

TRIP A1: SEQUENCE STRATIGRAPHY, SEDIMENTOLOGY, AND PALEONTOLOGY OF THE UPPER CRETACEOUS NAVESINK FORMATION, NEW JERSEY

J BRET BENNINGTON

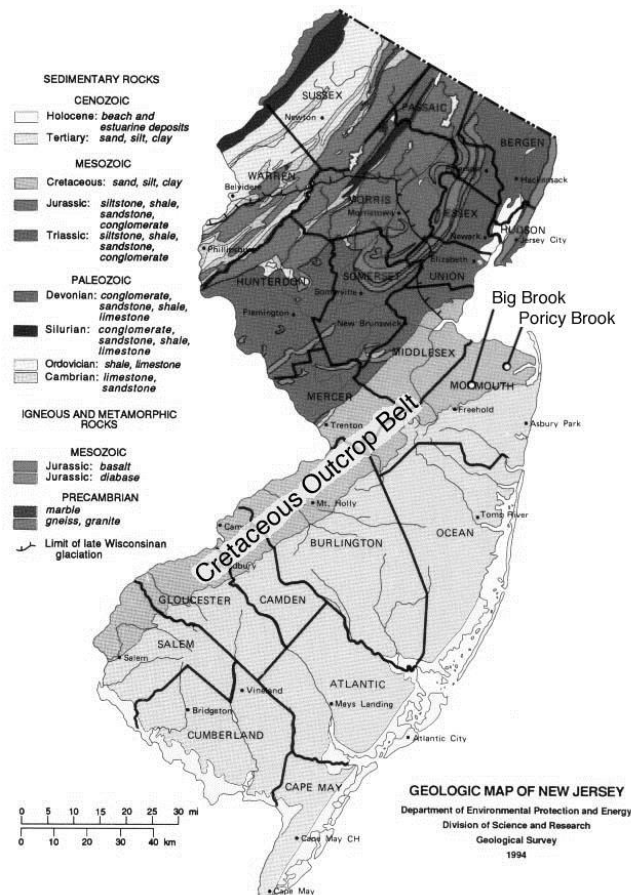
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INTRODUCTION

Overview of the Navesink Formation

The Navesink Formation is an 8 meter thick interval of fossiliferous glauconitic sand exposed along the eastern margin of the Cretaceous outcrop belt in New Jersey (Figure 1). At the northern end of the outcrop belt in Monmouth County, the Navesink Formation is accessible along the banks of Big Brook between Hillsdale Road and Boundary Road and along the banks of Poricy Brook, at Poricy Park on the Middletown-Lincroft Road. These two localities have long been known to fossil hunters as accessible places to collect Late Cretaceous marine fossils. Less widely appreciated is the fact that the Navesink Formation contains an excellent sedimentological record of the transition from an inner shelf to an outer shelf environment during a sea-level rise. The changes in environment that occurred with the

Figure 1. Geologic map of New Jersey showing Cretaceous outcrop belt and field trip stream exposure locations.

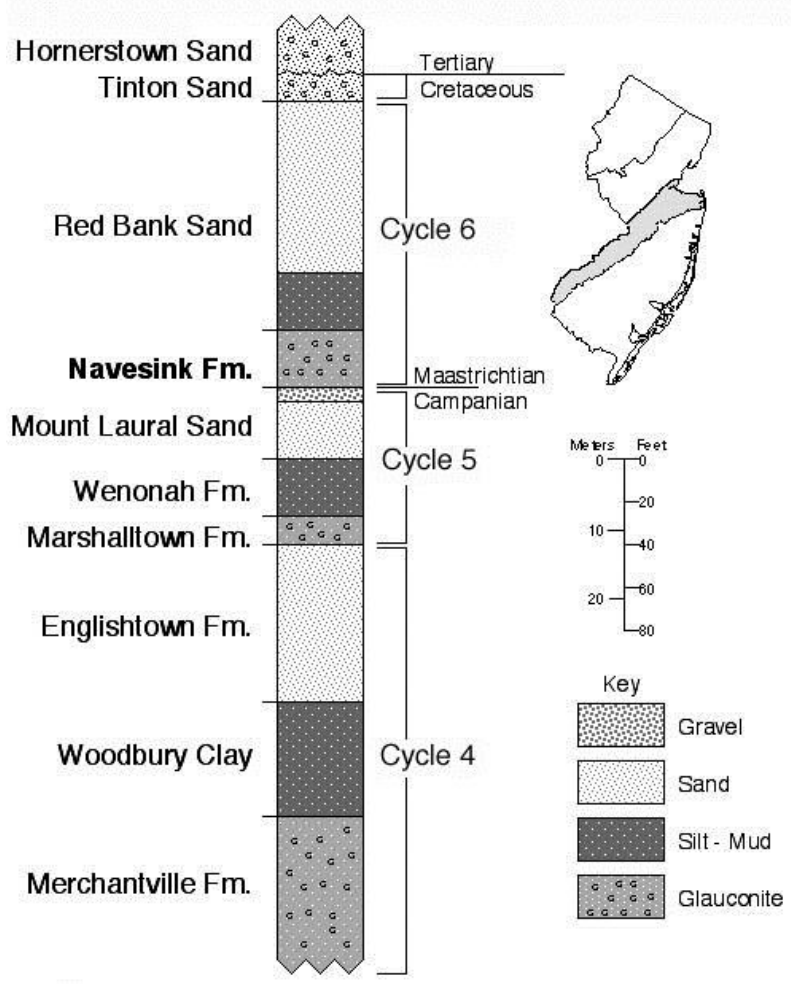


changes in sea level are recorded in a sequence of sedimentary facies defined by distinctive suites of sediments, trace fossils, and macrofossils. Our objective on this field trip is to examine the various features that define each facies, as well as the characteristics of the transitions between facies. The explanations for the transitions between facies and the sequence stratigraphic interpretation of the Navesink are incompletely understood and provide opportunities for discussion and debate. Likewise, the mechanisms of shell bed formation in the upper Navesink remain an unsolved mystery – was the primary control on shell accumulation biological, sedimentological, or environmental?

The Navesink Formation in Time and Stratigraphy

The age of the Navesink sediments has been estimated to range from approximately 70 million years at the base of the formation to approximately 66 million years at the top on the basis of Sr-isotope age estimates (Sugarman et al., 1995). Stratigraphically, the Navesink is placed at the base of the Maastrichtian Stage of the Upper Cretaceous, and is thus the beginning of the end of the Mesozoic (Figure 2). The Navesink is also the basal formation in the last of six depositional cycles developed during the Late Cretaceous on the Atlantic Coastal Plain. These sequences of marine sediments were deposited during cycles of sea level rise and fall (transgression and regression) and are separated from each other by disconformity surfaces representing intervals during which the coastal plain was exposed

Figure 2. Stratigraphic formations and cycles in the uppermost Cretaceous of the New Jersey coastal plain (after Owens et al., 1970 and Owens and Gohn, 1985).



and eroding. The Navesink records the marine transgression that initiated deposition of cycle 6 and grades continuously into the overlying Red Bank Sand, which was deposited during the regressive part of the cycle (Figure 2). The majority of sediment in the Navesink Formation consists of glauconite, which occurs as dark green, lobate, sand-sized grains with surface cracks. Glauconite is an iron-rich mica mineral that forms diagenetically at the sediment-water interface from clay minerals likely originally encapsulated into fecal pellets. Formation of glauconite sands occurs on the continental shelf during prolonged intervals of sediment starvation (Odin and Fullagar, 1998). Deposition rates for the upper Navesink Formation have been estimated to be approximately 1 m/Ma based on formation thickness and strontium isotope dates from different stratigraphic horizons (Sugarman et al., 1995). The low rate of sediment accumulation and scarcity of terrigenous sediment argue that the Navesink was deposited under sediment starved conditions during a transgression.

The Navesink Formation and Sequence Stratigraphy

A Sequence Stratigraphic Primer (based on Nichols, 1999)

Sequence stratigraphy is a method for understanding the formation of sedimentary strata within the context of cycles of relative sea level rise (transgression) and fall (regression). A stratigraphic sequence is basically a package of strata deposited during a single cycle of sea level rise and fall. Sequences are bounded above and below by unconformities, meaning that they are deposited between episodes of significant sea level fall. Sea level fall of several tens of meters will cause subaerial exposure of the coastal plain and downcutting and erosion by rivers draining out to the receding shoreline. On the shelf, deep water sediments will be overlain by shallow water sediments. If sea level fall is extensive enough to expose the entire shelf, then a widespread unconformity surface will develop – a sequence boundary. There is no cycle order (length or time scale) implicit in the definition of a sequence - one could conceivably define a sequence for any order of cycle. In practice, however, sequences are reserved for packages of strata bounded by regionally significant unconformities marked by significant erosion on the shelf and coastal plain.

Systems tracts are packages of strata within a sequence that can be attributed to formation during particular phases of rising and falling relative sea level (Fig. 3). Systems tracts have also been called facies tracts because they contain strata from related depositional environments.

Lowstand systems tract (LST): During a relative fall in sea level the shoreline moves seaward, exposing the continental shelf. Valleys are eroded into the coastal plain and shelf and submarine canyons are eroded into the slope. Sediment bypasses the shelf and slope and is deposited as turbidity currents in **submarine fans** on the basin floor. Sediment fans can also be deposited on the slope. As relative sea level stops falling sediments may begin to fill the valleys carved on the shelf, creating a **lowstand wedge**. Together, the lowstand wedge, slope fan, and basin-floor fan deposits form the LST. On most of the shelf, the LST may exist only as a surface of unconformity.

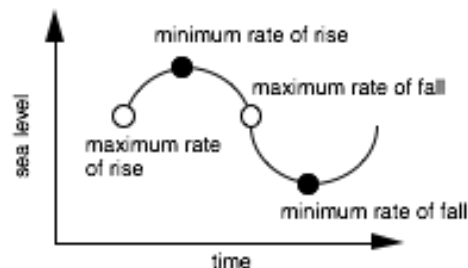


Figure 3. Cycle of sea level rise and fall

Transgressive Systems Tract (TST): As sea level starts to rise, base level increases and fluvial deposits form in incised valleys. The shelf becomes flooded again, creating a **marine flooding surface or transgressive surface (TS)** as the shoreline migrates landward, reworking the lowstand deposits or the surface of erosion developed during sea level fall. This reworked unconformity surface defines the beginning of a new sequence on the shelf and is called a **sequence boundary**. Above the sequence boundary, marine deposits of the TST are often thin due to sediment starvation as clastic sediments become trapped in flood plains and estuaries flooded during the time of maximum rate of rising sea level. This causes the deposition of a condensed section on the continental shelf characterized by authigenic sediments such as glauconite. As the rate of sea level rise begins to decline, rivers begin to build deltas out from the shoreline and clastic sediments begin prograding across the shelf. At some point prior to the beginning of renewed deposition of shelf clastics, the **maximum flooding surface (MFS)** – stratigraphic level of maximum relative sea level – is deposited. Shortly above the MFS the renewed deposition of alloctigenous sediments is shown by increasing quantities of terrigenous mud and sand.

Highstand Systems Tract (HST): This systems tract is characterized by aggradation of shelf sediments and then movement of the shoreline landward again as the rate of sea level rise slows, stops, and then reverses. Often this is the thickest part of the sequence because clastics stored in estuaries during sea level rise are flushed out onto the shelf during early sea level fall. The upper boundary of the HST is a sequence boundary, formed as sea level fall accelerates and begins to expose the coastal plain and shelf to erosion once again.

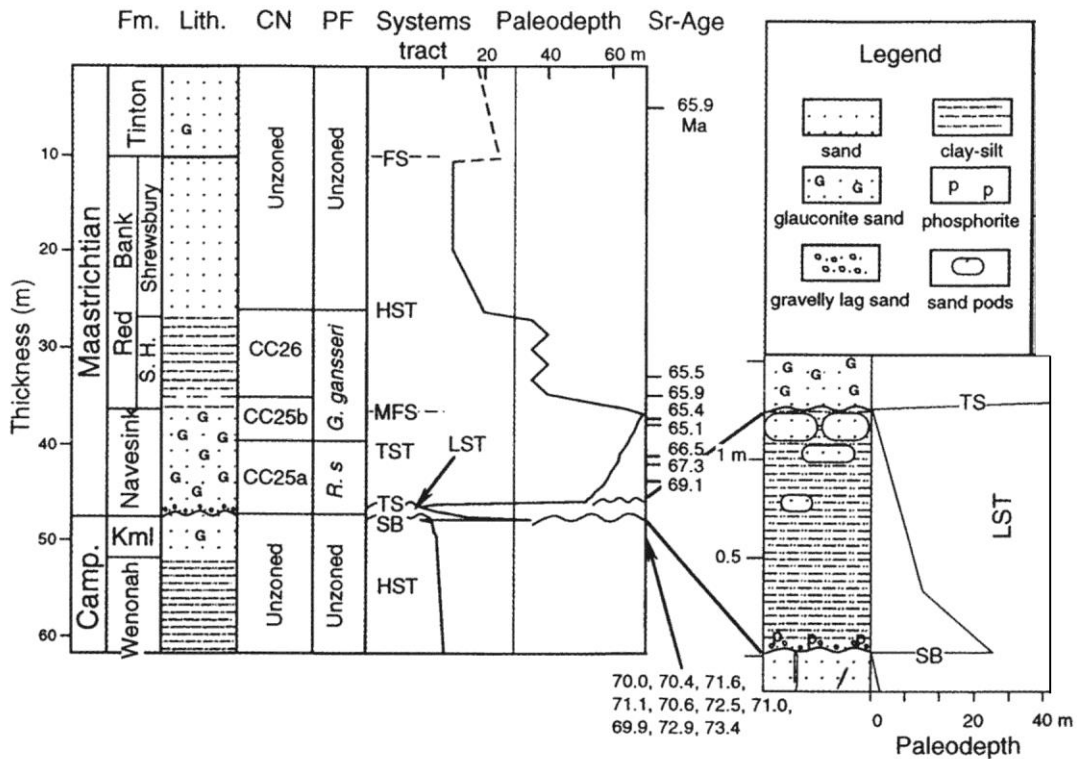


Figure 4. Sequence stratigraphic interpretation of the Navesink sequence from Miller et al., 1999, Fig. 2).

Sequence Stratigraphic Interpretation of the Navesink

The Navesink Formation has long been understood to be the transgressive interval in a sedimentary cycle that includes the overlying Red Bank and Tinton sands (e.g. Owens et al., 1968). Becker et al. (1996) identified a transgressive lag deposit at the base of the Navesink at Big Brook and other localities and argued that this lag deposit represents a significant erosional unconformity. Miller et al. (1999) identify this lag as a major sequence boundary (Fig. 4). Unfortunately, the lag deposit is not exposed where it is easily accessible (it outcrops about a mile upstream from the Boundary Road bridge and is usually covered by slumping) and we will not be able to view it. Above this sequence boundary the Navesink Formation preserves deposits of the transgressive systems tract (TST). Martino and Curran (1990) describe two distinct lithofacies within the Navesink, a 0-4 meter transgressive sheet sand overlain by muddy, glauconite sand. Miller et al. (1999) describe one meter of clay-silt with reworked sand pods at the base of the Navesink (Fig. 4), which they interpret to be a deposit of the lowstand systems tract (LST). The difference between these two interpretations lies in the placement of the transgressive surface (TS) which represents the initial flooding of the shelf during sea level rise. Martino and Curran (1990) place the TS directly above the erosional lag at the sequence boundary, whereas Miller et al. (1999; 2004) place the TS about 1.5 meters higher in the section, above what they interpret to be a regressive lowstand tract deposit (Figure 4). Miller et al. (2004) find evidence for two systems tracts within the Navesink sequence based on analysis of two boreholes from the New Jersey coastal plain with two distinct transgressive systems tracts, but this is not apparent in the outcrops visited on this field trip.

Navesink Sedimentary Facies

We have been studying the sedimentology and paleontology of the Navesink Formation at different stratigraphic levels, paying particular attention to bounding surfaces between facies. Our work has found evidence for four distinct lithofacies and biofacies overlying the transgressive lag at the base of the Navesink (Figure 5). Together, these facies appear to show a progressive but discontinuous rise in sea level beginning with the erosional lag at the sequence boundary (Bonelli and Bennington, 2000).

Facies A) A thin basal interval of fine quartz sand with abundant carbonaceous matter, mud and some glauconite (average 15% by weight – Fig. 6). This interval is extensively burrowed, with the distinctive trace fossil *Spongeliomorpha* (similar in form to the better known *Ophiomorpha* but with unlined burrow walls marked by longitudinal ridges [Bromley, 1996]). The claws of the callianassid crustacean *Protocallianassa sp.* are occasionally preserved within the burrows at the Big Brook locality. We interpret this facies to be sands deposited in an inner shelf environment. These muddy sands must have been sufficiently cohesive to permit callianassids to excavate burrows without the need to line the burrow walls with fecal pellets, which would have produced *Ophiomorpha* traces (Bromley, 1996).

Facies B) A fining-upward interval of muddy, fine to very fine quartz sand with abundant carbonaceous matter and some glauconite (average 15% by weight – Fig. 6). This facies is characterized by a diverse bivalve fauna, including both epifaunal and burrowing forms, preserved as composite molds in the unlithified sediment. Genera identified include *Inoceramus*, *Trigonia*, *Crassatellites*, *Lima*, *Periplomya* (?), and *Linearea*. Burrows consisting of small (5 mm diameter), sand-lined tubes are found in this facies. We interpret this Facies B to represent a deeper water inner shelf environment inhabited by a diverse fauna of epifaunal and infaunal mollusks.

Facies C) Fine quartz sands that include increasing numbers of glauconite grains (average 25% by weight – Fig. 6) and a decrease in carbonaceous matter. The sediments are extensively bioturbated with dense burrows of *Thalassinoides*. Also present are phosphatic grains. Macrofossils in this interval include gryphaeid oysters, pectens and common belemnites. The contact between Facies B and Facies C appears to be erosional and is marked by irregular sandy blobs of uncertain origin, phosphatic pebbles, belemnite guards, and large, branching burrows (*Thalassinoides*) that penetrate vertically, piping dark, glauconitic sands from Facies C down into the lighter mud-rich sediments of Facies B. This contact appears to mark a significant decrease in the rate of sediment influx combined with current winnowing of the upper surface of Facies B. Similar contacts have been observed in Tertiary sediments on the New Jersey slope, where they are interpreted to be current eroded firmgrounds (Savrda et al., 2001). The sandy blobs may be the remnants of a lag layer of quartz sand produced by winnowing, possibly concentrated into horizontal burrows. Facies C appears to represent a transitional environment between inner and outer shelf depths. The boundary between Facies C and D is considered by some authors to be a transgressive surface, characterized by reworked sediments and marking the start of the transgressive systems tract (Miller et al., 1999; Miller et al., 2004).

Facies D) Glauconite sands (average 90% by weight – Fig. 6) with little to no detrital quartz grains. The sediments are extensively bioturbated with dense burrows of *Thalassinoides*. This facies includes two shell-rich intervals with abundant gryphaeid oysters. The lower interval is dominated by articulated individuals of the oyster *Exogyra costata* and contains few other species. The upper fossiliferous interval is more diverse and dominated by the oysters *Pycnodonte mutabilis* and *Agerostrea mesenterica*, with an accessory fauna of *Choristothyris* brachiopods and small pectens. Benthic and planktic foraminifera are very abundant in the upper shell bed. Also common are the spines from burrowing echinoids, although echinoid body fossils are not found. Of the large oysters, almost 100% show evidence of biocorrosion, primarily in the form of clionid borings, but also present are borings attributable to lithophagid bivalves, acrothoracican barnacles, and polychaete annelids. Encrusting organisms are also common and include several species of bryozoa, serpulid annelids, and small oysters. Many large oyster valves are almost completely biodegraded and some show evidence of having remained partially buried for extended periods of time. Most bivalved specimens are disarticulated, although approximately even valve ratios are present in samples. These observations suggest a benthic environment undisturbed by wave activity or pulses of substantial sediment input, where shells remained exposed on the sediment surface for long periods of time or became partly buried by the activities of burrowing organisms. The upper shell bed is a backlap shellbed deposited near the position of the maximum flooding surface (MFS) (Bennington et al., 1999). Modern sediments composed almost exclusively of glauconite grains are found in current swept, open marine environments of the middle to outer shelf at depths greater than 60 m, with the optimum depth of glauconite formation found to be approximately 200 m near the top of the continental slope (Odin and Fullagar, 1988).

Facies E) Similar to facies D but with increasing amounts of very fine quartz sand, showing the transition to the overlying Red Bank Formation.

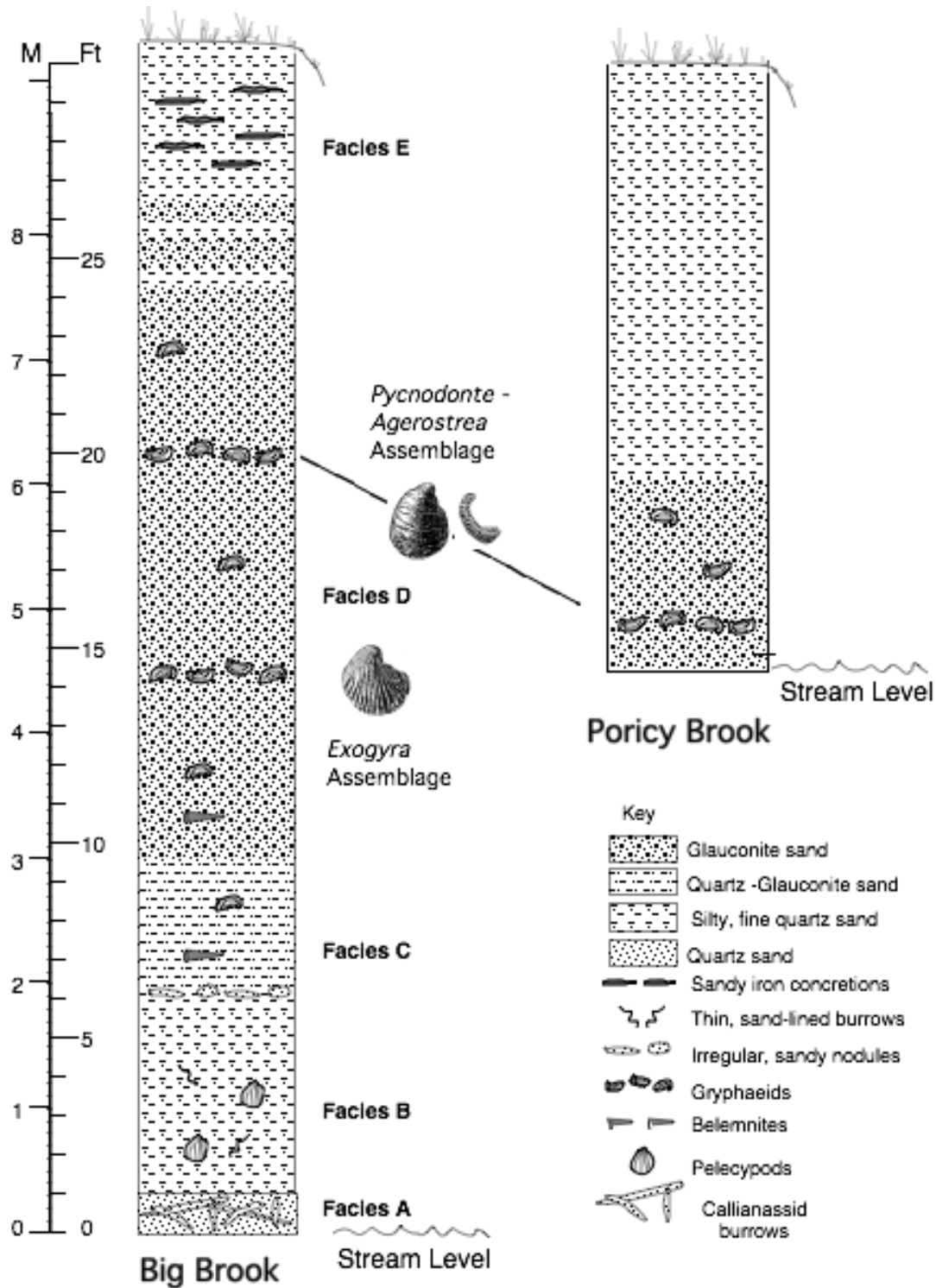


Figure 5. Summary diagram of the Navesink Formation at the Big Brook and Poricy Brook localities visited on this field trip.

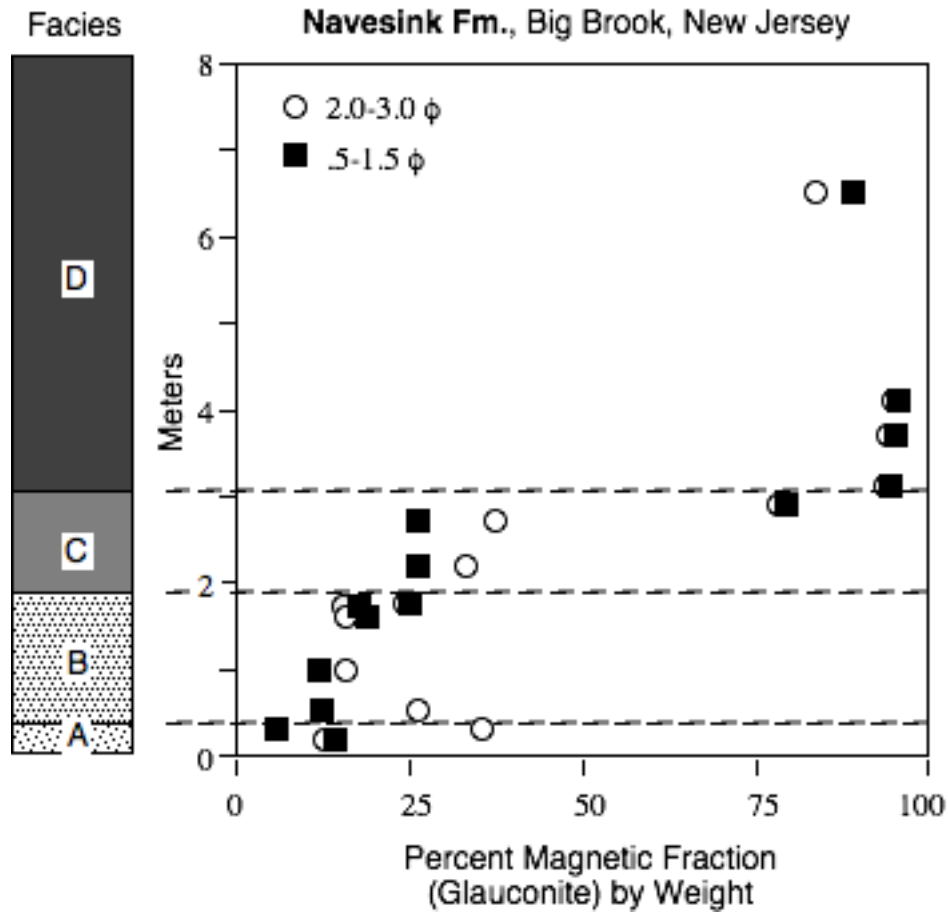


Figure 6. Percentage of coarse to fine glauconite grains by weight in sediments from different facies in the Navesink Formation at Big Brook, New Jersey. Each data point is the mean of separate runs on three splits from a single sample. 95% confidence intervals around each value are +/- 4% or less for all samples.

Navesink Paleontology

The Navesink Formation is the most fossiliferous and accessible Cretaceous unit in the northern Atlantic Coastal Plain. It is well known to both professional paleontologists and amateur collectors for its abundant invertebrate and vertebrate faunas. Public familiarity with the Navesink is enhanced by exposures along Big Brook and Poricy Brook in Monmouth County, NJ where fossil collecting is permitted on county land. The long history of collecting in the Navesink has produced a number of rare finds and an extensive faunal list for the formation (see Rose, 2000; Kuehne, 1999; Lauginiger, 1986).

Vertebrate Fossils

Vertebrate fossils consist chiefly of common shark teeth and less common bony fish, and marine reptile teeth. The greatest abundance of vertebrate remains are reported to originate from a lag deposit at the base of the formation that is not usually exposed (Rose, 2000). However, the occasional shark tooth has been found in bulk samples of sediment collected from the upper glauconite sand interval of the Navesink, so it seems likely that vertebrate remains are scattered throughout the unit. The most reliable way to recover vertebrate fossils from the Navesink is to sieve the stream sediments through a 1 cm²

mesh, carefully inspecting the remaining gravel for shiny black pieces of tooth and bone. The most abundant shark teeth found are from the genera *Cretolamna* (mackerel shark) *Scapanorhynchus* (goblin shark) and *Squalicorax*. Also commonly found are sawfish rostral spines from the genus *Ischyrhiza* and spike-like teeth from the bony fish *Enchodus*. More unusual finds may include conical mosasaur teeth, the flat teeth of shell-crushing fish and rays, and bones and shell plates from marine turtles. Dinosaur remains have been recovered from the Navesink, but they are extremely rare. To date, isolated bones and teeth from the genera *Ornithomimus* (ornithomimosaurid theropod), *Dryptosaurus* (tyrannosaurid theropod?), *Hadrosaurus* (ornithopod), and the dorsal osteoscutum of an ankylosaur have been found (Rose, 2000).

Invertebrate Fossils

Invertebrate fossils and burrows are found throughout the Navesink Formation (see the description of facies above). At the localities visited on this field trip aragonitic mollusks, while abundant in the lower interval of the formation, are poorly preserved occurring as molds and composite molds in clay-rich sands. Small chalky specimens of the pelecypod *Chlamys venustus* are common in the lower glauconitic sands, but the most abundant species are those with calcite shells, including the guards of the squid *Belemnitella americana*, the large gryphaeid oysters *Exogyra costata* and *Pycnodonte mutabilis*, the small ostreid oyster *Agerostrea mesenterica*, and the brachiopod *Choristothyris plicata*. These last four species compose most of the fauna of two shell beds within the upper Navesink we will observe on this field trip. The most prominent shell bed is a 30 cm thick concentration of shells that forms the uppermost shell bed in the Navesink and appears to be widespread, occurring at approximately the same stratigraphic level along both Poricy Brook and Big Brook, at localities 10 kilometers distant. A study that sampled this shell bed at a hierarchy of spatial scales concluded that the fossil assemblage was statistically indistinguishable between the two localities (Bennington, 2003), supporting the correlation of the shell bed and suggesting that its formation was a regional event (Figure 6). Bennington et al. (1999) interpreted this shell bed to be a “backlap”

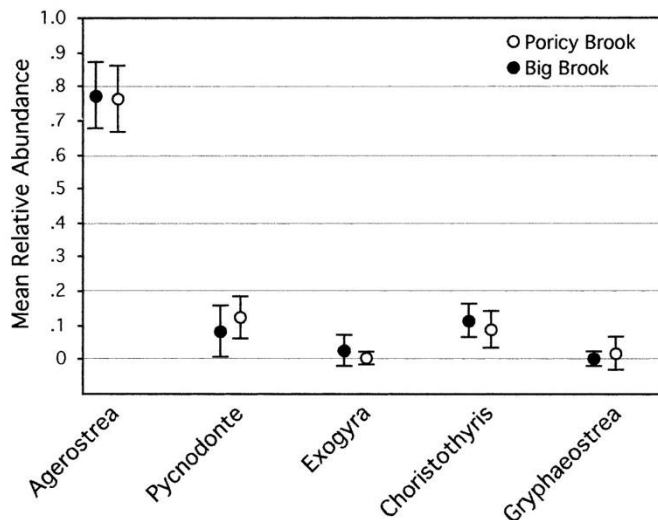


Figure 6. Comparison from Bennington 2003 of the mean relative abundance and 95% cluster confidence intervals for the five most abundant species between the uppermost Navesink shell bed at the Poricy Brook and Big Brook Boundary Road localities.

shell bed deposited during maximum transgression under conditions of sediment starvation below wave base and in the absence of substantial current winnowing. Evidence for this includes the observation that most of the large oyster shells are extensively biocorroded by the boring sponge *Cliona*, yet specimens are commonly found partially articulated or with both valves in close proximity. Thus, shells

appear to have been exposed on the sediment surface for significant periods of time, but were relatively undisturbed by currents. What is not clear are the exact mechanisms that generated the concentration of shells, given that sedimentation rates in the upper Navesink appear to have been uniformly slow. One possibility is that the benthic environment of the upper Navesink was relatively dysaerobic, perhaps due to thermal stratification of the overlying ocean, preventing the colonization of the benthos by macroinvertebrates except during relatively brief intervals of bottom oxygenation. However, the extensively bioturbated fabric of the glauconitic sands argues for an actively burrowing infauna (spines from burrowing echinoids are common) which does not corroborate a dysaerobic benthos. For now, the mechanism of shell bed generation in the upper Navesink remains a puzzle.

Preservation of Shell Color in *Pycnodonte* oysters

One of the most interesting attributes of the oyster fauna of the Navesink Formation is the preservation of original shell coloration in many specimens of *Pycnodonte*. Distinct bands of reddish pigmentation extend radially from the umbo to the margin of the shell. The pattern of banding is highly variable from individual to individual, ranging from thick bands that cover most of the shell to a few grouped bands or a single thin band. Color bands in *Pycnodonte convexa* have been reported previously in specimens from Utah and New Jersey (Stokes and Stifel, 1964) and are also found in specimens from the Coon Creek Formation in Mississippi, which is correlative with the Navesink. Although shell coloration is rarely preserved in fossils, radial color bands have been noted in a variety of fossil gryphaeids and in one gryph-shaped ostreid (Stenzel, 1971), suggesting that this may have been a common color pattern in these oysters.

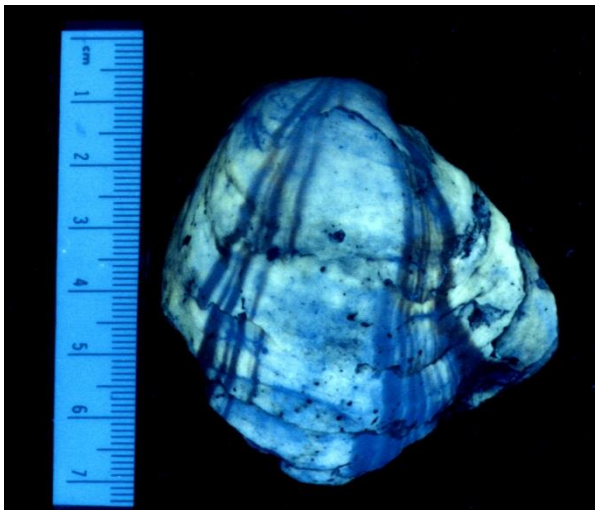


Figure 7. Specimen of *Pycnodonte* photographed under longwave UV light. Note the prominent radial bands of pigmented shell displaced laterally along intervals of shell growth disruption caused by damage to the former margin of the shell.

Careful observation of the color banding in *Pycnodonte* reveals that the radial bands are displaced laterally along distinct growth disruptions marked by abrupt thickening, healed, crenellated breaks, and localized, abrupt changes in the slope of the outer shell surface (Figure 7). These disruptions are best explained as the result of damage to the shell margin by durophagous predators such as crabs. If the shell margin was broken irregularly and then later repaired, but with the mantle in a slightly different position, the newly formed shell bands, although of the same number and width as before, would begin regrowing in a different position along the margin of the shell after the break. Modern oysters are commonly preyed upon by crabs and lobsters that snip away at and crush the shell margin (LaBarbera,

1981) and Cretaceous oysters commonly bear indentations and other signs of breakage-induced shell repair (Dietl et al., 2000). LaBarbera (1981) demonstrated that modern crab species (blue crabs and stone crabs) will attack and attempt to consume resin models of extinct gryph-shaped oysters based on visual rather than olfactory sensing. This raises the possibility that the color banding on gryphaeid oysters served to break up the visual outline of the shell, providing a form of camouflage. In any case, the color band disruptions provide a unique record of the frequency and timing of crustacean attacks throughout the life of the oyster. Many *Pycnodonte* valves show multiple disruptions throughout the life of the oyster, suggesting that crustacean attacks, although a constant threat, were not often lethal.

Microfossils

Microfossils, including benthic and planktonic foraminifera, ostracods, burrowing echinoid spines, and fish scales are common in the glauconitic sediments of the upper Navesink Formation. Wet sieving sediments, particularly those associated with the uppermost shell layer, yields an abundance of specimens useful for introducing students to the study of micropaleontology (Baker, 1995).

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UPPER CRETACEOUS NAVESINK FORMATION, NEW JERSEY**

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FIELD GUIDE AND ROAD LOG

Meeting Point: north side of parking lot of the Double Tree Inn, 425 Route 59, Nanuet, NY 10954

Meeting Point Coordinates: 41.090773°N, 73.995446°W

Meeting Time: 8:30 AM

Distance in miles (km)

Cumu- lative	Point to Point	Route Description
0.0 (0.0)	0.0 (0.0)	Assemble at the north side of the hotel parking lot. Follow exit road 150 ft to Rt. 59. Exit turning right onto Rt. 59.
0.3 (.48)	0.3 (.48)	Merge onto Palisades Interstate Parkway N toward Bear Mountain.
1.3 (2.1)	1.0 (1.6)	Take exit 9W to merge onto I87 N toward Albany.
3.9 (6.3)	2.6 (4.2)	Take exit 14A to merge onto Garden State Pkwy toward New Jersey.
64.9 (104.4)	61 (98)	Take exit 114 toward Holmdel, Middletown, NJ.
65.3 (105.1)	0.4 (.6)	At the end of the exit road, turn left onto Red Hill Rd.
65.6 (105.4)	0.3 (.5)	Turn right on Dwight Rd.
67.4 (108.5)	1.8 (2.9)	Turn left onto Middletown-Lincroft Rd.
68 (109.5)	0.6 (1.0)	Turn right onto Oak Hill Rd.
68.8 (110.7)	0.8 (1.3)	Turn right into entrance to Poricy Park.

STOP 1, Poricy Park Nature Center, 345 Oak Hill Road, Middletown, NJ 07748

Location Coordinates: 40.369853°N, 74.097626°W

Meeting Time: approximately 10:00 AM

The Poricy Park Nature Center is located on the grounds of the Poricy Park Conservancy, a 250 acre tract of open space – the largest in Monmouth County. The nature center features an exhibit showcasing the common fossils recovered from the Navesink Formation. As the rest of the field trip stops are not located far from the nature center, we can carpool from here to cut down on the number of vehicles at subsequent stops. Bathrooms are also available in the nature center.

Distance in miles (km)

Cumu- lative	Point to Point	Route Description
68.8 (110.7)	0.0 (0.0)	Depart the nature center, turning left onto Oak Hill Rd.
69.2 (111.4)	0.4 (.65)	Turn left onto Middletown-Lincroft Road.
69.5 (111.8)	0.3 (.5)	Pull off into gravel parking area on left (SE) side of road.

STOP 2, Poricy Park Fossil Beds, Middletown, NJ

Location Coordinates: 40.369261°N, 74.116148°W

The Poricy Brook fossil locality is located in Monmouth County, NJ on the Middletown-Lincroft Road / Hwy 50. Fossil collecting is permitted within the rules stipulated by the park.

Sediments and Fossils

Only the uppermost section of the Navesink (Facies D – Figure 5 in the corresponding paper) is exposed at Poricy Brook. The upper shell bed is exposed at stream level and large specimens of *Pycnodonte* can be seen weathering out of the clayey glauconitic sands. Careful disaggregation of the shell bed sediments will reveal *Agerostrea*, *Exogyra*, and the brachiopod *Choristothyris*. Shell bed sediments also contain an abundant microfauna which can be extracted by soaking the sediment in household bleach for several days and then washing through a fine mesh to remove the clays. Careful examination of specimens of *Pycnodonte* will show that many contain faint red bands of original coloration preserved in the shell. In addition, most *Pycnodonte* record evidence of repeated predation attempts shown as irregular disruptions in the growth lines in the shell and displacements of the preserved color bands (Bennington, 2002; Bennington et al., 2000). Digging into the cut banks of the stream to obtain fossils is against the rules of the park, but I will try to obtain permission to collect some fresh specimens so we can observe the original shell coloration. Sieving the stream sediments will produce valves and fragments of the larger oysters as well as smaller specimens of belemnites, oysters, and brachiopods.

Distance in miles (km)

NYSGA: Geologic Diversity in NYC

Cumu- lative	Point to Point	Route Description
69.5 (111.8)	0.0 (0.0)	Depart, turn left (south) onto Middletown-Lincroft Rd.
71.4 (114.9)	1.9 (3.1)	Turn right onto West Front Street.
72.5 (116.7)	1.1 (1.8)	Turn left onto Everett Road at the end of West Front Street.
73.0 (117.5)	0.5 (.8)	Turn right onto Main Street.
75.5 (121.5)	2.5 (4.0)	Turn left onto State Route 34.
78.0 (125.5)	0.5 (.8)	Turn right onto Clover Hill Road.
79.4 (127.8)	1.4 (2.2)	Turn left onto Hillsdale Road.
80.5 (129.5)	1.1 (1.8)	Pull into parking area on right (east) side of Hillsdale Road.

STOP 3, Big Brook Hillsdale Road Locality, Colts Neck, NJ

Location Coordinates: 40.320442°N, 74.214300°W

The Navesink Formation is exposed in cut banks along Big Brook in Monmouth County, NJ and can be accessed from the Hillsdale Road entrance to the Big Brook Nature Preserve. Fossil collecting is permitted within the rules stipulated by the preserve. Walk upstream from the bridge on Hillsdale Road to the first large cut bank.

Sediments and Fossils

This section exposes the middle interval of the Navesink Formation, from the top of Facies B at stream level to midway through Facies D (Figure 5 in the corresponding paper). The contact between Facies B and C can be clearly seen as a break in the slope of the cut bank wall about 30 cm from stream level. Belemnite guards are easy to find in the sediments directly above the contact. About midway up the cut bank wall is the lower shell layer containing articulated specimens of *Exogyra costata*. The upper shell bed is exposed near the top of the slope downstream from the bridge. Burrows in the upper interval of Facies B can be observed to have originated above in Facies C, piping the darker, more glauconite-rich, sediment of Facies C downward into Facies B. Specimens of the pecten *Chlamys venustus* can be observed in the lower interval of Facies C. The contact between Facies B and C, which we will also see at Stop 4, is interpreted by some researchers (e.g. Miller et al., 1999; 2004) to be a transgressive surface of erosion as evidenced by a sharp disconformity, reworked sandy sediment, and phosphate nodules. The increase in abundance of fossil from pelagic organisms, in particular belemnite squid quards, suggests a significant decrease in sedimentation rate across the Facies B-C boundary.

Distance in miles (km)

Cumu-	Point to	Route Description
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NYSGA: Geologic Diversity in NYC

lative	Point	
80.5 (129.5)	0.0 (0.0)	Depart, turn right (south) onto Hillsdale Rd.
81.1 (130.5)	0.6 (1.0)	Turn right onto Crine Road at the end of Hillsdale Road.
81.6 (131.3)	0.5 (.8)	Turn right onto Boundary Road.
82.1 (132.1)	0.5 (.8)	Pull over on the right side of Boundary Road, just before the bridge.

STOP 4, Big Brook Boundary Road Locality, Colts Neck, NJ

Location Coordinates: 40.319194°N, 74.22304°W

Here the Navesink Formation can be accessed via a path down to the stream on the southeast side of the bridge over Big Brook at Boundary Road. Fossil collecting is permitted within the rules stipulated by the Big Brook Preserve. Walk **downstream** from the bridge on Boundary Road observing the sediments exposed in the cut banks. Avoid going upstream of the bridge – this reach is bordered by private property on the north side of the stream and the landowner is hostile toward fossil collectors.

Sediments and Fossils

Walking downstream from the bridge, one can observe Facies A through Facies D (Figure 5 in the corresponding paper) in various locations along the stream banks. At stream level the callianassid burrows (*Ophiomorpha*) typical of Facies A weather out of the sediment in relief and their branching structure can be observed. Just above eye level the contact between Facies B and C is marked by a horizon of light, sandy blobs. Belemnite guards can usually be found weathering out of the sediment in the first meter above the Facies B-C contact. The *Exogyra* shell bed observed at the last stop is also present here, but it is difficult to access. Climbing the vegetated slope of a large slump at the first large cut bank downstream of the bridge allows access to the upper shell bed, although it may be covered by loose sediment. Although the fossiliferous lag that marks the sequence boundary at the base of the Navesink is below stream level at this location, weathering of this horizon farther upstream creates a steady supply of vertebrate fossils that are washed downstream. Sieving the stream gravels in the downstream vicinity of the bridge will produce a variety of shark teeth, as well as fish teeth and the occasional bone or tooth fragment from a marine reptile.

Return to Meeting Headquarters

Distance in miles (km)

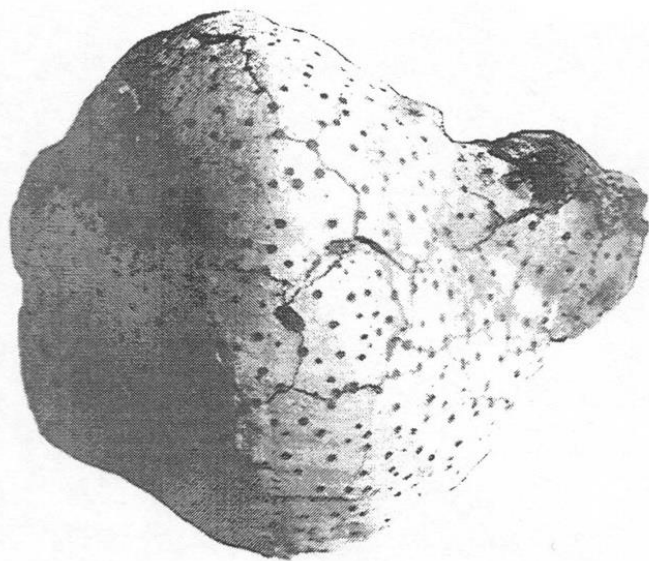
Cumu- lative	Point to Point	Route Description
82.1.5 (132.1)	0.0 (0.0)	Depart, make a u-turn and head south on Boundary Road.
82.6 (132.9)	0.5 (.8)	Turn right onto Vanderburg Road.
84.0 (135.2)	1.4 (2.3)	At the end of the road, turn left onto North Main Street.

NYSGA: Geologic Diversity in NYC

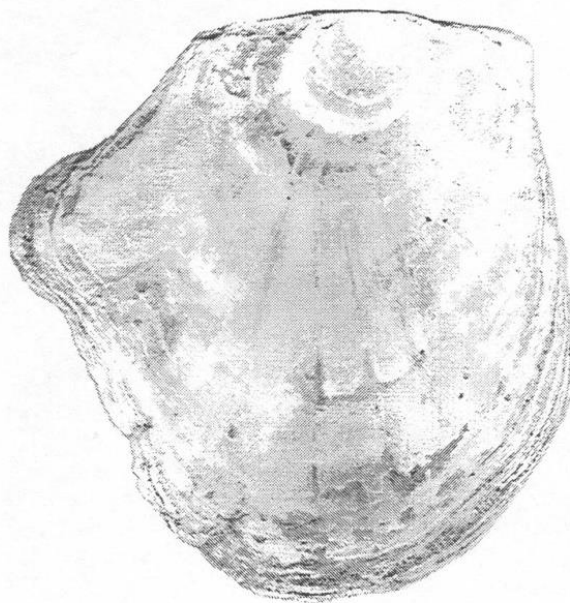
84.3 (135.7)	0.3 (.5)	Turn right to merge onto NJ-18 N toward New Brunswick.
89.4 (143.9)	5.1 (8.2)	Take exit 30 onto US-9 N toward the Amboys, New York.
96.6 (155.5)	7.2 (11.6)	Turn right to merge onto Garden State Parkway N.
99.0 (159.3)	2.4 (3.9)	Keep left on Garden State Parkway N.
145.0 (233.4)	46 (74)	Continue onto Gov Thomas E Dewey Thruway N.
146.3 (235.4)	1.3 (2.1)	Take exit to merge onto I-87 S toward New York City.
146.8 (236.3)	.5 (.8)	Keep left to merge onto I-87 S toward Tappan Zee Bridge.
147.7 (237.7)	0.9 (1.4)	Take exit 14 onto NY-59 toward Nanuet, Spring Valley.
148.0 (238.2)	0.3 (0.5)	Turn left onto W Route 59 toward Nanuet.
149.6 (240.8)	1.6 (2.6)	Meeting headquarters, Double Tree Inn, Nanuet is on the right.

REFERENCES CITED

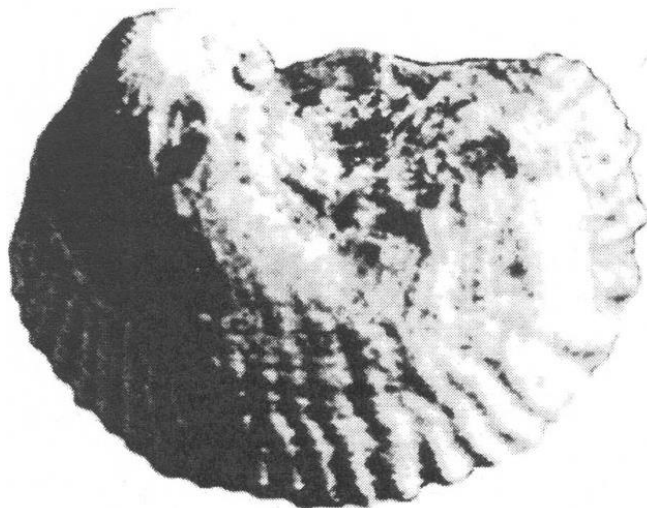
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- Miller, K.G., Sugarman, P.J., Browning, J.V., Kominz, M.A., Olsson, R.K., Feigenson, M.D., and Hernandez, J.C., 2004, Upper Cretaceous sequences and sea-level history, New Jersey Coastal Plain: *GSA Bulletin*, v. 116, p.368-393.



Pycnodonte mutabilis Morton
left valve, note the small holes made by the boring
sponge *Cliona cretacea*, x3/4



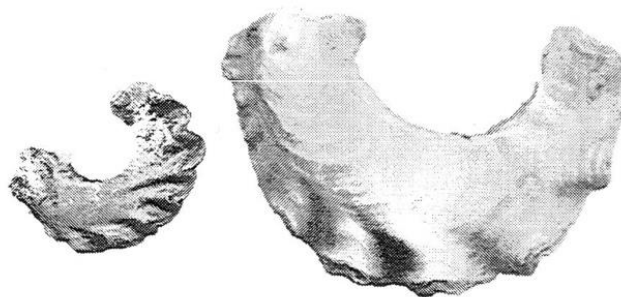
Pycnodonte mutabilis (Morton)
right valve, note the glove-like shape, x1



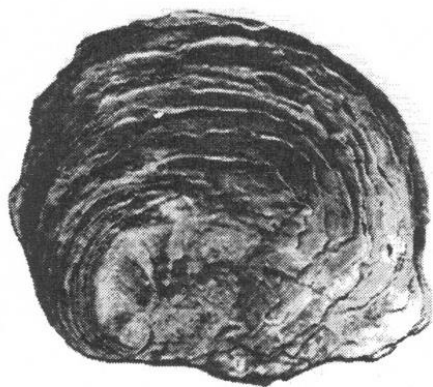
Exogyra costata Say
left valve exterior, x1



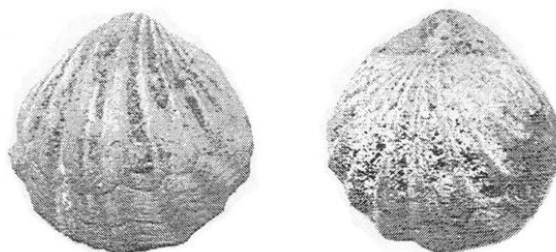
Belemnitella americana Morton
complete guard of a belemnite, x1



Agerostrea mesenterica Morton
right valves x1, middle x3, & edge view, x1



Exogyra costata Say
right valve, x1/2

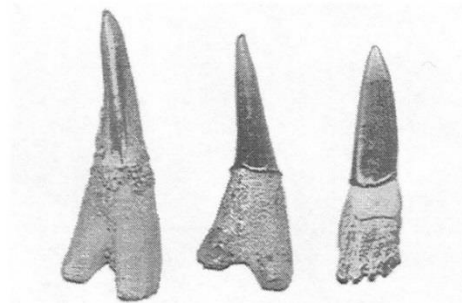


Choristothyris plicata Say
brachial (left) and pedicle (right) valves x2

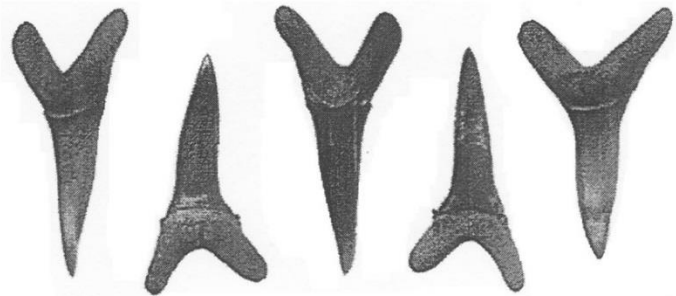
Plate 1. Common Invertebrate Fossils of the Navesink Formation (modified from Rose 2000)



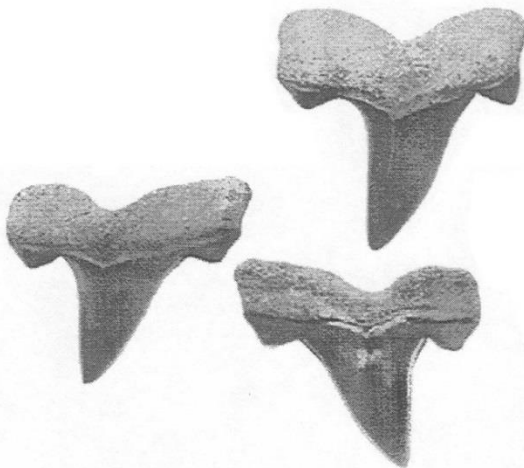
Enchodus ferox Leidy
mandibular tooth with jaw bone &
palatine tooth with jaw bone, x2



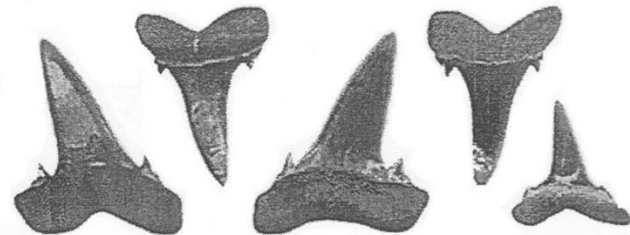
Ischyrrhiza mira Leidy
2 lateral views and one occlusal view of the rostral
spines of a sawfish, note the forked lateral profile,
all x2



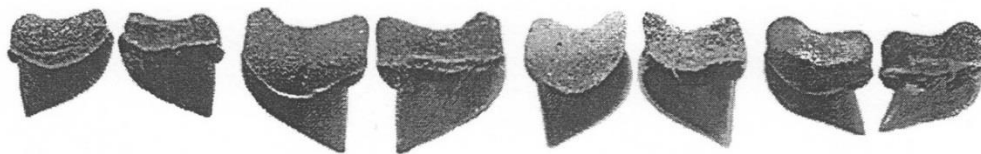
Scapanorhynchus texanus (Roemer)
lingual and labial views of the anterior teeth, all x1-1/2



Cretolamna appendiculata (Agassiz)
lingual and labial views, all x2



Scapanorhynchus texanus (Roemer)
lingual and labial views of the lateral teeth, all x1-1/2



Squalicorax kaupi (Agassiz)
lingual and labial views of 4 different teeth, all x1-1/2

Plate 2. Common Vertebrate Fossils of the Navesink Formation (modified from Rose, 2000)

TRIP A2: HISTORICAL SEDIMENT CARBON ACCUMULATION RATES AND CURRENT ACCRETION PATTERNS IN THE MEADOWLANDS OF NEW JERSEY

FRANCISCO ARTIGAS, JOSEPH GRZYB and MICHAEL STEPOWYJ
*Meadowlands Environmental Research Institute, One DeKorte Park Plaza
Lyndhurst, New Jersey 07071*

ABSTRACT

Historical carbon accumulation rates are preserved in the sediment stratigraphy of temperate macrotidal salt marshes. Tidal wetlands will most likely play a role as a source of carbon credits for a global carbon market (blue carbon) so estimating their long term carbon storage potential (i.e. greater than 100 years) and the marsh ability to persist over time is a necessary first step. If accretion rates are not keeping up with rising sea level there is a chance that these ecosystems could be completely inundated and lose their ability to capture carbon in the future. We analyzed the remaining carbon content in sediments using core samples and measured accretion rates and elevation change of marsh surfaces by performing Surface Elevation Table (SET) readings and feldspar marker readings over a 6 year period. Sediment core analysis shows a sharp increase in carbon accumulation rate that started around 600 years ago and reaches a maximum of 192.2 gr/m²/yr in the most recent layers. Measurement of surface and sub surface processes (i.e. accretion and subsidence) revealed that the average rate of marsh surface elevation change is approximately 4.6 mm/yr. The 60+ year rate of sea level rise established through tide gauge measurements in New York, Connecticut and Rhode Island average 2.6 mm yr⁻¹. Based on these figures we conclude that under the current circumstances, marsh surfaces in the Meadowlands are out passing sea level rise or at least they are keeping up with sea level rise.

INTRODUCTION

Tidal marshes in glaciated northern New Jersey are connected with the retreat of the Wisconsin Ice sheet (15,000 yr. B.P), the creation of a post glacial lake Hackensack, the rise in sea level and entry of tidewater into the Hackensack valley which resulted in deposition of peat and muck over the glacier lake sediments (Heusser, 1949; Peteet, 1980). An apparent reduction in the rate of sea level rise from 3,000 to 2,000 yr B.P. (Stuiver and Daddario, 1963) is now linked to the earliest development of coastal peats (3.8 m deep) in the Hackensack valley. Evidence of this early colonization are the *Alnus* seeds and associated fresh water species dated to 2060 +/-120 yr B.P. (Peteet, 1980) and basal peat formation over the same lake sediment dated to 2025+- 300 yr B.P. only a few Km away (Heusser, 1963). Palynology and peat stratigraphy evidence suggests marine transgressions and regressions, where established tidal marsh areas became sufficiently fresh water to support swamps containing alder and birch that later reverted back to marshland during marine transgressions (Heusser, 1963).

Tidal wetlands will most likely play a role as a source of carbon credits for a global carbon market so estimating their long term carbon storage potential (i.e. greater than 100 years) is a necessary first step (Freedman et al., 2009; Hansen, 2009). Moreover, solid baselines for accretion rates and quantifiable carbon flows would also be critical to any future CO₂ emission reduction program. On the other hand, if accretion rates are not keeping up with rising sea level there is danger that these ecosystems could be completely inundated and lose their ability to capture carbon. Furthermore, there is a need for standardized methods for quantifying carbon sequestration and carbon storage baselines as concluded by Chumra (2003), Rocha and Goulden (2009), Crooks et al. (2010) and Moffett et al. (2010).

Historical carbon accumulation rates are preserved in the sediment stratigraphy of temperate macrotidal salt marshes (Allen, 2000). The rates of vertical accumulation depend on the type of plant community, sediment inputs, flooding regime, micro topography and autocompaction of the peat (Pethick, 1979; Stumpf, 1983). Studies in Delaware Bay, the lower Hudson Valley and Connecticut (Bloom 1964; Fletcher et al., 1993; Pederson et al., 2005, respectively) show that around 6000 yr. ago palustrine wetlands occupied the coastal valleys of the north eastern shore and that by ~3000-2000 yr. B.P., the ongoing Holocene transgression created a variety of mud flats and subtidal environments and eventually the modern marsh, which is only a few hundred years old and holds the record of recent carbon sequestration rates (Pizzuto and Schwendt, 1997). The remaining carbon in the sediments not only accounts for carbon lost to the atmosphere through decomposition in the form of methane (CH₄), carbon monoxide (CO) and volatile organic carbon (VOC) but also accounts for leaching of dissolved inorganic and organic carbon and lateral particulate carbon transfers.

Due to sea level rise, surface and sub-surface processes (i.e. accretion and subsidence) of tidal marshes is an important factor in maintaining the ecosystems' ability to capture and store carbon. We analyze the accretion rate and elevation change of the meadowlands marsh ecosystems by performing Surface Elevation Table (SET) readings and feldspar marker readings. The SET is a leveling device measuring the relative elevation change of wetland sediments. These elevation readings allow us to see the buildup of the marsh in relation to rising seas. The shallow zone of subsidence contributes to the overall elevation of the marsh, as the subsurface processes in this zone counteract the increase in vertical accretion above the feldspar layer. Separating the vertical accretion surficial processes from the subsidence at depth is important in identifying different roles of the sediment column in marsh elevation dynamics. In this study we attempt to compare historical carbon accumulation rates by looking at carbon content in the sediment column and assess future carbon storage potential given local accretion rates and sea level rise forecasts.

METHODS

To explore the total organic carbon remaining in the sediments of a natural marsh, 50cm increment peat cores to a depth of 5.5 m were extracted from the nearby undisturbed Riverbend Wetland Preserve (RWP) tidal salt marsh (N 40° 45' 11.37"; W 74° 05' 36.62") (Figure 1). Only the upper 2.5 m of the core was used in this study. An important consideration to dating sediment profiles is the vertical stability of materials once they are deposited and minimizing disturbance while sampling. In our case, sediment cores were extracted with a Russian Peat Corer which minimizes compaction of the sample during extraction (Pitkanen et al., 2011). Core samples were saran wrapped, placed in a 50cm PVC pipe and transported in a cooler to the lab where they were stored in a 4°C refrigerator. Core segments were sampled from top to bottom every 6 cm with a 0.13 cm diameter brass auger. Total organic carbon (TOC) was determined using weight loss on ignition (LOI) method (500°C for 12 hrs) following Wang

(2011). Bulk density was determined by the sample ratio of mass over the volume. Total organic carbon (TOC) was determined as shown in Equation 5 following Dean's (1974) equation (1).

$$\text{TOC (g/cc)} = (\text{LOI in decimal}) / 2 \times \text{bulk density}$$

Equation 1.

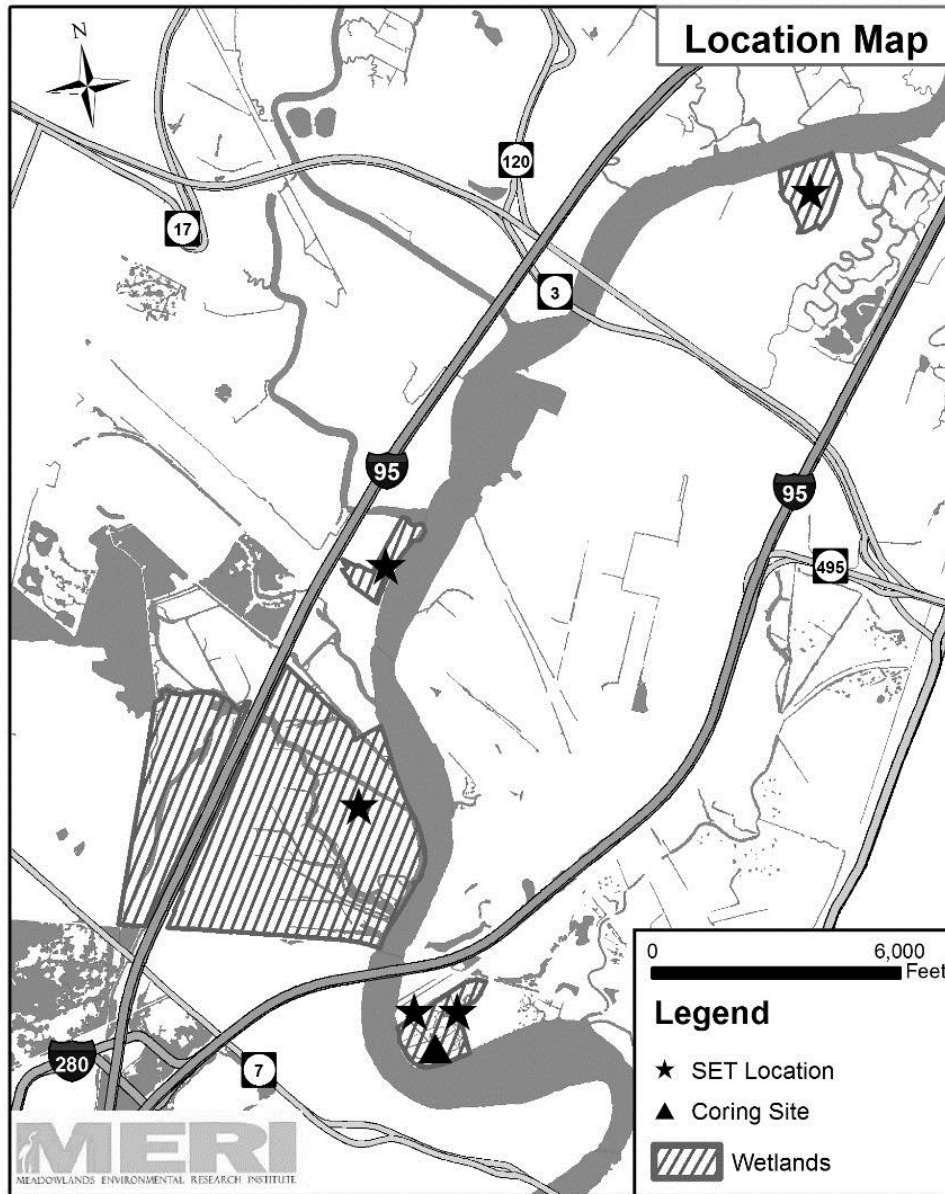


Figure 1. Location map of SET locations and coring site

The approximate time of recent carbon burial was determined by dating marsh sediment deposits using ^{137}Cs radioisotope. We applied this method, since ^{137}Cs has proven to be a reliable method for dating recent peat deposits in current studies (Orson et al., 1998; Jetter, 2000). Deeper stratigraphic

sequences on the other hand are distorted due to compaction involving a combination of physical and biochemical process that reduces the vertical thickness of the sediment column (Allen, 2000; Brain et al., 2012). Hence our age model is based on a combination of ^{137}Cs method for the most recent peat deposits, and for sediments deeper than 30 cm Heusser's (1963) and Peteet's (1980) age models were adopted. Fresh from the field, the first 30 cm of the core was cut into ten 3 cm segments, stored in air tight containers and shipped to a radioactive testing lab (University of Delaware, Department of Oceanography, Newark, DE) where ^{137}Cs isotope dating was performed according to Robbins and Edgington (1975) and Arnaud et al. (2006) using a high-purity Germanium well-type detector (Canberra Model GCW2523).

Both surface and subsurface process in the soil profile were measured to estimate marsh surface elevation. To measure changes in marsh elevation, five locations were chosen to span several miles of tidal wetlands and represent different vegetation and marsh regimes. To estimate subsurface process, three replicate plots with benchmark rods were measured at five sites with a soil elevation table (SET) apparatus (USGS, 2010). The SET apparatus is attached to the benchmark rod that gets permanently placed in the ground and extends several meters depth to the zone of deep subsidence. The rod attached to the benchmark pole acts as a constant plane in space and the distance from this plane down to the sediment surface is measured with pins. Over a period of 5.9 years and at each plot, nine pins are lowered from the benchmark rod plane to the marsh surface and readings taken in each of the four compass directions resulting in a total of 108 measurements for each of the 5 sites. Measurements obtained from each pin are compared to the previous sampling date reading, and the resulting differences become one data point that represents marsh surface elevation rate (mm/yr). The five sites measured include a restored *Spartina alterniflora* low marsh (Secaucus High School, SHS), a *Spartina alterniflora* low marsh (Saw Mill, SM), a *Spartina patens* dominated high marsh (Riverbend-Patens, RBP), a mixed *Spartina patens* and *Phragmites australis* high marsh (Riverbend Mixed, RBM) and a *Phragmites australis* dominated high marsh (Lyndhurst Riverside, LR) (Figure 1).

Vertical accretion or surface processes on the other hand, was measured using feldspar marker horizons at all three corners of each plot. Surface processes of deposition and erosion over time are measured from buildup of sediment from the feldspar horizon marker. Accretion was measured by taking readings at each of the three corners of each plot resulting in nine values for each site. The average of all readings for each site is shown in Table 1. Not all horizons produced recognizable accretion. Where negligible material accumulated above the horizon, "0.0 accretions" was designated. To obtain a yearly rate, the accretion value is divided by the number of days that have elapsed between establishment of the benchmark and the subsequent reading. Approximately five years and nine months elapsed between the readings. Table 1 provides the dates for each reading, accretion rate (mm/yr) and the time elapsed in days and years.

Marsh surface elevation change measured by the SET method captures both surface and subsurface processes occurring within the soil profile. The feldspar marker horizon reveals surfaces process only. We estimate the relative contribution of surface and subsurface process to marsh surface elevation by looking at the difference between shallow subsidence and accretion.

RESULTS

The variations in ^{137}Cs concentrations with depth show a well resolved peak at 5.5 cm depth (Figure 2), that coincides with maximum atmospheric fallout due to the testing of thermonuclear devices that started in 1954 and peaked in 1963/1964. We can infer that roughly 8 cm of sediments accumulated between 1954 and 2012, therefore – without accounting for compaction – on average, 1.4 mm of sediments accumulated per year since 1954.

Figure 3C shows a sharp increase in LOI values starting at 125 cm (~660 year BP) indicating a shift from subtidal environments dominated by mudflats to palustrine peats and finally to the modern emergent marsh (Holocene transgression in Allen, 2000). This change is corroborated by the marked decrease in bulk density for the same time period (Figure 3A).

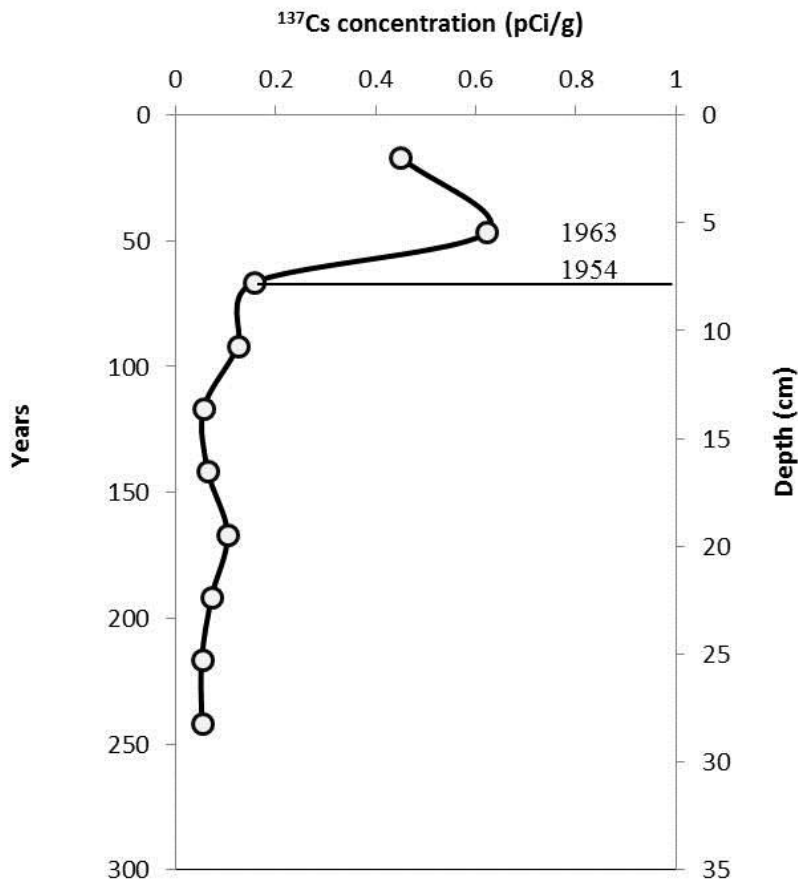


Figure 2. ^{137}Cs profile in sediment core of the Hackensack Meadowlands

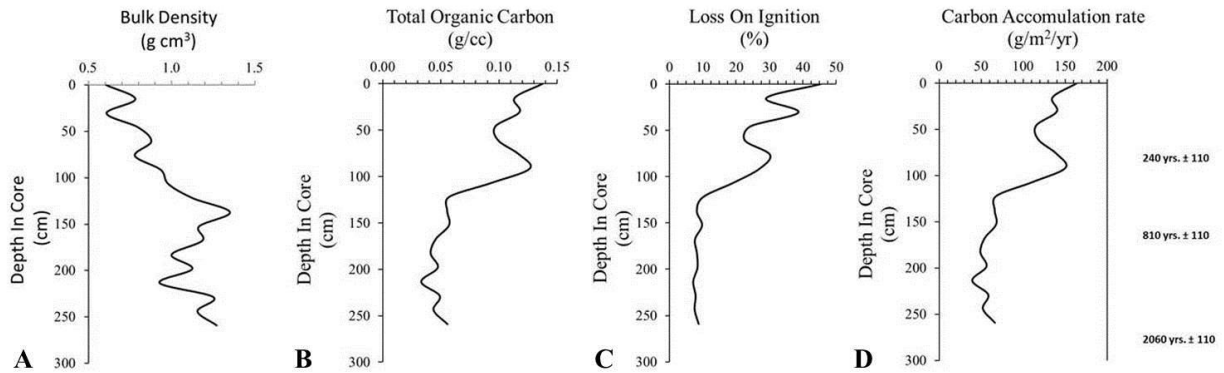


Figure 3. Bulk density (A), total organic carbon (B), loss on ignition (C) and carbon accumulation rate (D) in the sediment of the Hackensack Meadowlands over the course of approximately 1400 years

According to Artigas et al. (2015), after accounting for respiration, 22% of the carbon fixed by marsh vegetation on any given day is buried. The analysis of total organic carbon from the first 20 cm of the core shows that approximately 78% of the buried carbon remains stored 15 cm deep or at 134 years (¹³⁷Cs dating) and 50% of the carbon fixed by photosynthesis remains buried beyond 122 cm or 645 years B.P. Finally, Figure 3D shows a sharp increase in carbon accumulation rate around 600 years ago that reaches a maximum of 192.2 gr/m²/yr. in the most recent layers.

Days	Accretion (mm/yr)					Subsidence (mm/yr)				
	LN	RPP	RBM	SM	SHS	LN	RPP	RBM	SM	SHS
0	2.7	0	0	0	10	-6.05	-2.48	-5.96	4.66	0.03
181	4.6	5.3	5.4	7.7	5.26	-5.01	-0.78	-1.8	1.1	-1.51
349	3.9	5.7	7.8	13.8	4.4	-2.45	-0.33	0.22	8.29	-0.63
549	4.7	7.2	7.3	12	8.2	-1.55	0.32	-1.03	5.72	1.32
927	4.2	6.39	6.31	11.1	6.7	-3.33	0.47	-0.68	3.16	0.18
1434	3.4	5.03	5.05	9.9	8.9	-0.25	1.35	1.42	4.2	2.74
1799	4.4	5.67	7.18	9.7	7.9	1.22	1.5	2.02	4.96	2.06
2162	5	6.31	8.59	7.4	5.9	3.09	3.29	5.65	3.47	2.23

Table 1.- Accretion and subsidence rates in (mm/yr) for five different marsh surface type

Almost six years of accretion rate measurements from five different marsh surface types are presented in Figure 4. Each sampling date represents the average of nine measurements from the feldspar marker to the horizon. For the entire sampling period accretion rates remained above 4 mm/yr with an average of 6.6. mm/yr. The slopes of accretion rates over time were positive for all sites but were not significantly different from zero at p<0.05.

Subsurface process affecting marsh elevation (e.g. root growth, oxidation of organic matter, waterlogging, compaction, etc.) is captured by the SET measurement. The change in marsh surface elevation is expressed as the difference between shallow subsidence and accretion. All sites showed an

increase in elevation over time and this increase was significant for all sites ($p < 0.05$) but for Mill Creek (Figure 5). On average, when all sites are combined and surface and subsurface processes taken into account, the average rate of marsh surface elevation change is 4.6 mm/yr.

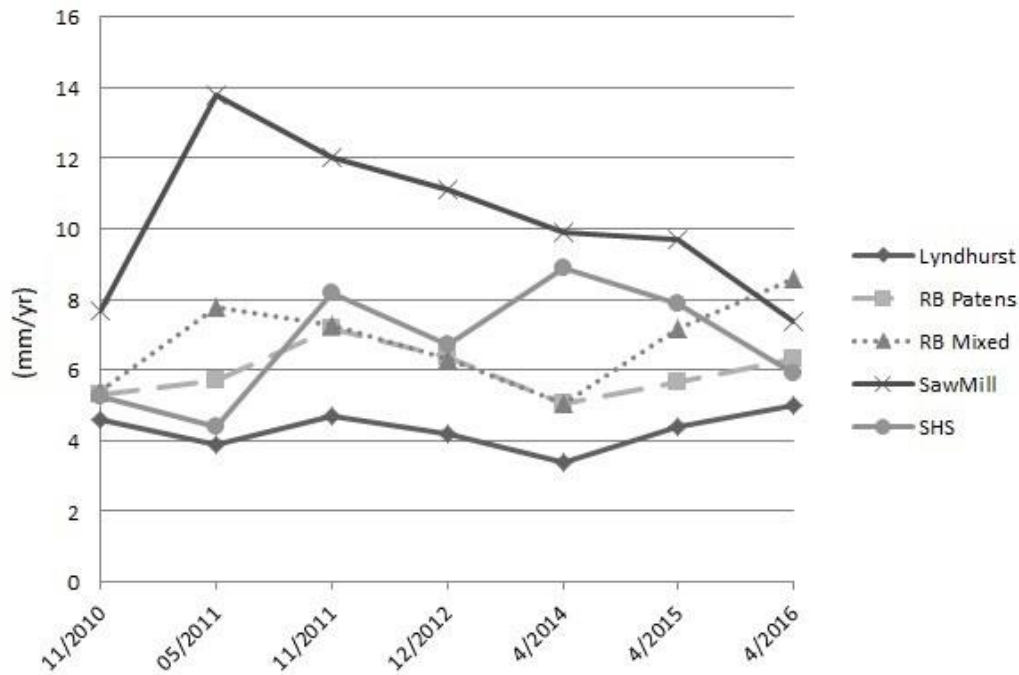


Figure 4. Accretion rates (mm/yr) from five different marsh surface types between 2010 and 2016

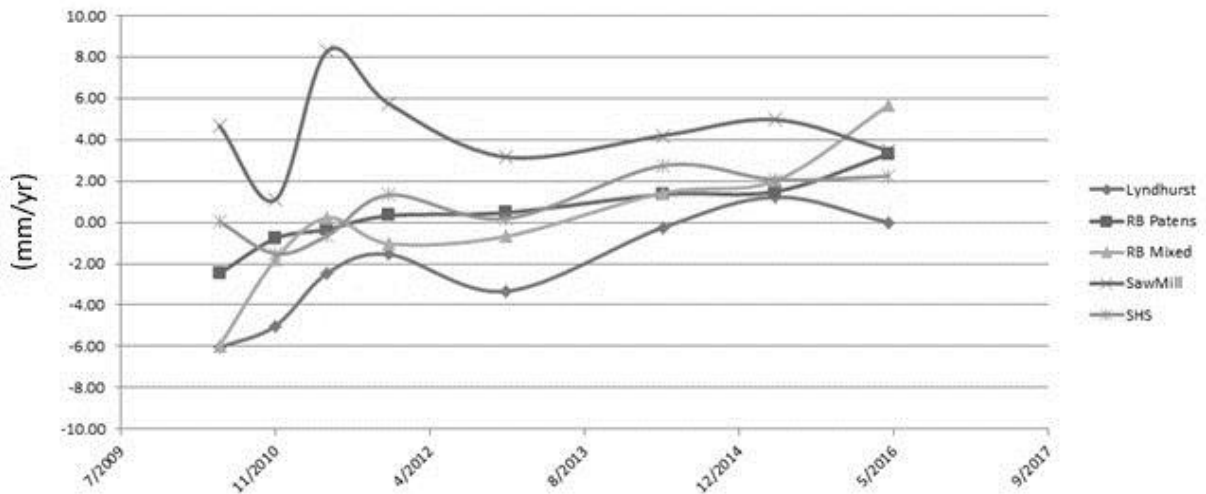


Figure 5. Shallow subsidence (accretion minus elevation) mm/yr.

DISCUSSION

Sediment core analysis shows that sharp increase in carbon accumulation rate that started around 600 years ago and reaches a maximum of 192.2 gr/m²/yr in the most recent layers. These data confirm the

generalization that short-term (0-150 years) rates of carbon accumulation are consistently larger than long-term (>1000 years) rates (Glaser et al., 2012)

Current Eddy Covariance measurements of carbon dioxide fluxes in the Meadowlands between the canopy and the atmosphere Artigas (2014) show that after accounting for respiration, 22 % of the carbon fixed through photosynthesis remains as standing biomass or is buried in any given growing season making tidal wetlands in this case net carbon sinks. Analyses of the remaining carbon in dated sediment core samples show that of the buried carbon pool, 78% remained in the sediments 130 years later and only the most recalcitrant carbon (50%) remains buried in the sediments beyond 645 years.

The annual rate of accretion based on the ^{137}Cs dating was estimated to be 1.4 mm. This is comparable with sedimentation rates of 1.8 mm yr⁻¹ that have been reported for comparable *Spartina patens* communities in Connecticut (Orson et al., 1998). In this study, however, sedimentation rates on the order of 5-7 mm yr⁻¹ were measured from feldspar horizons. Differences in sedimentation rates between what is observed from the core samples (1.4 mm/yr) and recent measurements from feldspar horizons (6.5 mm/yr) can be attributed to the age of the marsh (Pethick, 1979), distances from tidal creeks, availability of sediments, compaction and shallow subsidence (Cahoon et al., 1995). In this highly man modified environment, sediment loads from storm water outflows and sediment contributions from high capacity sewage treatment plants in the estuary suggests that true sedimentation rates may be more in line with values measured from the five permanent sediment elevation tables (i.e. 4.6 mm yr⁻¹) than from the estimates from the ^{137}Cs dating (1.4 mm/yr).

Surface and sub surface processes contribute to the overall elevation of the marsh and will be affected by sea level rise. Subsurface processes in this zone counteract the increase in vertical accretion above the feldspar layer. Separating the surficial processes of vertical accretion from the subsurface processes is important in identifying different roles of the sediment column in marsh elevation dynamics. In this case, when both processes are taken into account the average rate of marsh surface elevation change is 4.6 mm/yr. Church and White (2011) reported the global rise in sea level from 1900 to 2009 to be on average 1.7 ± 0.3 mm yr⁻¹, which has accelerated to 3.3 mm yr⁻¹ in recent years. Locally, however, the 60+ year rate of sea level rise established through tide gauge measurements in New York, Connecticut and Rhode Island average 2.6 mm yr⁻¹ (Orson et al., 1998). Based on these figures, we can conclude that under the current circumstances, marsh surfaces in the Meadowlands are exceeding regional sea level rise or they are at least keeping up with it.

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FIELD GUIDE AND ROAD LOG

Historical Sediment Carbon Accumulation Rates and Current Accretion Patterns in the Meadowlands of New Jersey

Authors: Francisco Artigas, Joseph Grzyb, and Michael Stepowyj

Directions from Nanuet to River Barge Park Marina

Get on Palisades Interstate Pkwy S
Continue to Fort Lee. Take the US 9W exit from Palisades Interstate Pkwy S
Get on I-95 in Ridgefield from US 46 W
Continue on I-95 S to N Connection Rd. Take the exit towards Sports Complex from I-95
Take Paterson Plank Rd to Outwater Ln, Carlstadt
End destination at River Barge Park. 269 Outwater Lane, Carlstadt 07072

Directions from River Barge Park Marina to Nanuet

Take Paterson Plank Rd and NJ-17 N to I-80 W
Take exit 62 toward Midland Ave/Saddle Brook. Continue to Garden State Pkwy
Exit 14-1 for I-87 S/I-287 E toward New York City, keep right and follow signs for Nanuet

Site 1: Secaucus High School Marsh

Secaucus High School Marsh is location where we collect Surface Elevation Table (SET) readings. The SET is a leveling device measuring the relative elevation change of wetland sediments. These elevation readings allow us to see the buildup of the marsh in relation to rising seas, referencing a fixed subsurface datum. This process evaluates the surface processes at hand such as sediment deposition and erosion. Below the feldspar horizon is the zone of shallow subsidence, a stratigraphic zone extending down to the bottom of the SET rod. The shallow zone of subsidence contributes to the overall elevation of the marsh, as the subsurface processes in this zone counteract the increase in vertical accretion above the feldspar layer. Separating the vertical accretion surficial processes from the subsidence at depth is important in identifying different roles of the stratigraphic column in marsh elevation dynamics.

Site 2: Riverbend Wetlands Preserve

To explore the total organic carbon remaining in the sediments of a natural marsh, 50cm increment peat cores to a depth of 5.5 m were extracted from the nearby undisturbed Riverbend Wetland Preserve (RWP) tidal salt marsh (N 400 45' 11.37"; W 740 05' 36.62")