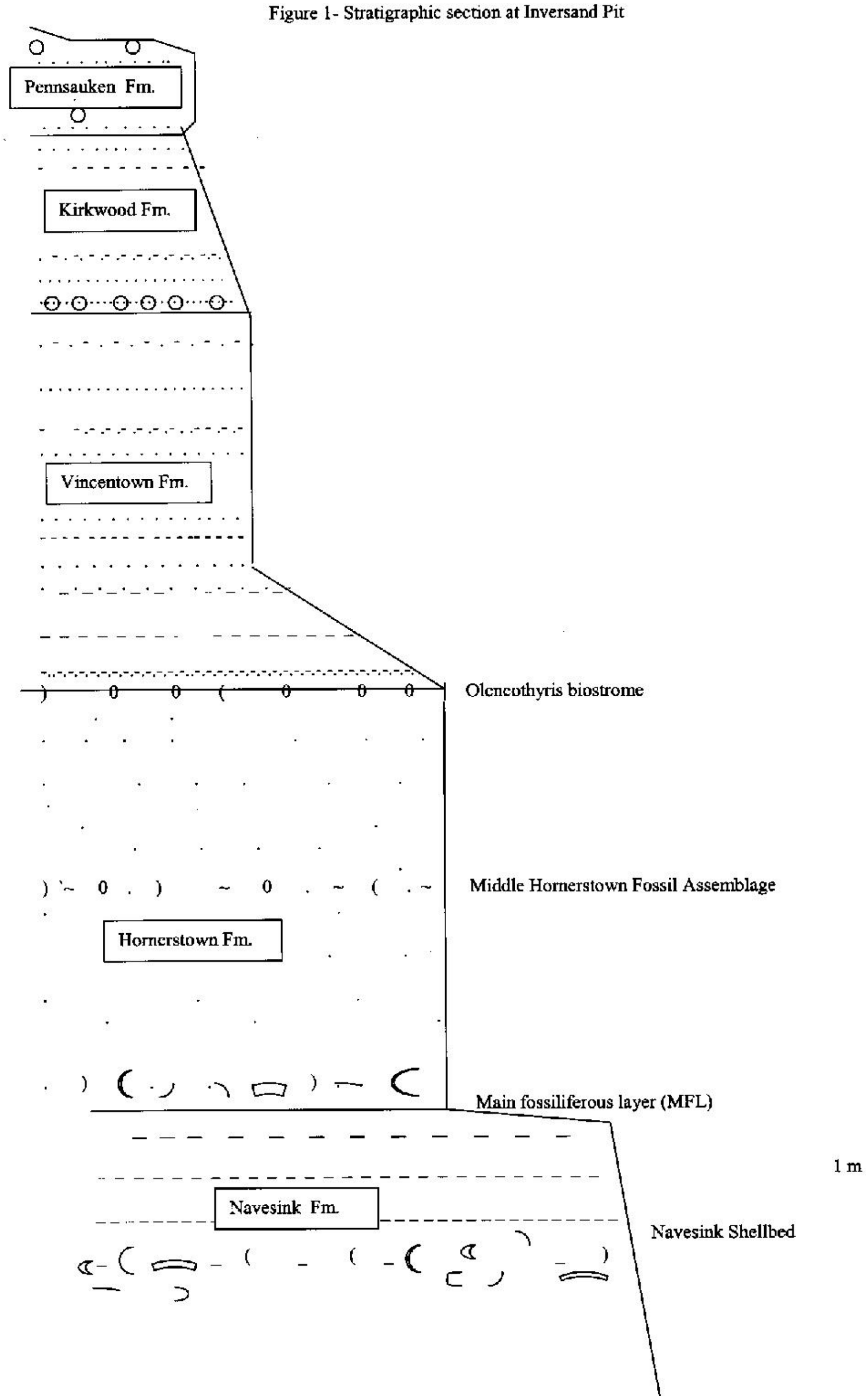
The old pit, closed down in 2000, exposed a wider and deeper section of the Navesink and hence produced more Cretaceous fossils. Most noteworthy of these were rare but important specimens of dinosaurs and mosasaurs. But the majority of specimens were the typical marine invertebrates found at many Late Cretaceous fossil sites. The oysters (*Exogyra, Pycnodont, Agerostrea)* are the most abundant specimens at this and many other Maastrichtian sites in New Jersey. Other mollusks found at this level include a number of mesogastropods and several cephalopods including steinkerns of *Belemnitella americana* living chambers, *Baculites* internal casts and a specimen of *Discoscaphites* which correlates to the upper part of the Fox Hills Formation in the Western Interior Seaway deposits. The shellbed in the lower part of the Navesink Formation produced most of the mosasaur specimens. Dinosaur specimens have come primarily from the uppermost part of the Navesink, near the contact with the overlying Hornerstown. This is also the source of modestly large pieces of lignitic logs, some showing branching. So the top of the chocolate marl shows some evidence of terrestrial input, suggesting shallowing upward in the Navesink depositional environment.

Hornerstown Formation Paleontology

The bulk of the fossils found at the pit are derived from several layers in or on the edges of the Hornerstown Formation. At the bottom of the greensand marl, the basal fossiliferous layer (sometimes called the MFL or "Main Fossiliferous Layer") produces a variety of marine invertebrates and vertebrate fossils. The most common fossils (up to 30 single valves per dm^3) are stacked or imbricated valves of *Pycnodont dissimilaris.* These are extremely fragile very thin disarticulated valves. Next in abundance is the bivalve

Cucullaea vulgaris. Various other mollusks are frequently found at this level including the gastropods *Turritella* and *Pyropsis.* Weathered sections of several species of ammonites found here have been interpreted as reworked from underlying deposits, and this has led to the overly facile interpretation that all the specimens in this layer are reworked. Other Cretaceous forms found in this layer include teeth of the extinct shark *Squalicorax* and isolated, often worn looking mosasaur bones.

Figure 1- Stratigraphic section at Inversand Pit



In this regard it is worthwhile to look at the mode of fossil occurrence here and at the taphonomy of the fossil concentration. The microstratigrapahy of this layer is well established and has been reported on in previous publications and presentations. At the base of the fossil concentration, the disarticulate oyster shells abound and define the base of the layer. Just above this and intermingled with it are the internal molds of the other molluscan species. The vertebrate remains tend to occur with concentrations of the mollusks underneath and around them. Finally the top of this horizon holds clusters and pockets of tiny bleached shark teeth, some split, and small fish spines of basal teleosts. All this happens within a vertical interval of three decimeters.

What is salient here is that many of the vertebrates are articulated, semi-articulated or associated skeletons of single individuals. This is in contrast to many coastal plain vertebrate fossil concentrations in which the fossils are primarily disarticulated single isolated elements, often showing signs of transport, abrasion, weathering and biological modification. The specimens of crocodiles and turtles form the basal Hornerstown are among the best preserved and most complete of their species; to dismiss such multi-element skeltons as "reworked" flies in the face of common sense let alone what is known of vertebrate taphonomy.

Higher up in the middle of the formation, there is a second concentration of fossils in the Hornerstown. This Middle Hornerstown layer has a higher density of more primitive forms but lower diversity of invertebrates and vertebrates. The dominant organisms in this layer are sponges, small brachiopods, smaller clams, and small solitary corals. The operative word here is "small"; this is a dwarfed fauna of minimalist organisms that are characterized by low metabolic rates, low trophic requirements and non-planktotrophic reproductive strategies. Even the clams that are present in this layer are dwarfed in size compared to bivalve fossils in layers above and below this one. The presence of dwarfed faunas after a mass extinction event has been noted elsewhere, and has sometimes been called the "Lilliput effect". I have suggested that this may be due to the paucity of planktonic food resources in the wake of the K/Pg mass extinction event (Gallagher, 1991, 1993, 2002, 2003), when foraminifera, for example, were reduced in size and diversity.

Vertebrates in this layer include lamnoid shark teeth and fragmentary cryptodire turtle remains. Larger shark teeth from more modern sharks are found higher up in the section. Crocodile specimens are found in the basal fossiliferous layer, and randomly distributed throughout the interval between the basal layer and the middle fossiliferous layer. The crocodiles found above the basal layer are no more or less complete than the crocodiles in the basal layer. There are several well documented specimens collected by myself and others from one and two meters above the basal layer. Can these crocodile specimens, similar in their completeness, preservation and taphonomic mode, all be reworked?

The abundance of large crocodiles and their diversity (five species in the basal Hornerstown) has led me to suggest that crocodiles experienced an evolutionary and ecological radiation into the marine realm once the apical predators of the late Cretaceous oceans, the mosasaurs, all became extinct. The crocodile spike is particularly noticeable when compared to croc diversity and abundance in Late Cretaceous marine deposits, where mosasaur remains are generally more common than crocodilians. The only exception to this in New Jersey is the Ellisdale site which actually represents an estuarine environment.

Vincentown Formation Paloentology

At or near the contact between the Hornerstown with the overlying Vincentown Formation, there a third fossil concentration visible at the pit. This is the *Oleneothyris harlani* biostrome, characterized by the large inflated terebratulid brachiopod *O. harlani*. This is a relatively new discovery here at the Inversand Pit, although this layer is well-documented from sites from Ocean County NJ, down to eastern North Carolina (Gallagher, 2002) the first fossils from this horizon started showing up in the new (current) excavation several years back; the older pits on this property never exposed this third *Oleneothyris* layer. It may be that the older excavations were not into the thicker section of Paleocene sediments exposed in the southeastern side of the new pit; as excavation proceeded into this thicker downdip section, the “Fat brach” layer showed up. Besides the large terebratulid, there are bivalves including the larger clam cast *Cyprimeria*, and oyster steinkerns as well, Here, the fossils are weathered looking internal casts (steinkerns) that do not preserve much detail. Vertebrates in this level include smaller and larger bleached looking lamnoid shark teeth often missing their roots; at least one specimen of the serrated edge tooth called *Paleocarcharodon* is known from this level, suggesting a shark fauna that is becoming more modern in aspect. A single fragmentary specimen of cryptodire turtle is also known from this concentration.

Above this in the Vincentown there are spotty clumps of mollusks, bryozoans, and the rare specimen of solitary coral; the upper part of the formation is nowhere near as fossiliferous as the stratotype section in Burlington County, where the decidedly different lime-sand facies from the top of the formation yields an amazing diversity of bryozoans.

What does it all mean?

The last of the marl mines (Fig. 2) offers us a glimpse into the profound ecological changes that accompanied the Cretaceous –Paleogene mass extinction event. While no convincing iridium anomaly, glassy spherules or other geochemical signatures of asteroid impact have been found here (Gallagher, 1992), the completeness of the fossil record is instructive in a broad way; I have suggested elsewhere (Gallagher, 1993, 2002) that if any time is missing between the Navesink and Hornerstown it is on the order of one hundred to several hundred thousand years, rather than the larger order of magnitude implied by the angular unconformity model espoused by USGS workers, among others.

Figure 2. Stratigraphic section at the current excavation, Inversand Pit, Sewell, NJ . Maastrichtian Navesink Formation at base; greensand and Hornerstown Formation forms the bulk of the cliff; lighter colored Miocene units (Kirkwood, Cohansey) on top. Total thickness= approximately 60 feet (20 m).

The base of the formation shows a typical Late Cretaceous marine ecosystem thriving in place in the later part of the Maastrichtian age. The abundant oysters provided an important link between rich planktonic food sources and the organisms higher up on the oceanic food chain. Mosasaurs prowled the water, the undisputed kings of the marine realm. At the top of the formation, the rare but important remains of dinosaurs (*Hadrosaurus minor, Dryptosaurus aquilunguis*) give us our best indication of what Late Maastrichtian dinosaur faunas were like on land.

The basal Hornerstown fossiliferous layer (“MFL”) shows us a fauna that is becoming much more modern in aspect. While the occasional isolated worn mosasaur bone is found here, it is possible that these are remnants from the underlying Cretaceous beds. The winners among the vertebrates after the K/Pg extinction are crocodiles, sea turtles and more modern varieties of lamnid sharks (Gallagher, 2006). The relative completeness of many of these vertebrate specimens argues against an overly facile interpretation of this bed as entirely reworked, as some would have it (see Richards and Gallagher, 1974 for a summary of earlier arguments). The articulated crocodile specimens, the complete turtle shells (some with limbs and skulls), and the strings of lamnid shark vertebrae found closely associated argue against reworking of these complex multi-element specimens. On the other hand, some typically Cretaceous taxa found in this bed (mosasaurs ammonites) display some evidence of wear. Elsewhere I have characterized this bed as a remanie deposit, a condensed section fossil lag deposited over a long interval (typical of glauconite deposits) incorporating the last representatives of the Cretaceous faunas with the accumulating remains of earliest Paleogene animals.

The middle Hornerstown layer is instructive as well. It contains a diminutive fauna of Paleozoic aspect, reminiscent of more ancient assemblages. The small primitive organisms (sponges, small brachiopods, solitary corals) are adapted to an oligotrophic ocean, a marine ecosystem in which planktonic food resources are restricted to a lower diversity of smaller forms- not much nutrition here. Bigger planktotrophic organisms are not as prevalent as down in the Late Cretaceous deposits, when foraminfera were larger, abundant and more diverse.

This is a warning from the geological past. Environmental stresses on the ocean (take your pick- asteroid impact or volcanically generated greenhouse warming) can and will affect planktonic populations, causing a crash in the base of the food chain that reverberates up the food chain to the higher levels, including large apical predators. Small sponges and brachiopods are not nearly as tasty as big fat juicy oysters.

The Vincentown Formation is a story of ecological revival. After several million years, the sea starts doing well again, as planktonic food resources rebound from the long disruption of the oceanic food chain evinced by the carbon isotope data. The lime-sand facies of the Vincentown may represent a paratropical bryozoan patch reef environment, associated with the Late Paleocene (Thanetian) hypsithermal maximum greenhouse.

The Inversand pit stands as the last of an almost extinct industry, marl mining. It is invaluable because it affords a larger view of the stratigraphic and fossil fauna successions in an area of limited outcrop. This allows us to interpret the great historical finds of dinosaurs, mosasaurs and other significant fossil discoveries of the 19th century in a modern stratigraphic context, and to apply new models, present-day paradigms, and hypotheses tests to this critical interval of the geologic record. But the Inversand Pit is rumored to be closing at some point in the indefinite future. It would be nice to preserve this last of the marl mines for future research and teaching; its is an invaluable tool for education in geology and paleontology. One suggestion might be a consortium of institutions (universities, museums) purchasing and maintaining the pit for educational and scientific purposes.

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