THE NEW JERSEY COASTAL PLAIN AND ITS RELATIONSHIP WITH THE BALTIMORE CANYON TROUGH

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Introduction

The coastal plain of New Jersey lies along the western edge of the Baltimore Canyon Trough, a large sedimentary basin which extends along the United States Middle Atlantic states (Fig. 1). The Baltimore Canyon Trough extends seaward beneath the continental shelf to the upper continental slope. A westward extension of the trough forms the Salisbury Embayment of New Jersey, Delaware, Maryland and eastern Virginia. The Raritan Embayment of northern New Jersey and Long Island is a shallow embayment. The South Jersey High separates these two embayments of the trough. The Baltimore Canyon Trough is composed of a seaward-thickening wedge of Mesozoic and Cenozoic sedimentary rocks which overlie a warped and faulted crystalline basement. The sediments that lie within the New Jersey Coastal Plain were deposited west of the main hinge line of deposition. Seaward of the hinge line the sedimentary rocks of the Baltimore Canyon Trough thicken to at least 14 km (Poag, 1979). In contrast the maximum thickness of sediments in the New Jersey Coastal Plain is less than 2 km in the Salisbury Embayment.

The sediments in the Baltimore Canyon Trough were initially deposited when North America and Africa separated during early Mesozoic time. The sediments (Figs. 2,3) that accumulated in the Baltimore Canyon Trough consist of limestones, sandstones, sands, shales, and clays (Poag, 1979). Diapir structures noted in geophysical profiles (Grow, 1980; Schlee and Grow, 1980) along the continental slope suggest evaporite deposition occurred in the early phases of continental separation. A deeply buried thick sequence of limestone of Jurassic and Early Cretaceous age is identified in multi-channel seismic reflection profiles of the trough and a carbonate bank or reef thought to represent the lower Cretaceous shelf edge is postulated to lie beneath the present day upper continental slope. Limestones of late Jurassic and early Cretaceous age were penetrated in the basal portion of the COST B-3 well which was drilled on the continental slope off New Jersey. The limestone sequence is confined to the deeper portions of the trough and does not extend beneath New Jersey.

Overlying the limestone sequence (Figs. 2,3) are upper Jurassic and lower Cretaceous nonmarine and shallow marine sandstones and shales (Poag, 1979). These sediments thin beneath New Jersey and lie upon crystalline basement rock. Where penetrated in wells they appear to be nonmarine in character although they

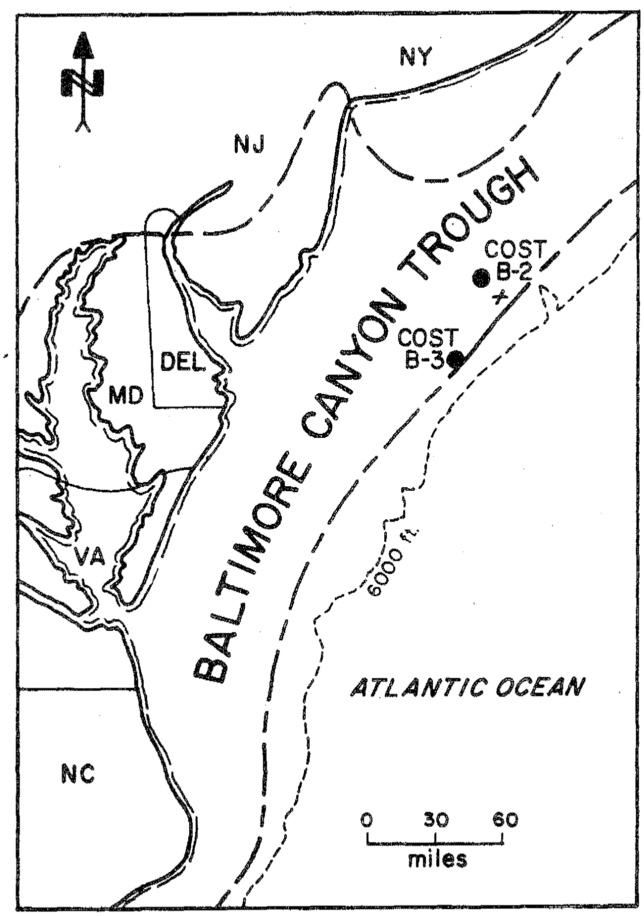


Fig. 1 Outline map of the Baltimore Canyon Trough and its relationship to the New Jersey Coastal Plain. Location of COST B-2 and B-3 wells is shown. The hatchered mark shows location of natural gas discoveries.

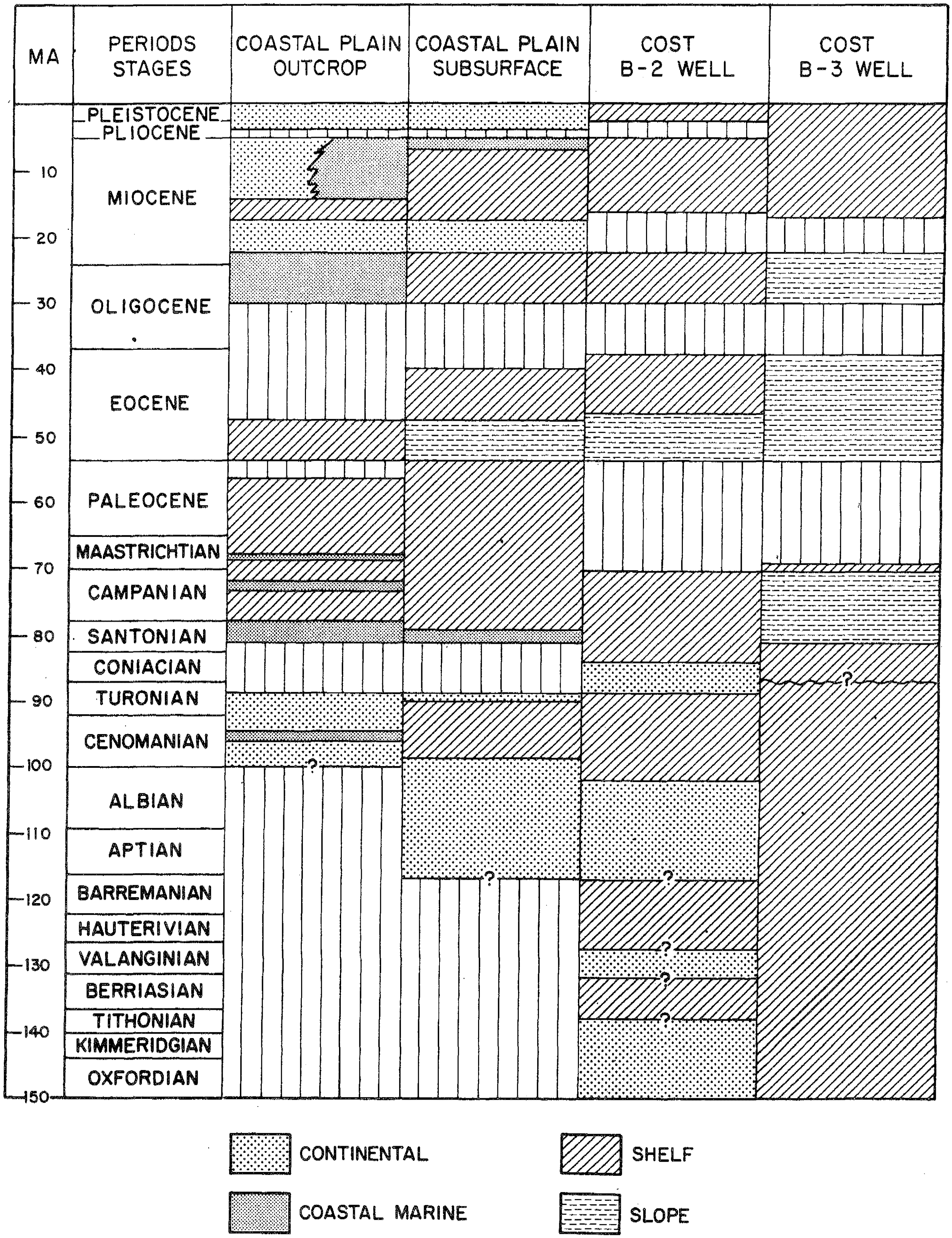


Fig. 2 Diagram showing distribution of the continental, coastal marine, shelf, and slope facies in time. Data on COST B-3 well is taken from Poag, 1980.

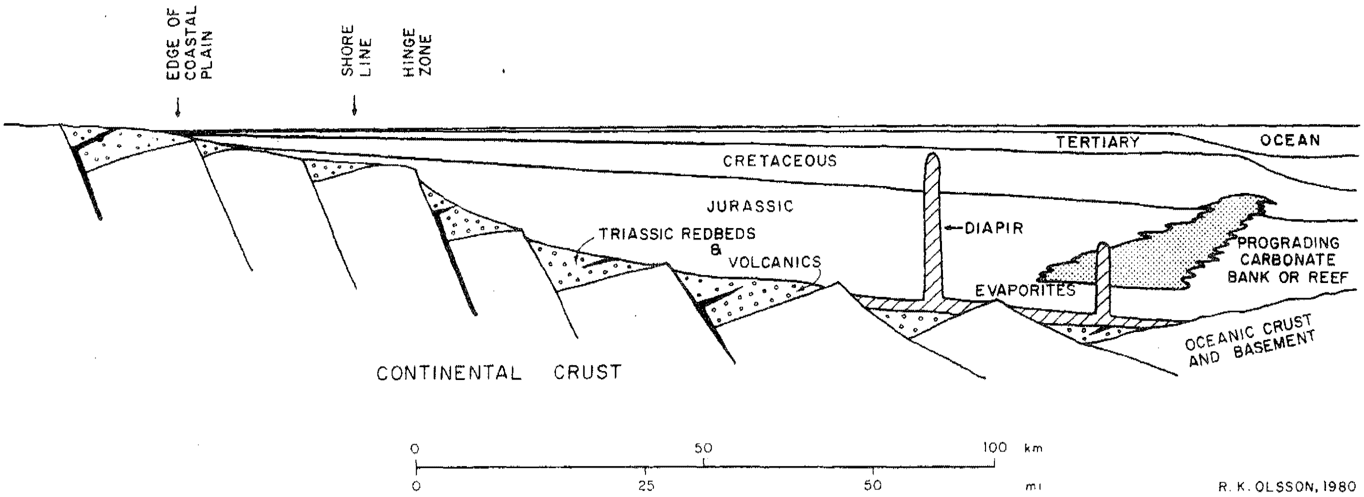


Fig. 3 Cross-section through Coastal Plain and Baltimore Canyon Trough modified after Schlee and Grow, 1980.

have not been thoroughly studied. The upper Cretaceous and Tertiary marine sequence that forms the major part of the New Jersey coastal plain belongs to a marine cycle that began during Aptian time and transgressed over the Atlantic margin, bringing sea level over the New Jersey area for the first time since the Atlantic began to open.

The sediments that were deposited in the coastal plain of New Jersey consist of fluvial sands, gravels, and varigated clays; coastal deposits of beach, lagoon, marsh, and related deposits; inner shelf sediments consisting of shore face sands with characteristic *Ophiomorpha* trace fossil assemblages and offshore micaceous clay and silty thinly bedded fine sands; mid and outer shelf clay glauconite sands and glauconitic clays, often extensively burrowed; and slope deposits composed of calcareous clays and silts. The formations of these various facies were deposited during major cycles of sea level change and are genetically related to sedimentary units that have been penetrated in the COST B-2 and B-3 wells in the Baltimore Canyon Trough. The relationship of the New Jersey formations to the units penetrated in these wells will be discussed in the section on lithologic units.

Geological History of Coastal Plain and Baltimore Canyon Trough

A general sequence of events based upon subsurface studies (Figs. 2,3) in the New Jersey coastal plain, data from the COST B-2 and B-3 wells, seismic reflection profiles, and seismic refraction studies can be constructed for the Baltimore Canyon Trough and the adjacent New Jersey coastal plain (Grow, 1980; Poag, 1979, 1980; Schlee and Grow, 1980; Sheridan, 1979).

The separation of North America and Africa began during the Triassic with extensive drifting and formation of faulted basins in which continental sediments accumulated. As continental separation began and the initial opening of the Atlantic occurred evaporite environments formed during the Late Triassic and Early Jurassic. Some of the rifted basins continued to receive continental sediments during Early Jurassic time. This early stage of development was accompanied by extensive volcanism consisting of intrusive and extrusive placement of basaltic and dioritic rocks.

As circulation within the developing Atlantic Ocean became less restricted during Jurassic time carbonate environments developed with bank and reef growth. Fluvial sediments were deposited over the Triassic rifted basins landward of the carbonates. During Jurassic to Early Cretaceous time as the Atlantic continued to widen the carbonate bank and reef complex prograded seaward over the oceanic basement (Fig.3). In the coastal plain area extensions of the Baltimore Canyon Trough developed as embayments. These embayments, the Salisbury and Raritan embayments, which are probably fault bounded, received thicker sequences of Jurassic and Lower Cretaceous fluvial sediments. In Late Jurassic and Early Cretaceous time shallow marine incursions began to extend landward of the carbonate complex (Fig. 3).

A major cycle of sea level rise began during Albian time and in the Cenomanian seas spread into the coastal plain area for the first time (Fig. 3). This cycle of sea level rise ended the deposition of carbonate sediments along the Lower Cretaceous shelf edge. The carbonates now lie beneath the present upper continental slope. The rise of sea level which began during Albian time lasted until the Turonian before being interrupted by a moderate fall in sea level. Nevertheless, renewed rise in sea level continued during the latter part of Late Cretaceous time. The Late Cretaceous stratigraphy of the coastal plain was controlled by individual cycles within this major rise of sea level. The deposition of marine sand, silt, and clay sifted with each sea level cycle.

Changes in sea level continued to influence deposition during the Paleocene and Eocene. During the Late Cretaceous and Paleocene sediments accumulated in shelf environments of deposition in the coastal plain and for the most part in the Baltimore Canyon Trough except in its most distal part. During the Early Eocene, however, bathyal environments of deposition extended into the coastal plain (Fig. 3). The Eocene shelf and slope profile appears to have been very gradual with no distinct shelf edge. Shelf deposition was reestablished in the coastal plain during the middle Eocene time and bathyal conditions retreated further out in the Baltimore Canyon Trough. Late Eocene shelf deposition occurred over most of the Baltimore Canyon Trough and may have extended into the coastal plain, although upper Eocene sediments are missing there.

At the end of Eocene time a major lowering of sea level occurred and the entire Baltimore Canyon Trough was subjected to erosion. Sea level rose during Late Oligocene time and the sea transgressed across an eroded and beveled surface into the coastal plain area.

During Miocene time clastics prograded over the Baltimore Canyon Trough and constructed the present shelf and edge profile (Fig. 3).

Sea Level Cycles

Sea level change has had an important influence on the stratigraphic development of the New Jersey coastal plain and the Baltimore Canyon Trough. Perhaps the two most important events are the Albian-Turonian rise in sea level which first established marine processes in the coastal plain and ended carbonate depositions in the Baltimore Canyon Trough, and the Oligocene lowering of sea level which may have exposed the entire Atlantic margin. In post Oligocene time progradation formed the present shelf profile and brought an end to the unique environment of glauconite formation that characterized the Late Cretaceous and Early Tertiary.

Vail and others (1977) have shown in their study of stratigraphic onlap and offlap sequences in seismic reflection profiles that major cycles of sea level change can be recognized and correlated from basin to basin. These changes which they believe to be eustatic in origin are the basis of the well known Vail curve of relative sea level change. Of interest to many geologists is the magnitude of sea level rise or fall. The magnitude of change shown on the Vail curve is derived from the extent of onlap and offlap sequences as viewed in seismic records and not from direct means of paleoenvironmental analysis. As such the Vail curve should be regarded as a first approximation in achieving a universal curve of sea level change in the geologic record.

Figures 4, 5, and 6 show the record of sea level change in the coastal plain and the Baltimore Canyon Trough. The magnitude of sea level rise and fall is estimated on paleontologic criteria, chiefly foraminifera. It can be observed that in many places there is general agreement with the timing of sea level cycles shown on the Vail curve but not necessarily with the magnitude or character of each cycle. Of note (Fig. 6) is the record of the upper Eocene and Oligocene which differs significantly from that of Vail and others in that the major lowering of sea level occurs in the lower Oligocene where they show a major rise in sea level.

Lithologic Units

Jurassic

Nonmarine coarse sandstone and red and green shale of probable Jurassic age lie upon crystalline basement beneath New Jersey. Similar rocks intercalated with marine shale were penetrated in the COST B-2 well where a thick Jurassic section is present. Carbonate sediments are present further to the east in the COST B-3 well and in lower intervals in the Baltimore Canyon Trough.

Potomac Group (Lower Cretaceous)

The Potomac Group consists of three formations of continental origin, the Patuxent, Arundel and Patapsco. These formations are well-developed south of New Jersey but they have not been recognized in New Jersey. However, palynological data indicates that small remnants of sediments of equivalent age are present in southern and central New Jersey. In the subsurface thick section of Lower Cretaceous continental sediments have been encountered. In the COST B-2 well the Lower Cretaceous rocks are mostly nonmarine in origin and contain thin coal seams. Thin shallow marine intervals are present in the lower and uppermost parts of the Lower Cretaceous section in this well. Further east in the COST B-3 well the Lower Cretaceous is a marine sequence of sand, shales, and thin beds of limestone and dolomite. Multichannel reflection profiles along the upper continental slope indicate the presence of a carbonate bank or reef which may represent the Lower Cretaceous shelf edge.

Raritan Formation

The Upper Cretaceous stratigraphic sequence in New Jersey begins with the nonmarine Raritan Formation

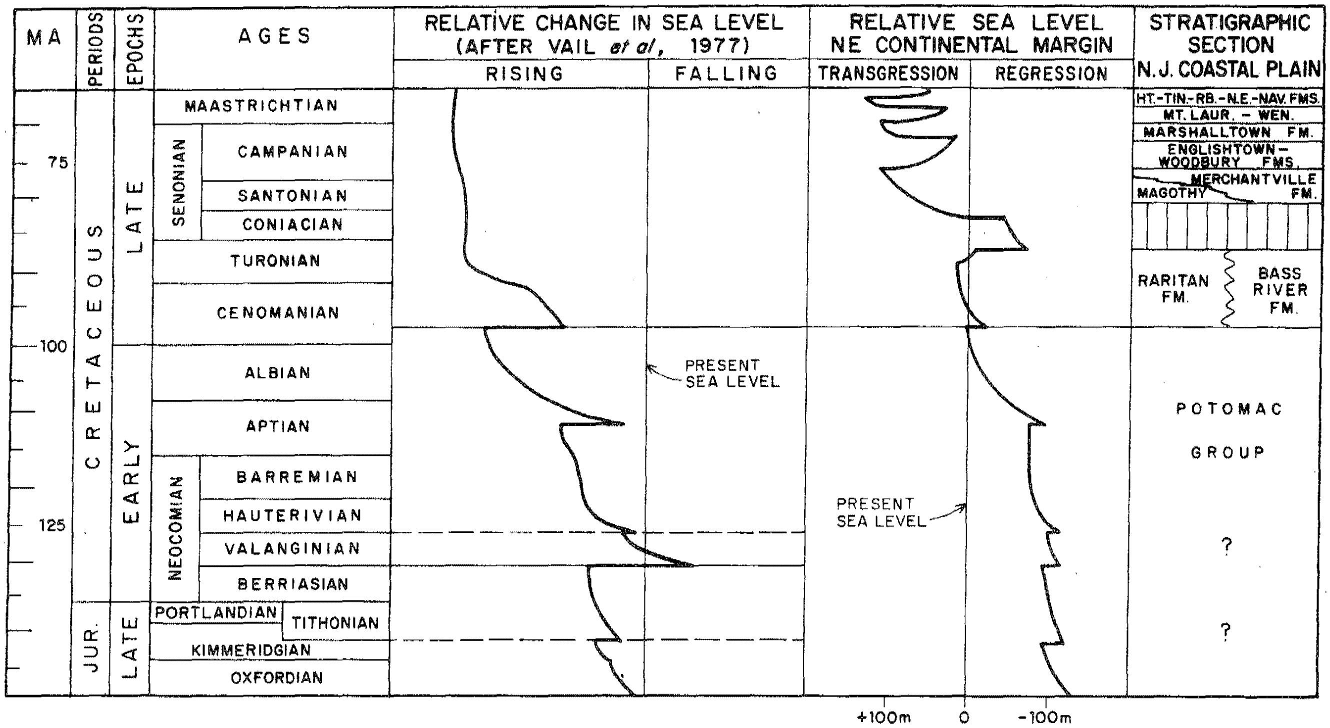


Fig. 4 Stratigraphy and sea-level changes for the Upper Jurassic and Cretaceous of the New Jersey Coastal Plain showing estimated Paleobathymetry. Comparison is made with the curve of Vail *et. al.*, 1977.

which consists of light-colored sands and variegated clays. Several members which vary greatly in thickness and lateral extent have been recognized in the Raritan. One of these units, the Woodbridge Clay, contains marine fossils, thus indicating the first marine deposition in the New Jersey Cretaceous. The coastal sediments of the Woodbridge are limited in extent and are overlain by other continental deposits of the Raritan. The indication of marine deposition in outcrop is more fully expressed in the New Jersey subsurface where the Raritan is replaced by the marine Bass River Formation.

Bass River Formation

This subsurface formation is composed of an olive-gray to olive-black, chloritic, glauconitic, clayey silt which in places contains a considerable amount of shell material. The Bass River reaches a maximum thickness of 400 feet in its downdip extent but pinches out some 15 miles or so from outcroppings of the Raritan. Undoubtedly, the Woodbridge Clay represents coastal deposition marginal to Bass River shelf deposition.

The Bass River is a time-transgressive unit; its age spans the lowermost Cenomanian (Upper Washitan) to lower Turonian (Eagle Fordan). In the farthest downdip wells the formation encompasses this entire interval whereas in updip wells only the Turonian is present. Palynological studies (Doyle, 1969; Wolfe and Pakiser, 1971) show that the Raritan Formation in its type locality ranges in age from late Cenomanian to early Turonian, whereas the upper part of the Patapsco Formation (Potomac Group) is equated with the lower Cenomanian. Thus, the Bass River is not only a marine equivalent of the Raritan but also of the uppermost part of the Potomac Group. The Bass River which is one of the most extensive units in the subsurface of the New Jersey Coastal Plain was deposited during a world-wide transgression that began in Albian time. This transgression which brough marine processes into New Jersey for the first time is clearly observed in the Baltimore Canyon Trough in the shoreward overlapping of the nonmarine Lower Cretaceous sediments by Albian marine sandstone and shales. The transgression ended during Turonian time.

Magothy Formation

The Magothy Formation is separated from the underlying Raritan Formation by an upper Turonian-Coniacian (Lower Austin) disconformity. The disconformity persists in most of the subsurface of New Jersey except in the Salisbury Embayment. The disconformity disappears eastward in the Baltimore Canyon Trough where nonmarine (B-2) and marine (B-3) sediments are present. Palynologic data indicate that the Magothy is Santonian (Late Austin) in age.

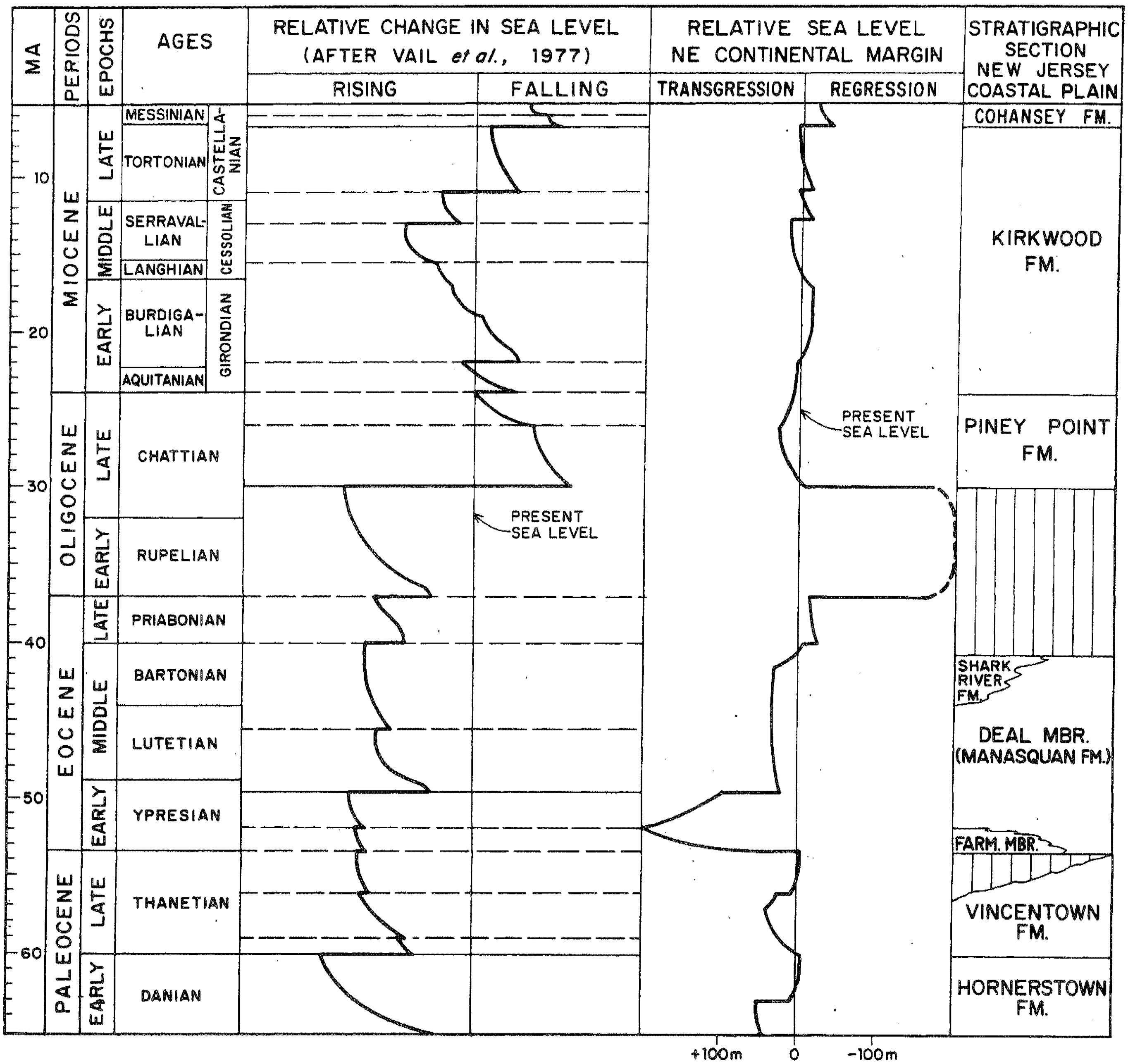


Fig. 5 Stratigraphy and sea-level changes for the Paleocene to Miocene of the New Jersey Coastal Plain showing estimated Paleobathymetry. Comparison is made with the curve of Vail *et al.*, 1977.

The interstratified dark carbonaceous-rich silty clays and light-colored sands and laminated clays of the Magothy were deposited in a coastal environment. In the subsurface the Magothy thins and is partly replaced by the marine Merchantville Formation, thus indicating that the Magothy is a coastal facies associated with a transgressing sea.

Merchantville Formation

The glauconitic, micaceous clays and clayey silts of the Merchantville Formation are the first massive shelf deposited sediments to be exposed in the Upper Cretaceous section of New Jersey. They contain a diverse assemblage of megafossils which are preserved mostly as molds; calcium carbonate has been leached from outcroppings of the Merchantville. The formation can be recognized in outcrop southward into Delaware.

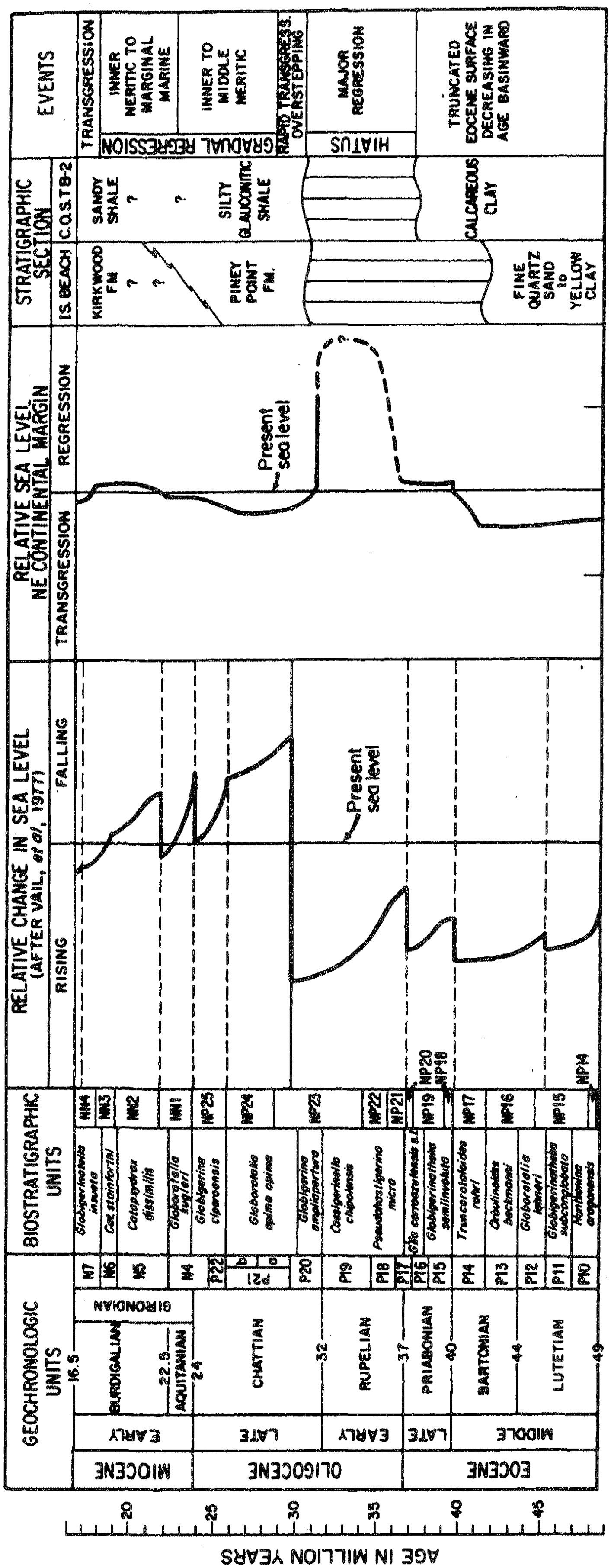


Fig. 6 Stratigraphy and sea-level changes of the Oligocene event showing estimated Paleobathymetry and Biostratigraphic framework. Comparison is made with the curve of Vail *et. al.*, 1977.

In downdip sections it thickens and is partially equivalent to the Magothy Formation. In outcrop the Merchantville contains a lower Campanian (lower Taylor) molluscan fauna. In the subsurface the lower part of the Merchantville is Santonian in age and the upper part lies within the lower Campanian. It thus becomes clear that the Merchantville is transgressive with respect to the Magothy. The Merchantville was deposited during the second major transgression of the Late Cretaceous. Dark gray micaceous silty mudstone and calcareous mudstone penetrated in the COST B-2 and B-3 wells, respectively, were deposited during the Merchantville transgression.

Woodbury Formation

The Merchantville Formation grades upward into a light to dark gray, micaceous, chloritic, silty clay with minor amounts of glauconite, siderite, and lignite. This lithology is typical of the Woodbury Formation. Although it is sometimes difficult to place a lithologic boundary between these two formations, the Woodbury represents sediments depositied under shoaler inner shelf conditions. This is evident in subsurface sections where well-preserved foraminiferal assemblages record this change.

In downdip sections there is a pronounced thickening of the Woodbury as it interfingers and replaces the sands of the overlying Englishtown Formation. In the Salisbury Embayment the Campanian interval occupied by the Woodbury up-structure consists of clays and chalks. To the east in the Baltimore Canyon Trough the Woodbury regressive trend is evident in correlative mudstone and sandstone in the B-2 well.

Englishtown Formation

The Englishtown Formation consists of quartz sands, silty sands, and silts which are thickest on the northeast and gradually thin and disappear along strike on the southeast. It also thins downdip where it is replaced by the Woodbury Formation. Thus, the Englishtown occupies a stratigraphic position landward of the inner shelf Woodbury. The presence in places of cross-stratified sands and the trace fossil *Ophiomorpha* indicate a coastal to shoreface environment. It appears to mark the maximum phase of a regression that began during deposition of the Woodbury.

Marshalltown Formation

In outcrop the Marshalltown is a very thin unit which consists of a burrowed (mottled), clayey, to silty, micaceous, quartz glauconite sand. Although thin, it is remarkably persistant along strike and can be recognized from northern New Jersey into Delaware. The

Marshalltown sediments which were deposited under mid-shelf conditions overlie the Englishtown and signal a renewed transgression of the sea during latest Campanian time. This transgressive cycle is also evident in the calcareous mudstones in the uppermost Campanian in the COST B-2 and B-3 wells.

The formation thickens somewhat in the New Jersey subsurface where it overlies first the Englishtown and then the Woodbury. It loses lithologic identity in the far subsurface in the Salisbury Embayment.

At certain localities shell beds of the oyster *Exogyra ponderosa* contain well-preserved microfossils whereas at other localities only molds of megafossils occur.

Wenonah Formation

The Wenonah Formation consists of a gray, clayey, silty, slightly glauconitic, micaceous, fine quartz sand. It is gradational with the Marshalltown Formation and with the overlying Mt. Laurel Formation. It contains molds of marine fossils and various types of trace fossil burrows. The formation is best developed in outcrop in the central and northern parts of the coastal plain. It thins and disappears in the southern part.

A regressive facies relationship exists between the Wenonah and the Mt. Laurel. The fine-grained Wenonah was deposited under inner shelf conditions adjacent to coarser-grained shoreface deposition of the Mt. Laurel. The thinning and replacement of the Wenonah in outcrop, thus, is related to its replacement by the Mt. Laurel. In the subsurface the formation is replaced by clays, sandy silts and silts.

Mt. Laurel Formation

The Mt. Laurel Formation is more variable in lithology than the Wenonah Formation. Lithology consists of gray, massive, medium-grained sands to thin-bedded light gray to white, fine to medium sands with thin chocolate brown silt and clay layers. Cross-bedding is common in the thin-bedded sequences. The upper 6 feet or so is bioturbated with glauconite infilling of burrows and is a poorly sorted clayey sand containing rounded pebbles and abraded fossil molds. This part may be a lag deposit related to the overlying transgressive Navesink.

The thin-bedded sections contain abundant burrows of the trace fossil *Ophiomorpha* and others. The trace fossils and associated sedimentary features indicate shoreface to transitional offshore deposition for the Mt. Laurel. Shell layers are present in the uppermost portion of the formation in the central part of the outcrop belt. They may be related, however, to deposition of the Navesink mid-shelf facies.

In the subsurface the Mt. Laurel becomes finer-grained and merges into the Wenonah, its offshore counterpart.

Navesink Formation

A return to mid-shelf conditions following deposition of the Mt. Laurel and Wenonah formations resulted in accumulation of the light to dark gray clayey glauconite sands of the transgressive Navesink Formation. The Navesink is a burrow-mottled unit that is rich in skeletal fossil content. The most prominent megafossils are the oysters *Exogyra, Pycnodonte, Ostrea;* the brachiopod *Choristothyris*; and the belemnite *Belemnitella*. In addition to these, molds of various molluscs are common, microfossils (foraminifera, ostracodes, coccoliths, dinoflagellates, epibiont bryozoans) are abundant, and fish and reptilian remains are present.

The Navesink is recognized only in New Jersey; it thins along strike on the south and disappears north of Delaware. In the subsurface the Navesink glauconites blend with similar younger sediments and it becomes difficult to separate the Navesink as a formation. The glauconite content of this stratigraphic interval diminishes in the far downdip.

Redbank Formation

In the northern part of the coastal plain, thick, micaceous, feldspathic quartz sands lie above the Navesink. These sands comprise the Redbank Formation. They are of limited geographic extent, thin rapidly, and disappear north of the central part of the outcrop belt as well as in the shallow subsurface. On the south and downdip the Redbank is replaced by the dark gray-brown, clayey glauconite sands of the New Egypt Formation.

The Redbank is composed of two members, a lower Sandy Hook Member and an upper Shrewsbury Member. The Sandy Hook Member is a dark gray, micaceous, silty, fine to medium, feldspathic quartz sand. In places it contains well-preserved microfossils and small megafossils. The Sandy Hook represents mid to inner shelf deposition related to a regressive phase following the Navesink transgression.

Continued shoaling resulted in deposition of the light gray to white, micaceous, fine to medium feldspathic quartz sands of the Shrewsbury. Large scale cross-bedding and the trace fossil *Ophiomorpha* indicate deposition in an inner shelf environment.

New Egypt Formation

The New Egypt Formation is a clayey glauconite facies that was deposited peripherally to the Redbank sands. It has been considered as a more glauconitic facies of the lower Redbank but paleontological data (Koch and Olsson, 1977) show that it is equivalent to the entire Redbank and to the Tinton Formation as well. The New Egypt is a shelf facies marginal to these formations. It lies above the Navesink Formation and in turn is overlain by the Hornerstown Formation.

Tinton Formation

The Tinton Formation is the only indurated unit in the Upper Cretaceous section of New Jersey. It is very thin and is more limited in extent than the Redbank Formation upon which it lies. It is a brownish-green, argillaceous, medium to coarse, quartz and glauconite sandstone interbedded with layers and lenses of gray claystone. Molds of molluscs, crab claws, and the trace fossil *Ophiomorpha* are common in places.

The formation is interpreted as an inner shelf facies related to the regressive Redbank facies. In fact, it was once regarded as an upper member of the Redbank.

Maestrichtian-Paleocene Hiatus

The Maestrichtian-Paleocene section in the New Jersey coastal plain disappears eastward in the Baltimore Canyon Trough. Paleocene rocks are missing in the B-2 and B-3 wells. Only lower Maestrichtian rocks are present in the B-3 well. Thus curiously, a significant unconformity which appears unrelated to the coastal plain occurs in the Baltimore Canyon Trough.

Hornerstown Formation

The Hornerstown Formation is unusual in several ways, that is, in regards to its lithology and to its age. It is almost a pure glauconite sand, containing little fine-grained matrix. This gives it a distinctive deep-green color. It is a very persistent unit that can be traced along the entire outcrop belt in New Jersey and southward into Maryland. This massive and extensively burrowed facies originated in an inner to mid shelf environment. In the subsurface increasing amounts of clay matrix are present and it gradually loses its lithologic characteristics in the far downdip.

The Hornerstown has been regarded as the basal formation in the Tertiary of New Jersey. However, recent paleontological data (Baird, 1964; Richards, *et al.*, 1973; Richards and Gallagher, 1974; Koch and Olsson, 1974, 1975; Koch, 1975) indicate that the basal beds are Cretaceous in age (*ie*. the top of the Cretaceous System in New Jersey lies within the Hornerstown). A varied assortment of fossil remains of invertebrate megafossils, microfossils (foraminifera, ostracods, coccoliths, dinoflagellates), and vertebrates (fish, reptiles, birds) are found in the formation. A five foot shell bed consisting of the brachiopod *Oleneothyris* and the oyster *Pycnodonte* occurs at the top of the formation. The age of the Hornerstown thus ranges from latest Maestrichtian to mid-Paleocene.

The Hornerstown also plays prominently in a stratigraphic argument at the Cretaceous-Tertiary boundary. The successive stratigraphic overlap along strike from north to south of the Hornerstown over the Tinton, Redbank and New Egypt (basal Redbank and on the far south Navesink of others) has been interpreted as an angular unconformity (Clark, 1897; Cooke and Stephenson, 1928; Minard, *et al.*, 1969). However, paleontological criteria (Koch and Olsson, 1977) demonstrates a facies relationship below the Hornerstown. The Hornerstown is transgressive over the regressively related formations below.

Vincentown Formation

The Vincentown Formation contains two prominent facies, a massive quartz sand facies and a quartz calcarenite facies rich in bryozoans and foraminifera. It lies upon the Hornerstown Formation along the entire outcrop belt. Although it is up to 100 feet thick in outcrop, it thins rapidly in the shallow subsurface where it is replaced by a silt facies. Thus it is regressive over the Hornerstown.

The paleontologic content of the Vincentown places it as an upper Paleocene inner to mid-shelf facies.

Manasquan Formation

Eocene deposits in New Jersey begin with the Manasquan Formation which is separated from the Vincentown Formation below by a slight disconformity. The disconformity seems to be limited to the outcrop area and the shallow subsurface; no evidence of its presence has been found in the deeper subsurface where silts and clays have replaced the Vincentown.

The Manasquan has been divided into two members by Enright (1969), a lower Farmingdale Member and an upper Deal Member. The Farmingdale Member is a mottled, slightly clayey, medium to coarse, quartzose glauconite sand. It is characteristic and persistent along the outcrop strike but loses its distinctive lithology in the subsurface and disappears some 20 miles downdip where it is replaced by the Deal Member. The Farmingdale is a mid shelf facies transgressive over the Vincentown.

The Deal Member is a very distinctive unit, especially in the subsurface where it thickens considerably as it replaces the Farmingdale and the Shark River above. It is a slightly glauconitic, clayey, fine-grained quartz sand to clayey, sandy silt. It becomes more clayey as it extends into the subsurface where it ranges from the lower to mid Eocene.

The Deal is very rich in microfossils; in places it is composed largely of microfossil remains. In addition to foraminifera, coccoliths, and dinoflagellates, it also contains abundant siliceous microfossils (radiolarians, diatoms, sponge spicules), the first known occurence of these fossils in New Jersey. This assemblage of fossils indicates shelf and upper slope conditions for the deposition of this unit which is transgressive over the Farmingdale.

Eastward in the Baltimore Canyon Trough the Deal interval becomes more clayey and calcareous and contains very fossiliferous limestones. In places almost pure calcareous ooze is present. These sediments accumulated under bathyal environments of deposition.

The Shark River Formation contains two members, the Squankum Member and the Toms River Member. The Squankum Member is limited to the northern part of the outcrop belt. The argillaceous, glauconite sands and quartzose glauconitic mudstones of the Squankum are rapidly replaced in the subsurface by the clays and silts of the Deal. Sharks teeth and various molluscan molds are present in the Squankum.

The Toms River Member is recognized only in the subsurface where it reaches a thickness of approximately 80 feet. It, however, decreases rapidly in thickness downdip and is replaced by the Deal. The micaceous slightly clayey and glauconitic, fine to medium grained quartz sand of the Toms River was deposited under inner shelf conditions.

UPPER EOCENE-LOWER OLIGOCENE UNCONFORMITY

An extensive beveled erosional surface on Eocene rocks can be traced from the subsurface of New Jersey into the Baltimore Canyon Trough (Olsson and Miller, 1979). This surface which transgresses lower to middle Eocene rocks in New Jersey to upper Eocene rocks in the COST B-2 and B-3 wells is overlain by upper Oligocene rocks which in New Jersey are called the Piney Point Formation. The unconformity which can be traced southward in the coastal plain (Olsson, Miller and Ungrady, 1980) resulted from a major lowstand of sea level during early Oligocene time.

Piney Point Formation

The Piney Point Formation, a subsurface unit of Maryland and Delaware, was first identified in southern New Jersey by Richards (1967). The formation occurs throughout the subsurface of New Jersey where it ranges from 0 to 400+ feet in thickness (Olsson and Miller, 1979; Olsson, Miller, and Ungrady, 1980). The Piney Point consists of olive-gray to brownish-yellow glauconitic silt and medium to coarse quartz and glauconite sand, which in places becomes very coarse and shelly. Although some of the glauconite is unweathered much of it is well rounded and polished. In addition, weathered Eocene lithoclasts and reworked, recrystallized Eocene foraminifera are present, especially in the lower sections.

Foraminiferal studies (Olsson and Miller, 1979; Olsson, Miller and Ungrady, 1980) show that the Piney Point is late Oligocene in age and that it was deposited as a transgressive deposit upon an eroded and beveled Eocene surface. Seaward in the Baltimore Canyon Trough in the B-2 and B-3 wells upper Oligocene olive-gray silt, clay, and glauconite rest upon upper Eocene calcareous claystones.

Kirkwood Formation

Gray-brown sand, silt, and clay overlie the Piney Point in the subsurface whereas updip along the outcrop belt they lie upon Cretaceous to Eocene formations. These sediments which belong to the Kirkwood formation consist of a complex of coastal and inner shelf facies. The basal portion of the Kirkwood is regressive over the Piney Point and the updip portions of the formation appear to interfinger with the Piney Point (Olsson, Miller, and Ungrady, 1980).

In the subsurface of New Jersey three marine intervals are recognizable in the Kirkwood, an uppermost Oligocene?-lower Miocene interval, a middle Miocene interval and an upper interval of uncertain age.

The Kirkwood was deposited during the progradation and buildup of the present continental shelf and edge which began in the Miocene (Grow, 1980; Schlee and Grow, 1980). Seismic profiles of the Baltimore Canyon Trough clearly show prograding sand beds which define the present shelf and slope.

ROAD LOG

Log of trip begins at Turnpike entrance off of Route 18. Stay on 18.

Mileage

0.0 Head East on Route 18

1.0 Turn right at jughandle to South River. Cross Route 18 and immediately bear right onto Turnpike St.

1.9 At traffic light turn left on West Prospect St.

2.5 Bear left at light. Follow Reid St.

2.8 South River, Junction with Highway 535. Turn left and follow 535 over bridge. Also known as Washington Rd.

5.5 Washington Rd. crosses R.R. track in Sayreville.

5.9 Debark from buses and cross road to Sayreville Pit.

STOP 1 Raritan Formation overlain by the Pensauken Formation (Pleistocene?). The sands and clays of the Raritan represent continental and coastal marine sediments deposited adjacent to a transgressing sea. The marine facies of the transgression is encountered in coastal plain wells. The subsurface marine unit is called the Bass River Formation.

Pensauken Formation 5-10 feet
dark yellowish-brown sand and gravel. Large scale steeply dipping cross-beds represent slip faces of fluvial bars. Approximately 50 yds. to the west a fining upward sequence is present. Gravel and lithic fragments are present at contact with Raritan Formation.

Raritan Formation (Woodbridge Member) 65 feet
interbedded sand and clay with numerous siderite and iron oxide cemented sand layers. Two directions of planar cross-bedding can be observed. The cross-bedding probably represents sand waves of a meandering stream or of intertidal currents. Marine fossils are present in some of the sand layers. 30-40 feet.

sand and clay containing abundant carbonized wood. 5 feet.

dark-gray clay and silt, sharp contact with overlying unit. Fine bedding (0.5 mm) composed of clay-silt laminations. 20 feet.

Correlation: Plant fossils and palynological remains in the Raritan indicate a Cenomanian to Turonian (Washita to Eagle Ford) age. Marine fossils (planktonic foraminifera) of a similar age occur in the Bass River marine facies in N.J. coastal plain wells.

6.1 Walk along Washington Rd. to Sayreville Jr. High where buses are parked. Trip continues along Washington Rd.

6.4 Turn right on Ernston Rd.

7.5 Cross Route 9. Continue straight on Ernston Rd.

8.1 Turn sharp right onto dirt road leading into excavation area. Follow road to area bearing left at first fork.

8.8 Park and walk to ravine. Exposure is off Garden State Parkway.

STOP 2 Magothy Formation overlain by Pleistocene? sediments. The Magothy represents estuarine sediments deposited in front of the advancing Merchantville sea. This exposure represents an intertidal sequence of tidal delta sands and lagoonal clays.

Pleistocene? 1 ½ feet
Sand and gravel

Magothy Formation 45 feet
dark gray sands and clays with carbonaceous rich layers, uniformly cross-bedded sands, intermixed flaser bedding and layers of rip-up clasts. 29 feet.

dark gray laminated clay which laterally on the east side of exposure grades into interbedded sands and clays, carbonaceous rich layers. 8 feet.

dark gray alternating sands and clays. 8 feet.

Correlation: Palynological studies indicated that the Magothy is Santonian in age. This suggests that the Coniacian is absent due to disconformity. This is confirmed in the subsurface on the absence of marine assemblages of Coniacian age.

9.5 Return to Ernston Rd. Continue north.

9.8 Pass under Garden State Parkway

10.4 Turn right on Route 9

13.4 Turn right on Cliffwood Avenue.

14.1 Cross R.R. tracks, Midland Glass Co. on left

14.5 Turn right on secondary road just past old church on left and just before Garden State Parkway (GSP) overpass

14.7 Turn left at beige-colored house

14.75 Park and walk across road to pit

STOP 3 Woodbury, Merchantville, and Magothy Formations. The Merchantville Formation represents the second major transgression in the Upper Cretaceous sequence of New Jersey. Subsequent transgressions and regressions of the Cretaceous appear to have fluctuated about the Merchantville strandline.

Woodbury Formation 5-10 feet
dark gray micaceous clayey silt

Merchantville Formation 12 feet
dark gray to greenish black, uniformly bedded sandy silt and clay to sandy clay. Glauconite, mica, and siderite are abundant throughout. Many molds of molluscs are present.

Magothy Formation 8 feet
dark gray alternating fine sand, silt, and silty clay. Rare *Ophiomorpha* burrows.

Correlation: Ammonite species (*Scaphites hippocrepis* and others) found in the Merchantville in outcrop date this formation as early Campanian (Taylor) in age. In the subsurface marine assemblages (planktonic foraminifera) of Santonian (Austin) to early Campanian age are present in the Merchantville thus demonstrating its partial equivalence with the Magothy.

14.75 Turn around and retrace route to Cliffwood Avenue

15.0 Turn right and cross over GSP

15.3 Turn left at traffic light onto Matawan Rd. Exxon station on far right corner

15.6 Turn right onto Ravine Drive

16.7 Pass Matawan Lake on the right

17.0 Matawan. Turn right onto Main St.

17.5 Turn left (South) onto Route 34.

19.4 Turn left off of highway and park by furniture store. Walk to excavations to the rear.

STOP 4 The base of the section is exposed in the lower excavation and the upper part is exposed in the higher excavation behind the gymnasium

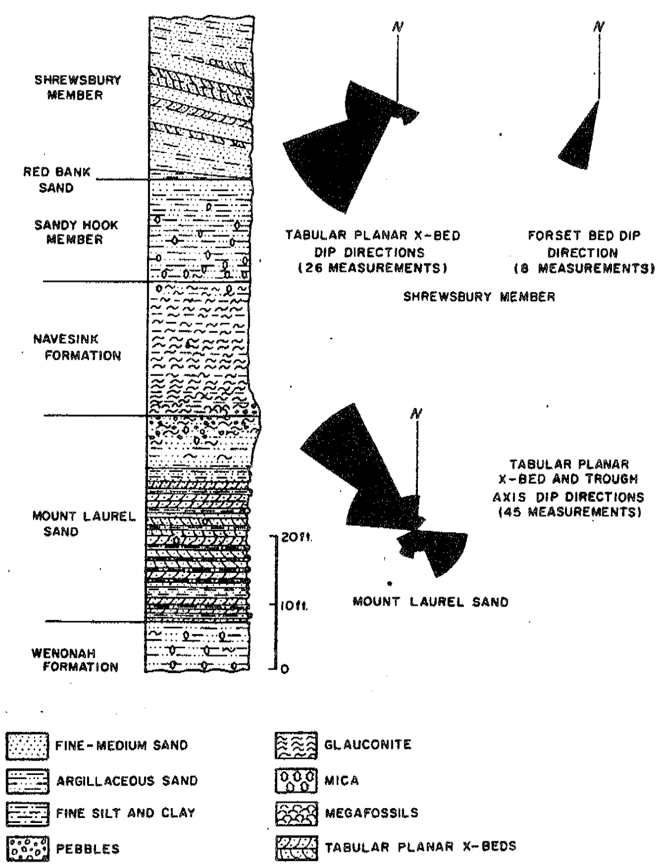


Fig. 7 Stratigraphic section for stops 4 and 5.

Wenonah Formation overlain by Mt. Laurel, Navesink, and Redbank formations. The sedimentary units at this stop and the next were deposited during a regressive-transgressive-regressive cycle. Bedding characteristics and trace fossil morphology position these units in a marine profile of the transgressive-regressive cycle. See fig. for a composite section.

Redbank Formation (Sandy Hook Member) 15 feet
dark gray, very micaceous; argillaceous, feldspathic, fine quartz sand with disrupted sandy laminae and occasional small-scale cross-laminae. Thick-bedded with mottled texture. Contains sand-filled burrow tubes and the trace fossil *Zoophycus*.

The above features suggest that the Sandy Hook was deposited in an inner shelf environment not far from the shoreface.

Navesink Formation 20 feet
dark gray clayey, silty, glauconite sand. Burrowed mottled. Contact with the over-lying Sandy Hook is gradational. The basal 2 feet of the Navesink contains abundant molds of megafossils and rounded pebbles. Megafossils include large bivalves, gastropods, and phragmacones of belemnites.

The Navesink represents the typical glauconitic shelf facies of the Cretaceous of New Jersey. Paleobathymetric indicators (various fossil groups and sediment characteristics) suggest deposition under mid-shelf conditions.

Mt. Laurel Formation 27-33 feet
Thin to medium bedded light gray to white fine to medium sand with thin chocolate brown silt and clay layers. The sand is well-sorted, angular, and slightly glauconitic with dark micaceous laminae. Tabular planar cross-bedding is common in the sand beds. The beds range in thickness from 2-3 inches at the base of the section to 4-6 inches at the top. Maximum thickness is 15 inches. Common broad shallow trough cross-bedding suggests shoreward migration of lunate megaripples. The paleocurrent direction is bimodal, being northwest and southeast. The predominate direction is to the northwest (onshore).

The upper 6 feet is bioturbated and consists of a poorly sorted clayey sand and containing rounded pebbles, abraded fossil molds, and glauconite. Glauconite infills burrows in the upper 3 feet.

Vertical cylindrical burrows of the trace fossil *Ophiomorpha* and cylindrical to rod-shaped burrows of the trace fossil *Asterosoma* are present in the lower 20 feet of the section. From about 15-20 feet above the base large robust vertical cylindrical and ellipsoidal horizontal burrows of *Ophiomorpha* predominate. *Thalassinoides* also occurs within this interval.

The sedimentary characterisitics and the trace fossil associations indicate that the lower 10 feet of the Mt. Laurel Sand was deposited in a transitional zone from offshore (innermost shelf) to shoreface (just below the surf zone). The interval from 10-20 feet above the base represents lower shoreface deposition. The uppermost 6 feet of the Mt. Laurel may be a lag deposit related to deposition of the overlying transgressive Navesink.

Wenonah Formation 8 feet
gray clayey, slightly glauconitic, micaceous, fine quartz sand. Burrowed mottled with indistinguishable bedding. Occasional large clay-filled subvertical burrows *(Asterosoma)* and *Zoophycus*

The Wenonah represents an inner shelf facies related to a minor regression prior to the Navesink transgression.

19.4 Proceed South on Route 34

19.7 Turn left off highway and park by Ern Construction Co. Walk to excavations to the rear.

STOP 5 The basal part of the section is exposed behind the Ern Construction Co. and the upper part is exposed above and just beyond in a long excavation.

Redbank Formation (Sandy Hook and Shrewsbury Members). Continuation of the section from Stop 4. It represents regression shoaling after the Navesink transgression.

Redbank Formation (Shrewsbury Member) 25+ feet
Light gray to white, micaceous, feldspathic, mostly well-sorted fine to medium quartz sand. The lower 10 feet is slightly silty. Occasional thin clay horizons define inclined bedding which represents forset beds of a prograding sand body. Planar cross-stratification occurs within the forset beds. Both dip south-westward.

The trace fossil assemblage includes vertical cylindrical and horizontal ellipsoidal *Ophiomorpha,* rod-shaped *Asterosoma,* and *Chondrites.*

Redbank Formation (Sandy Hook Member) 15 feet
Dark gray, very micaceous, argillaceous, feldspathic, fine quartz sand. Mottled texture with sand-filled burrow tubes and the trace fossil *Zoophycus.* The large light-dark mottled shapes are caused by weathering related permeability

19.7 Continue South on Route 34

22.5 Turn left at traffic light (Pleasant Valley Inn on near right corner) onto Route 520 towards Holmdel (520 is W. Main St.)

23.7 Turn left on Middletown Rd. Village School-Holmdel will be visible on the left

24.8 Bear left. Stay on Middletown Rd.

25.9 Traffic light. Continue across intersection

26.5 Cross over Garden State Parkway

26.8 Turn right onto Monmouth Co. Route 12 (Dwight Rd.)

28.5 Turn left onto Middletown-Lincroft Rd. Thompson School on left

28.9 Turn right into parking lot just beyond small bridge. Poricy Park fossil beds area. Walk along path to stream bank.

STOP 6 Navesink Formation overlain by Redbank Formation (Sandy Hook Member). In contrast to the Navesink at Stop 4, at this locality the formation is richly fossiliferous with skeletal material.

Redbank Formation (Sandy Hook Member) 25 feet
Dark gray, micaceous, feldspathic, fine to medium quartz sand. Glauconitic in the basal part which contains microfossils and small megafossils.

Navesink Formation 15 feet
Greenish-black, clayey glauconite sand. Several shell layers are present. The oysters *Exogyra, Pycnodonte,* and *Ostrea;* the brachiopod *Choristothyris;* and the belemnite *Belemnitella* are well-preserved and common. Molds of various molluscs are common and an extensive well-preserved epibiont bryozoan fauna is present. Microfossils include foraminifera, ostracodes, coccoliths, and dinoflagellates.

28.9 Turn around and retrace route. Stay on Middletown-Lincroft Rd.

30.0 Pass under GSP

31.9 Traffic light at major intersection. Continue straight across on Swimming River Rd.

32.8 Swimming River Dam on the right

33.1 Cross over R.R. tracks

33.8 Junction. Continue straight ahead on Route 537

34.2 Tinton Falls. Turn left and immediately park by restaurant. Walk behind restaurant.

Optional Stop

Type locality of the Tinton Formation, the only indurated unit within the Upper Cretaceous section. The formation is very limited in its geographic extent, disappearing within a short distance along strike to the southwest and in a downdip direction.

Tinton formation 22 feet
Brownish green, argillaceous, quartz and glauconite sandstone interbedded with layers and lenses of gray claystone. Molds of megafossils of gastropods and pelecypods are common. Rare specimens of the ammonite *Sphenodiscus* occur. A well-developed dinoflagellate flora is also present.

The Tinton probably represents an inner shelf facies related to the Redbank regressive facies. It is latest Maestrichtian in age.

34.2 Return to Route 537. Turn left and South

34.7 Turn right onto Wayside Rd.

37.1 Turn right onto Route 547 (Shafto Rd.)

41.6 Junction of N.J. Route 33 and Route 547

45.3 Farmingdale. Turn left on Routes 547 and 524

47.2 Turn right onto Squankum-Yellowbrook Rd.

48.5 Stop by dirt road on left. Walk along road to riverbank on the right

STOP 7 Manasquan and Shark River Formations overlain by Piney Point (?) and Kirkwood Formations. A major disconformity is present here wherein the middle and upper Eocene and the lower Oligocene is missing. More of the Eocene and the Oligocene is encountered in the subsurface, however. Marine deposition that began in the late Cretaceous continued in the early Tertiary. It ended during late Eocene time with a large scale regression. The overlying transgressive Piney Point was deposited under inner shelf conditions on an eroded Eocene surface. The basal Kirkwood is probably a shoreward facies of the Piney Point.

Kirkwood Formation 6-7 feet
Chocolate brown clay 5-6 feet

Piney Point Formation ?
Brown, medium to coarse quartz sand 1 foot

Shark River Formation (Squankum Member) 6 feet
Cream to gray brown, argillaceous, glauconite sand. Upper 1-3 feet indurated. Numerous molds of Molluscan megafossils, plus sharks teeth.

Return: Retrace route to Farmingdale. Turn left onto 524. Take 524 to Route 9, then to Route 18, and Route 18 to turnpike.

REFERENCES CITED

Baird, D., 1964, A Fossil Sea-Turtle from New Jersey, New Jersey State Mus. Invest., No. 1:26 p.

Clark, W.B., 1897, Report on the Upper Cretaceous Formations of New Jersey. Ann. Report State Geologist, 1897:161-120.

Cooke, C.W. and Stephenson, L.W., 1928, The Eocene Age of the supposed late Upper Cretaceous greensand marls of New Jersey. Jour. of Geology, 36:139-148.

Doyle, J.A., 1969a, Cretaceous angiosperm pollen of the Atlantic Coastal Plain and its evolutionary significance. Arnold Arboretum Jour., v. 50, no. 1, p. 1-35.

____________, 1969b, Angiosperm pollen evolution and biostratigraphy of the basal Cretaceous formations of Maryland, Delaware and New Jersey (abs.). Geol. Soc. America, Abs. with Programs, (v. 1). pt. 7, p. 51

Enright, R., 1969, The stratigraphy and clay mineralogy of Eocene sediments of the northern New Jersey Coastal Plain. *in* S. Subitzky ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions, p. 14-20.

Grow, J.A., 1980, Deep structure and evolution of the Baltimore Canyon Trough in the vicinity of the COST No. B-3 well. *in* Geological Studies of the COST No. B-3 well, United States mid-Atlantic continental slope area (P.E. Scholle, ed.), p. 117-124.

Koch, R.C. and Olsson, R.K., 1974, Microfossil biostratigraphy of the uppermost Cretaceous beds of New Jersey. Abstracts, northeast sectional mtgs., Geol. Soc. Amer., p. 45-46.

____________, 1977, Dinoflagellate and planktonic foraminiferal biostratigraphy of the uppermost Cretaceous of New Jerssey. Jour. Paleontology, v. 51, p. 480-491.

Minard, J.P., Owens, J.P., Sohl, N.F., Gill, H.E., and Mello, J.P., 1969, Cretaceous Tertiary boundary in New Jersey. Delaware and Eastern Maryland. U.S. Geol. Surv. Bull. 1274-H:33p.

Olsson, R.K., 1978, Summary of lithostratigraphy and biostratigraphy of Atlantic Coastal plain (northern part). *in* Sheridan, R.E., et al., 1978, Initial Reports of the Deep Sea Drilling Project, v. 44, Washington (U.S. Government Printing Office), p. 941-947.

____________, and Miller, K.G., 1979, Oligocene transgressive sediments of New Jersey continental margin. American Association of Petroleum Geologists Bulletin, v. 63, p. 505.

____________, Miller, K.G., and Ungrady, T.E., 1980, Late Oligocene Point transgression of Atlantic coastal plain. Northeastern sectional meetings, Geological Soc. Amer., v. 12, p. 76.

Poag, C.W., 1979, Stratigraphy and depositional environments of Baltimore Canyon Trough. Amer. Assoc. Petroleum Geologists Bull., v. 63, p. 1452-1466.

____________, 1980, Foraminiferal stratigraphy, paleoenvironments, and depositional cycles in the outer Baltimore Canyon Trough. *in* Geological studies of the COST No. B-3 well, United States mid-Atlantic continental slope area (P.E. Scholle, ed.), p. 44-66.

Richards, H.G., 1967, Stratigraphy of Atlantic Coastal Plain between Long Island and Georgia: review, American Association of Petroleum Geologists Bulletin, v. 51, p. 2400-2429.

____________, White, R.S., Jr., Madden, K., 1973, Upper Cretaceous Geology and Palentology at Sewell, New Jersey. (abstr.) Geol. Soc. Amer., Northeastern Section Mtg., Allentown, Pa.

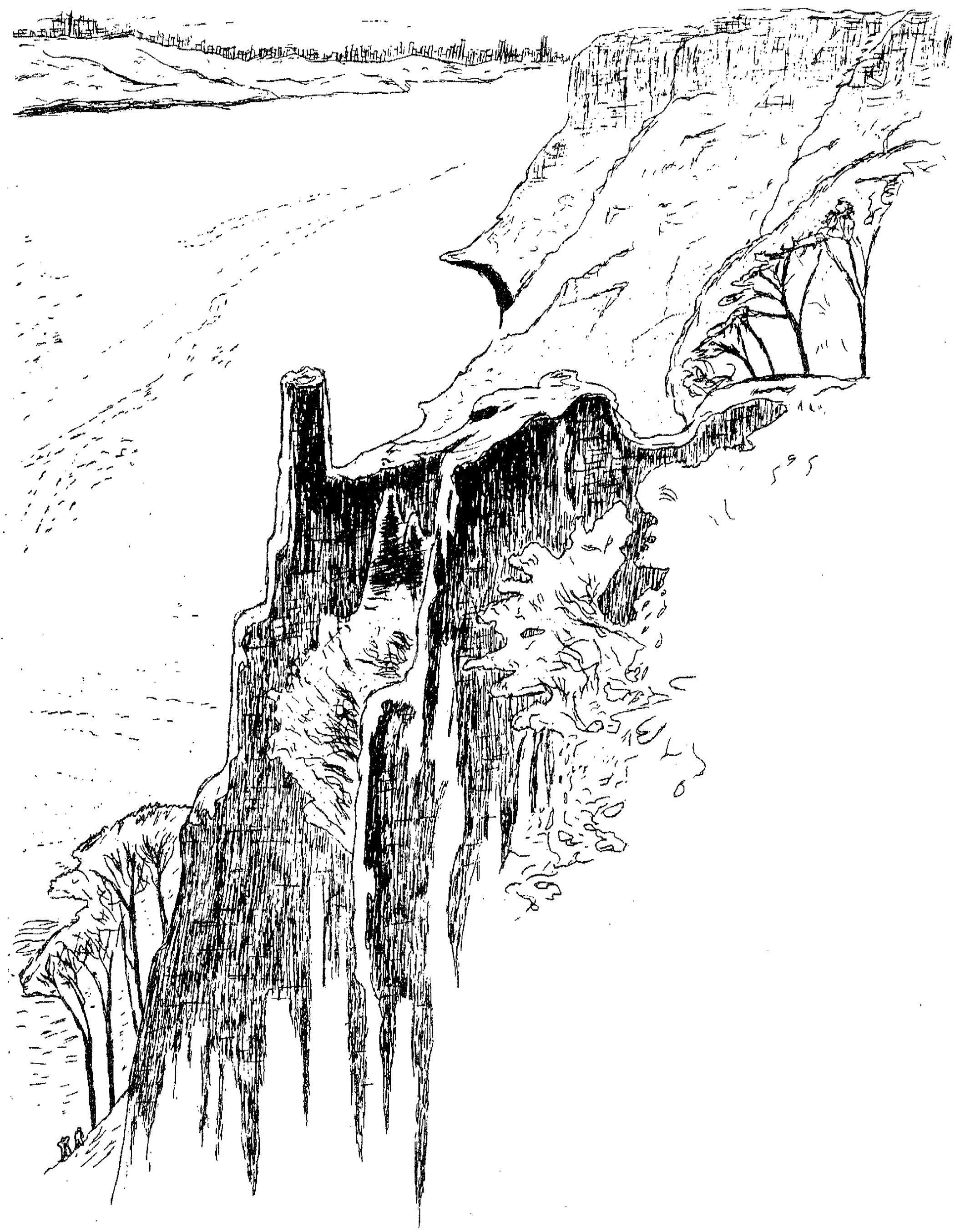
____________, and Gallagher, W., 1974, The problem of the Cretaceous- Tertiary boundary in New Jersey. Notulae Naturae, no. 449:1-6.

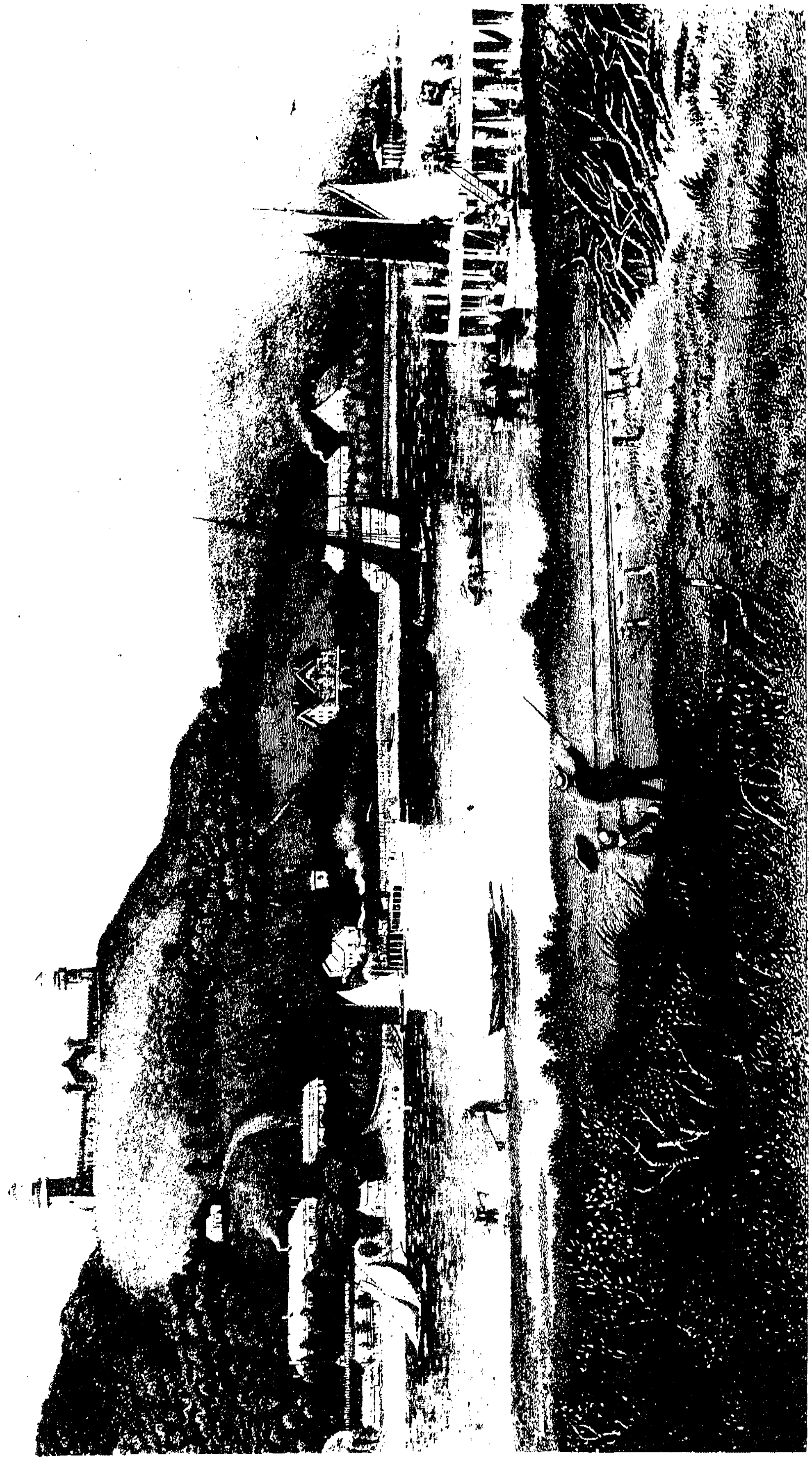
Schlee, J.S. and Grow, J.A., 1980, Seismic stratigraphy in the vicinity of the COST No. B-3 well. *in* Geological studies of the COST No. B-3 well, United States mid-Atlantic continental slope area (P.E. Scholle, ed.), p. 111-116.

Sheridan, R.E., Grow, J.A., Behrendt, J.C., and Bayer, K.C., 1979, Seismic refraction study of the continental edge off the eastern United States. Tectonophysics, v. 59, p. 1-26.

Vail, P.R., R.M. Mitchum, Jr., and S. Thompson, III, 1977, Seismic stratigraphy and global changes of sea level, Part 4: Global cycles of relative changes of sea level: *in* Seismic stratigraphy-applications to hydrocarbon exploration (C.E. Payton, ed.) American Association of Petroleum Geologists Memoir 26, p. 83-97.

Wolfe, J.A., and Pakiser, H.M., 1971, Stratigraphic interpretations of some Cretaceous microfossils floras of the Middle Atlantic States. U.S. Geol. Survey Prof. Paper 750-B, p. B35-47.





THE HIGHLANDS OF THE NEVERSINK
by W. Wellstood
From *Picturesque America*, Vol I, 1872.