Paleontology and Sequence Stratigraphy of the Upper Cretaceous Navesink Formation, New Jersey

Long Island Geologists Field Trip
October 18, 2003

J Bret Bennington
Hofstra University

<table>
<thead>
<tr>
<th>Ma</th>
<th>AGE</th>
<th>PLANKTONIC FORAMINIFERA ZONES</th>
<th>SEQUENCE CURVE</th>
<th>PALEO BATHYMETRY (METERS)</th>
<th>NEW JERSEY COASTAL PLAIN FORMATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>CAMPANIAN</td>
<td>G. helvetica</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>MAESTRATIAN</td>
<td>G. confervum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>PALEOCENE</td>
<td>G. coopers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>EOCENE</td>
<td>G. polyzoa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>EOCENE</td>
<td>G. primula</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>EOCENE</td>
<td>G. laticosta</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>EOCENE</td>
<td>G. concava</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>EOCENE</td>
<td>G. primitiva</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>EOCENE</td>
<td>G. arcuata, G. angulosa</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Image of a tooth](image)
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 (Fig. 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 excellent 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 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. These transitions are incompletely understood, so the interpretations presented on this field trip should be considered a work in progress. Nevertheless, the story that emerges of sea level rise on the Late Cretaceous continental shelf will be clearly seen and some good examples of Cretaceous fossils will be collected before the day is done.

Figure 1. Geologic map of New Jersey showing Cretaceous outcrop and field trip localities.
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 (Fig. 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 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 (Fig. 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. Formation of glauconite sands occurs on the continental shelf during

![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).](image)
prolonged intervals of sediment starvation (Odin and Fullagar, 1998). Deposition rates for the upper Navesink Formation have been estimated to be approximately 1 m/m.y. 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 show that the Navesink was deposited under sediment starved conditions.

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.

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

Figure 3. Cycle of sea level rise and fall
**marine flooding surface** 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 alloogenic 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).](image)
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) place the TS about 1.5 meters higher in the section, above what they interpret to be a regressive lowstand tract deposit (Fig. 4).

A Detailed Look at Navesink Facies

We have been looking in detail at the sedimentology and paleontology 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 *Thallassinoïdes*. Also present are phosphatic grains. Macofossils 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 (*Thallasinoïdes*) 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. We interpret Facies C to represent a transitional environment between inner and outer shelf depths.

**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 *Thallassinoïdes*. 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 anellids. Encrusting organisms are also common and include several species of bryozoa, serpulid anellids, 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.
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.
Brief Descriptions of the Field Trip Localities

Stop #1, Poricy Brook

Location
Poricy Park is located in Monmouth County, NJ on the Middletown-Lincroft Road / Hwy 50 (Fig. 7). Fossil collecting is permitted within the rules stipulated by the park.

Sediments and Fossils
Only the uppermost section of the Navesink (Facies D – Fig. 5) 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).

Figure 7. Map showing location of Poricy Brook Navesink Locality.
Optional Stop #2, Big Brook at Hillsdale Road

Location
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 (Fig. 8). 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 (Fig. 5). 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.

![Figure 8. Map showing location of Big Brook Navesink Localities.](image)
Stop #3, Big Brook at Boundary Road

Location

The Navesink Formation is exposed in cut banks along Big Brook in Monmouth County, NJ and can be accessed from the bridge at Boundary Road (Fig. 8). 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. Do not go upstream of the bridge – this reach is private property and the landowner is hostile toward fossil collectors.

Sediments and Fossils

Walking downstream from the bridge, one can observe Facies A through Facies D (Fig. 5) 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. 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.

References Cited


For additional information on identifying Navesink fossils, visit:

The Big Brook Identification Page
http://www.njfossils.net/cover.html