MINERALOGICAL, SEDIMENTOLOGICAL, AND PALEOECOLOGICAL ANALYSIS OF TRANSGRESSIVE SYSTEMS TRACT FACIES IN THE UPPER CRETACEOUS NAVESINK FORMATION, BIG BROOK, NEW JERSEY

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Abstract: Analyses of the sediments, fossils, and heavy minerals found through a stratigraphic section of the Upper Cretaceous Navesink Formation at Big Brook, New Jersey reveal new insights into the sequence of depositional environments developed during Navesink transgression. Bulk samples were collected in outcrop below and above apparent facies changes and at fossiliferous horizons. These samples were disaggregated to remove the macrofossil fauna and wet sieved to remove silt and clay. Sand-sized material was dry sieved to estimate weight-percent distributions and heavy mineral fractions were obtained from sample splits using heavy liquid separation and were identified by x-ray diffraction. Results of these analyses identify the base of the Navesink Formation near stream level as a poorly developed transgressive lag enriched in heavy minerals. Below the Navesink sediments are burrowed, fine-grained quartz sands of the Mount Laurel Sand / Wenonah Formation rich in lignite, mica, and siderite. These sediments appear to represent estuarine facies deposited as valley-fill during early transgression. Above the base of the Navesink, sediments are rich in glauconite sand and oxidized pyrite and depleted in quartz and most heavy minerals, indicating deposition out on the shelf away from the shoreline. Two distinct fossiliferous horizons occur in the Navesink at this locality, each with a distinct fossil assemblage. The lower horizon is dominated by the large oyster *Exogyra* with lesser numbers of pectenid bivalves. The upper horizon contains a more diverse assemblage dominated by the oysters *Pycnodonte* and *Agerostrea*, with lesser numbers of the brachiopod *Choristothyris*. Although all of these species are noted in the literature to be typical components of glauconitic sand faunas in the Upper Cretaceous (Gallagher, 1984; Gallagher et al., 1986; Owens et al., 1968), their occurrence at this locality in two assemblages of mutually exclusive composition strongly suggests the development and colonization of two different benthic environments during the Navesink transgression. Furthermore, the distribution of carbonate through the section shows that shelly horizons in the Navesink represent thin intervals that have escaped groundwater leaching and do not neccessarily represent isolated episodes of colonization by oyster faunas ('oyster banks').

Introduction

Upper Cretaceous strata of the Raritan embayment outcrop on the western side of the coastal plain in southern to central New Jersey (Figure 1). In outcrop, the formations of the Upper Cretaceous can be grouped into three cycles of deposition produced by three complete episodes of sea level rise and fall (Gohn, 1995). The transgressive deposits at the base of the 3rd cycle in the New Jersey sequence compose the Navesink Formation (Figure 1) which is typically described as a "massive unconsolidated dark-greenish-gray clayey and silty medium to coarse (glauconite) sand" (Owens et al., 1968). The Navesink is fossiliferous, containing both a marine macrofauna and microfauna, and has been assigned an earliest Maastrichtian age based on these faunas (Gohn, 1995; Kennedy et al., 1995; Self-Trail and Bybell, 1995).

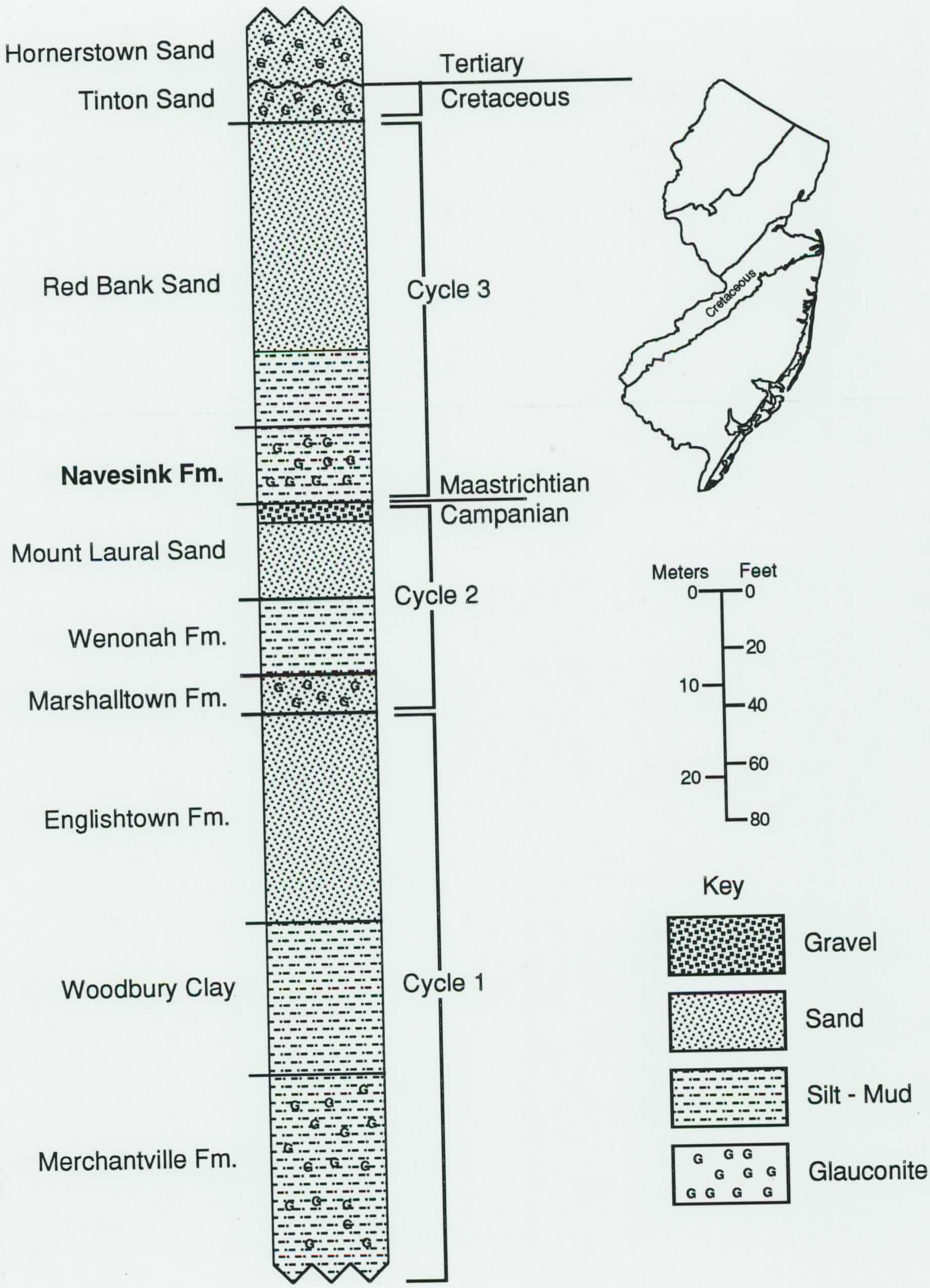

Figure 1. Upper Cretaceous Stratigraphy of the New Jersey Coastal Plain

In north-central New Jersey the Navesink is well-exposed along the banks of Big Brook at the Boundary Road Bridge, which for many years has been a famous collecting locality for both invertebrate fossils and shark teeth (Gallagher et al., 1986). Unfortunately, in spite of the notoriety of this outcrop, very little detailed information has been published about its sedimentological and paleontological characteristics, particularly as they relate to the specific stratigraphic sequence exposed at Big Brook. Furthermore, few detailed analyses of Navesink deposition in general are available, nor has there been much detailed study of the facies and fossil assemblages found in the Upper Cretaceous transgressive units of the New Jersey coastal plain. To provide some information about the locality at Big Brook, as well as to begin to examine in detail the nature of glauconitic transgressive strata in the Upper Cretaceous, we undertook a program of detailed measuring and sampling of the Navesink Formation at the Big Brook locality.

Study Area and Methods

The Big Brook outcrop measured in this study is located outside the town of Freehold in Monmouth County, New Jersey. The outcrop can be accessed by taking Route 79 North out of Freehold for 5.3 miles, turning right onto Route 520 for one mile, and turning right onto Boundary Road for 1.5 miles (Lauginiger, 1986). The exposure is located in the first high cut bank downstream of the bridge. The outcrop was measured from stream level to the soil horizon at the top of the bank. Bulk sediment samples of approximately 1 kg were taken from each of six levels above and below facies changes and at fossiliferous horizons (Figure 2). In the laboratory, samples were disaggregated by hand and described, and all macrofossil material was removed. .5 kg splits of the bulk samples were treated with household bleach for one week and then wet-sieved to remove the clay and silt fraction, which was collected and dried. The remaining sand fraction was dry-sieved to obtain the weight-percent distribution of particle size classes.

For the heavy mineral analysis, the dry-sieved sand was split to obtain samples of a few hundred grams. Heavy minerals were separated from light minerals (quartz, feldspars, mica) in a separatory funnel using S.G. Bromoform at a specific gravity of 2.85. To remove glauconite from the heavy mineral fraction obtained, a second separation was performed in a test tube using Acetylene Tetrabromide with a specific gravity of 2.96. The resulting heavy mineral fraction was examined under the stereoscopic microscope and classified into different mineral species by visible characteristics. Dominant mineral species were concentrated using a vacuum needle to manupulate small grains. Approximately 2 mg of each species was crushed in a micro mortar under acetone and concentrated on an x-ray micro smear mount of about 1/8 inch in diameter. The smear mounts were scanned from 8° to 60° 2 Θ using Cu K-alpha radiation with the chart recorder set at 5K cps. Identification of species was done principally by direct comparison with similarly prepared scans of micro smear mounts of known minerals.

Results

Lithological and paleontological observations made on the stratigraphic section at the Big Brook locality and the locations of bulk samples in the section are presented in Figure 2. Results from the size-fraction and heavy mineral analyses are summarized in Figure 3.

Sample 4.5'

The basal 5' of the section is a dark gray, clayey, silty fine sand with small horizontal and vertical burrows throughout. Shelly fossils were not noted in outcrop or in the disaggregated sample, although a few small pieces of fish scale were recovered. Almost 50% of sample 4.5' is

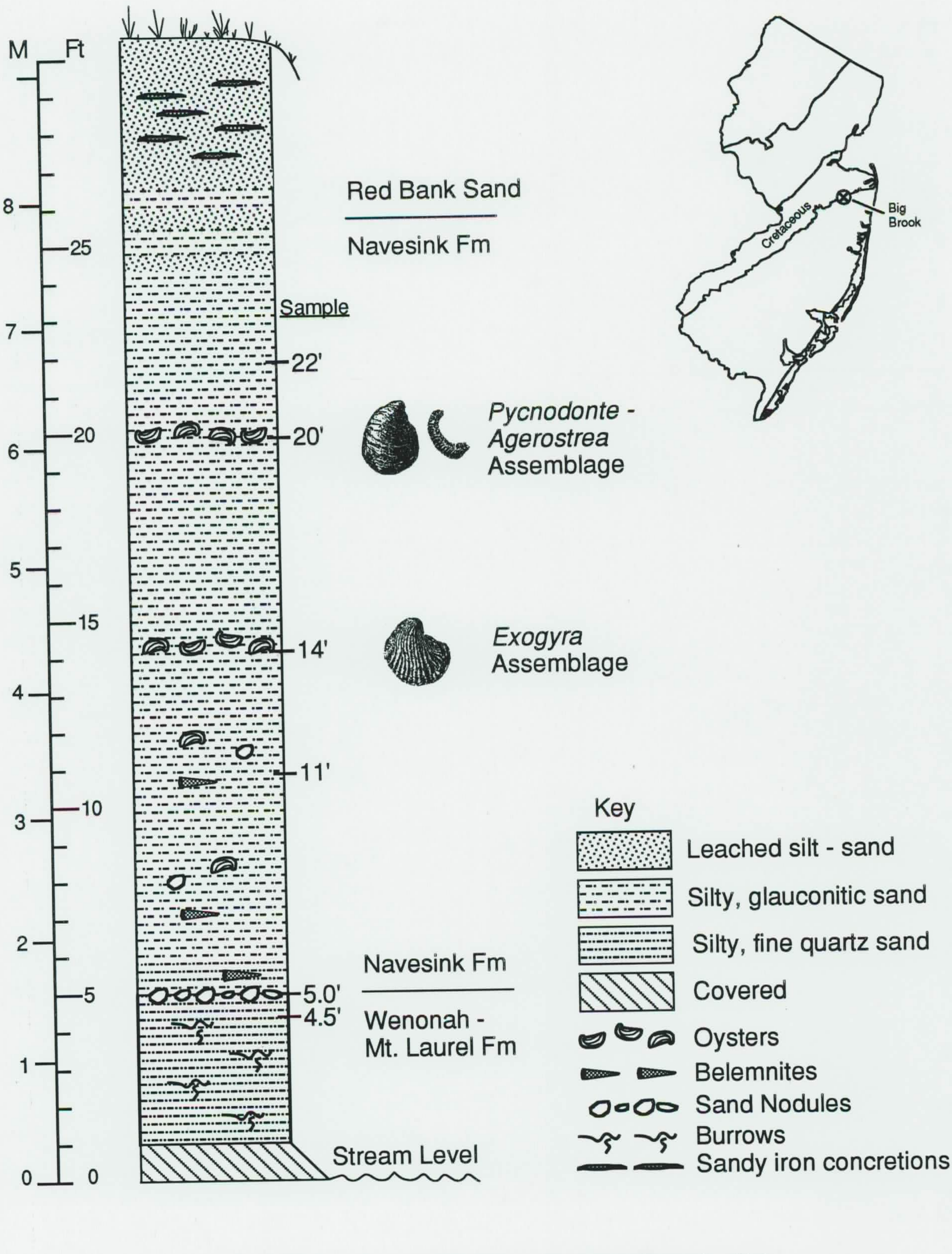

Figure 2. Locality Nav 2a Big Brook, NJ

silt and clay, with the remaining 50% composed primarily of very fine quartz sand. Muscovite mica is abundant in the sample and small fragments of lignitic material are very abundant. Heavy minerals are rare, with the exception of siderite, which comprises the majority of the heavy mineral recovered. Also noted were grains of labradorite and clinopyroxene.

Sample 5.0'

This sample was taken at the horizon 5 feet above the base of the outcrop where there is a distinct change to a darker colored lithology. This horizon is also marked by the presence of rounded sand nodules (app. 1-3 cm in diameter) of unknown origin and by the lowest occurrence of guard shells of *Belemnitella americana* noted in the outcrop. Relative to the subjacent sample, the sample at 5.0' contains little silt and clay (18%) and is greatly enriched in grains in the fine to very coarse classes. The majority of the grains are composed of quartz, but mica and glauconite are also present. In the heavy mineral analysis, a much greater variety of heavy minerals were recovered, including chlorapatite, garnet, amphibole, and others including tentatively identified spinel and scapolite. Belemnite guard shells were noted at or near this interval in outcrop and several small gastropod fragments and fish scales were recovered in the disaggregated sample.

Sample 11'

This sample was collected about halfway between the facies change near the base of the outcrop and the first shelly horizon above. Belemnite guard shells and rare fragments of the oyster *Exogyra costata* were noted throughout this interval. Sample 11' is composed almost completely of grains of glauconite. Minor amounts of quartz were also noted. Very little heavy mineral was recovered. Larger glauconite grains have an orange, oxidized coating and appear to be somewhat weathered. No shelly material was noted in the disaggregated sample, although several fish scales and small fish bones were found.

Sample 14'

This sample was collected at the level of the lowest distinct shelly horizon in the outcrop. Articulated shells of the oyster *Exogyra costata* are abundant at this horizon. Also noted were the thin shells of an unidentified pectenid bivalve. No other macrofaunal species were found. As in the subjacent sample, glauconite is the major mineral constituent, with minor amounts of quartz present. Small grains of phosphate were also noted, often occurring as distinctive spiral pellets. Oxidized pyrite was the major component of the heavy mineral fraction. In the disaggregated sample fragments of oyster and pecten shell were common and fish scales and bones were present. An abundant calcareous microfauna was noted, made up of many species of ostracoda and foraminiferida. Below a phi size of 2.5 sieved fractions contained abundant foraminifera, including two species (*'Globigerina'*, *Globotruncana*) known to be planktonic (Baker, 1995).

Sample 20'

This sample was collected at the level of the second and highest distinct shelly horizon in the outcrop. Articulated and disarticulated shells of the oysters *Pycnodonte mutabilis* and *Agerostrea mesenterica* are abundant at this horizon. Also noted was the brachiopod *Choristothyris plicata*. In the sieved sample, fish scales and fragments of pectenid bivalve shell, echinoid spines, and bryozoan colonies were found. Glauconite is the major mineral constituent, with minor amounts of quartz. Small grains of phosphate are also present, and oxidized pyrite was the major component of the heavy mineral fraction. An abundant calcareous microfauna was noted, made up of many species of ostracoda and foraminiferida, including planktonic species.

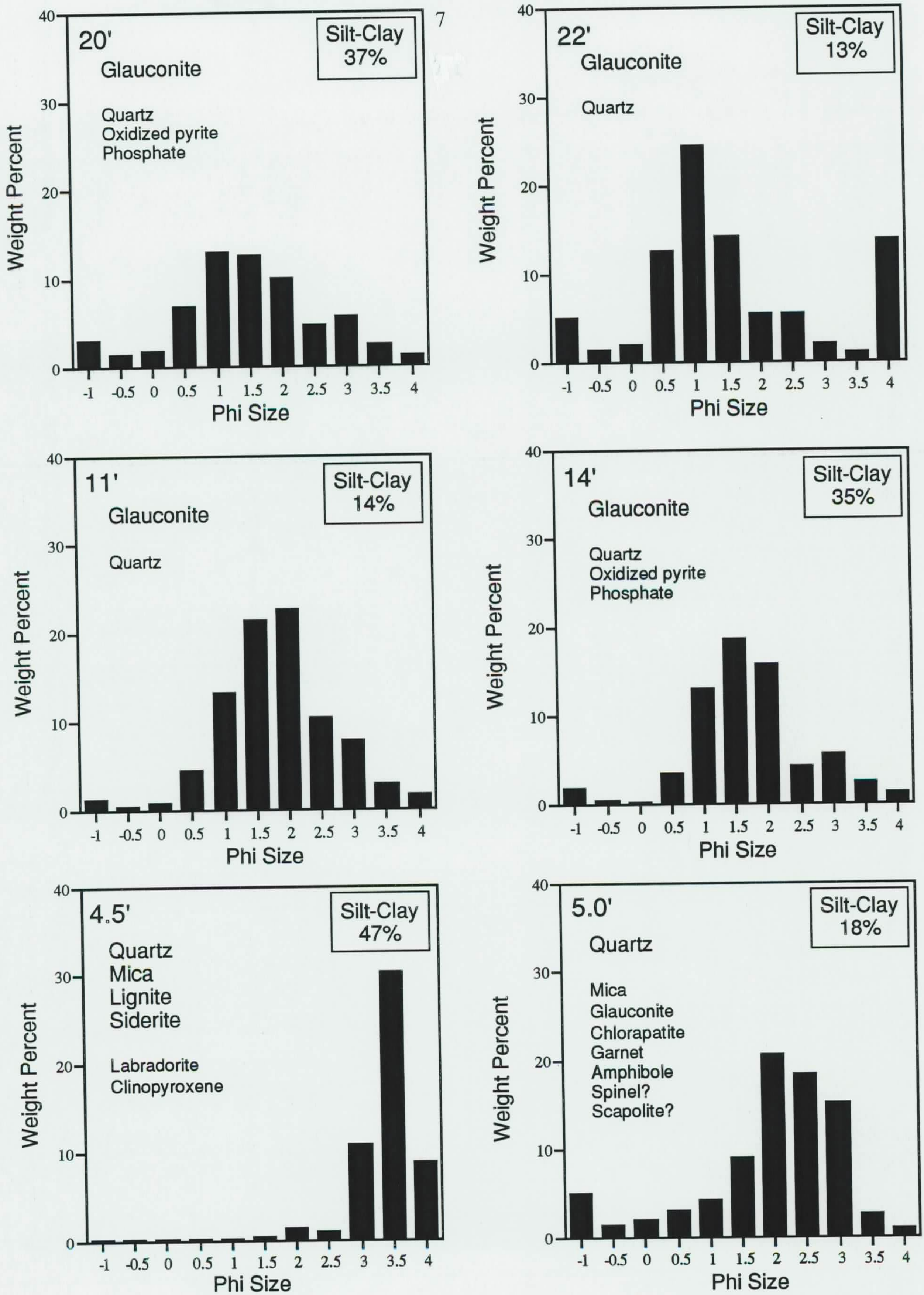

Figure 3. Summary of results from sedimentological and heavy mineral analyses.

Sample 22"

This sample is from the highest level in the section that could be reached from below. It is composed primarily of glauconite with minor amounts of quartz. Larger glauconite grains have an orange, oxidized coating and appear to be somewhat weathered. Very little heavy mineral was recovered from the sample. Calcareous macro- and microfauna are missing, although several external molds of the brachiopod *Choristothyris* were found.

Discussion

It is generally agreed that the depositional sequences in the Cretaceous of the New Jersey coastal plain correspond to cycles of sea level change, with the transgressive facies in each cycle characterized by clay-rich, glauconitic silts and sands (greensands) and the non-glauconitic silty and sandy facies representing regression (Olsson, 1987). In sequence stratigraphic terminology glauconitic facies represent deposition of the transgressive systems tract during relative sea level rise. If this is true, then the highstand deposits produced during shoreline progradation must be represented by the overlying clays and silts without glauconite that coarsen into sands. Lowstand would then be marked by gravels and disconformities below the glauconitic sands at the base of the following cycle. Valleys incised into the coastal plain during lowstand may be filled with sediments deposited during subsequent transgression (Posamentier and Vail, 1988). It has also been noted by Gohn (1995) that where this has occurred in the coastal plain sequence, the coarse-grained, shallow marine sediments expected to lie below the base of the transgressive glauconitic sands of the next cycle may be missing in a disconformity or may be replaced by estuarine facies deposited as valley-fill during early transgression .

At Big Brook, the glauconitic sands of the Navesink Formation are underlain by strata of the Wenonah-Mount Laurel Formation characterized as massive, micaceous, silty black clays with laminae of comminuted organic matter (Gallagher et al., 1986). Near the base of the Navesink these strata are extensively burrowed and contain significant amounts of siderite and comminuted lignite. Siderite is an iron carbonate mineral formed diagenetically in the pore waters of oxygen depleted sediments in fresh and brackish water environments rich in decomposing organics (Berner, 1981). The presence of siderite and abundant organic material in sample 4.5' combined with the abundance of horizontal and vertical burrows and fine-grained sand, silt, and clay argues strongly for deposition under fresh water to marginal marine, estuarine conditions. Also of possible significance is the presence of labradorite and clinopyroxene in phases normally destroyed during weathering, particularly in marine environments. This igneous mineral assemblage might have been produced from erosion of Jurassic basalts located to the northwest.

The lack of a distinct disconformity at the base of the Navesink Formation at Big Brook may be a result of the original erosional surface developed during lowstand having been covered by estuarine deposits during initial transgression. The coarser sands seen in sample 5.0' can be attributed to deposition during migration of the shoreface over the esturarine deposits to form a weakly developed transgressive lag. This scenario is supported by the greater variety and abundance of detrital heavy mineral grains in this sample, suggesting some degree of concentration by winnowing. The appearance of gastropods and belemnite guards also supports the supposition that the base of the Navesink represents the arrival of a fully marine environment with the shoreface.

The remaining four samples and the stratigraphic interval they encompass are relatively similar, being composed of authigenic glauconite with a very small detrital component. This is generally agreed to indicate deposition on the middle to outer shelf, below wave base in relatively deep water (Gallagher, 1984; Olsson, 1987; Owens et al., 1968). The principle heavy mineral component of these samples is pyrite, an early diagenetic iron sulfide that commonly forms in the pore waters of fine-grained, organic-rich, marine sediments (Berner, 1981). What is puzzling about the glauconitic interval at Big Brook is the distribution of macro- and microfossils. The distinct layers of oyster-dominated shell material seen in glauconitic facies in the Cretaceous are commonly referred to as 'oyster banks'. This is in direct analogy to the shell buildups produced by modern oysters on shallow water, muddy bottoms, such as occur along the coast of Georgia. However, it is not at all clear that this analogy is appropriate. Mesozoic oysters such as *Exogyra* and *Pycnodonte* were solitary, semi-infaunal animals living in deep water. Unlike modern oysters, they do not appear to have required a hard substrate above the mud to cement themselves to and would not have required the presence of a previously established accumulation of oyster shells to ensure their survival. Therefore, rather than being mutualistic accumulations of oyster shells analogous to modern oyster banks, we propose two alternative explanations for the Navesink shell beds. 1) The shell beds represent episodes of opportunistic colonization of the sea floor, possibly during times of increased oxygen supply to the waters near the shelf benthos. The intervening barren intervals represent times when environmental conditions on the sea floor inhibited colonization by shelly fauna. 2) The shell beds are stratigraphic intervals that have been isolated from groundwater leaching. In this scenario, shelly fossils were originally abundant throughout the Navesink but have since been dissolved from all but a few thin intervals. This explanation is supported by the abundance of planktonic forams in the shelly intervals and by the almost complete absence of any calcareous material and by the generally weathered appearance of the glauconite and lack of pyrite (which can also be oxidized and leached by groundwater) in the barren intervals. However, it is still not clear why certain intervals would be protected from groundwater leaching, nor is it known why these protected intervals should be so rich in shelly fauna.

Finally, the significance (if any) of the different fossil assemblages at Big Brook is unknown. The upper shelly interval is a much more diverse marine assemblage than the lower shelly interval. It is possible that the composition of each fauna was controlled by environmental parameters such as oxygen availability or nutrient supply not evidenced by any change in depositional parameters. Perhaps the more diverse fauna is indicative of better oxygenated conditions, perhaps related to shallowing due to the onset of regression? Resolution of this question will require comparisons of the fossil assemblages at Big Brook with fossil assemblages from other Navesink localities and from other Upper Cretaceous glauconitic facies.

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References Cited

Baker, J. E. B. (1995) Simple methods for extracting microfossils of the Navesink Formation (Cretaceous; N.J.), *in* Contributions to the Paleontology of New Jersey, The Geological Association of New Jersey, Vol. XII, p. 302-309.

Berner, R. B. (1981) A new geochemical classification of sedimentary environments: Journal of Sedimentary Petrology, v. 51, no. 2, p. 359-365.

Gallagher, W. B. (1984) Paleoecology of the Delaware Valley region: The Mosasaur, v. 2, p. 9-43.

Gallagher, W. B., Parris, D. C., and Spamer, E. E. (1986) Paleontology, biostratigraphy, and depositional environments of the Cretaceous - Tertiary transition in the New Jersey coastal plain: The Mosasaur, v. 3, p. 1-15.

Gohn, G. S. (1995) Ostracode biostratigraphy of the Upper Cretaceous marine sediments in the New Jersey coastal plain, *in* Contributions to the Paleontology of New Jersey, The Geological Association of New Jersey, Vol. XII, p. 87-101.

Kennedy, W. J., Johnson, R. O., and Cobban, W. A. (1995) Upper Cretaceous ammonite faunas of New Jersey, *in* Contributions to the Paleontology of New Jersey, The Geological Association of New Jersey, Vol. XII, p. 24-55.

Lauginiger, E. M. (1986) An Upper Cretaceous vertebrate assemblage from Big Brook, New Jersey: The Mosasaur, v. 3, p. 53-61.

Olsson, R. K. (1987) Cretaceous stratigraphy of the Atlantic Coastal Plain, Atlantic Highlands of New Jersey, Geological Society of America Centennial Field Guide - Northeastern Section, Geological Society of America, p. 87-90.

Owens, J. P., Minard, J. P., and Sohl, N. F. (1968) Cretaceous deltas in the northern New Jersey coastal plain, *in* Finks, R. M., ed., Guidebook to Field Excursions at the 40th Annual Meeting of the New York State Geological Association, New York State Geological Association, p. 33-49.

Posamentier, H. W., and Vail, P. R. (1988) Eustatic controls on clastic deposition II - Sequence and systems tract models, *in* Wilgus, C. K., Hastings, B. S., Kendall, C. G. S. C., Posmentier, H. W., Ross, C. A., and Van Wagoner, J. C., eds., Sea-level Changes: An Integrated Approach, Society of Economic Paleontologists and Minerologists Special Publication, p. 125-154.

Self-Trail, J. M., and Bybell, L. M. (1995) Cretaceous and Paleogene calcareous nannofossil biostratigraphy of New Jersey, *in* Contributions to the Paleontology of New Jersey, The Geological Association of New Jersey, Vol. XII, NJ, p. 102-139.