the Coastal Plain for the first time about 5 million years later. From that time (95 mya) to the Pleistocene Epoch (beginning about 2 mya), changes in sea level have had a major impact on deposition in the Coastal Plain. At Allaire State Park, the effects of sea level changes on Coastal Plain sediments during the past 55 million years are readily observable (fig. 2).

Geology and Sea Level at Allaire State Park

A geologic map of the coastal plain sediments exposed at Allaire State Park is shown in figure 3. This map shows the distribution of sediments at the earth's surface, and is compiled from field data collected by the New Jersey Geological Survey. In the Coastal Plain, geologic deposits are commonly exposed in river valleys, and an excellent example of this is found along the Manasquan River at Allaire State Park. However, because these formations are typically covered by surficial deposits of soil, alluvium (river sediment) and colluvium (hillslope sediment; fig. 4), drilling is generally required to map them. At Allaire State Park, the New Jersey Geological Survey drilled a continuous core hole in 1988 to a depth of 413 feet to collect subsurface geologic information, which is important to understand the distribution and thickness of coastal plain aquifers and their confining units.

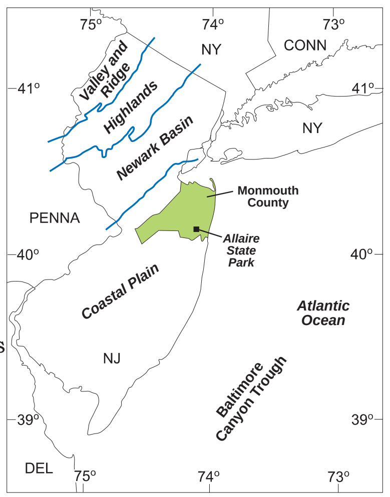


Figure 1. Geologic setting of Allaire State Park.

The Manasquan, the oldest formation shown, crops out along the Manasquan River Valley, Marsh Bog Brook, and Mingamahone Brook in the northwest section of the park (fig. 3). It consists of a lower, clayey, quartz-glauconite sand, and an upper, fine quartz sand or silt. Glauconite is a green to greenish-black iron potassium silicate mineral which was formerly mined for use as a fertilizer because of its potassium and phosphate content. The outcrop of this formation may contain poorly preserved macrofauna (fossil animals large enough to be seen with the naked eye) such as mollusk shells. At the Allaire State Park core hole, however, the Manasquan contains microfauna (fossil animals too small to be seen with the naked eye). Especially useful are foraminifera (one-celled protozoa with a calcite shell), which are valuable in determining the formation's age and in estimating ancient seawater depths. The Manasquan Formation is Eocene in age , 55 - 50 million years old. Seawater in southeastern New Jersey reached a maximum depth of about 600 feet in the early Eocene, which was also a time of peak warmth during the Cenozoic Era.

The Manasquan is overlain by the Shark River Formation, and an unconformity separates the two. An unconformity is a surface that represents a time break in the geologic record. It shows that erosion had taken place or that new material was not deposited. About 5 million years of time is represented by the irregular surface separating the Manasquan and Shark River Formations. This time gap, known as a hiatus, was the result of a significant lowering of global sea level.

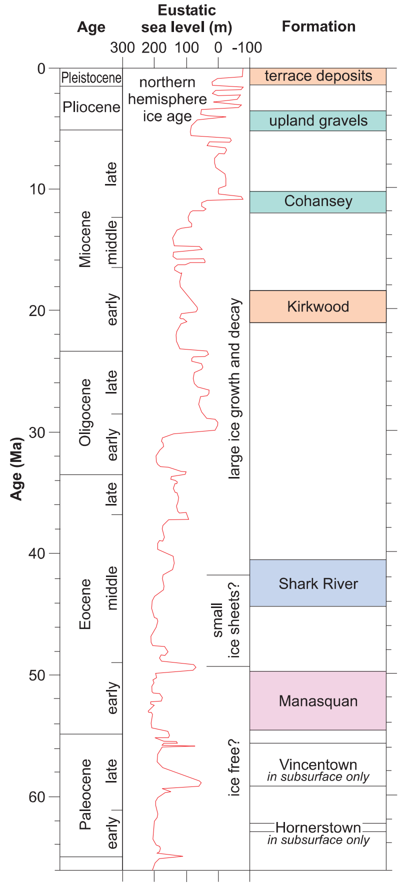


Figure 2. Sea-level history and geologic formations at Allaire State Park. Sea-level history after Haq and others, 1987.

This exposed previously deposited coastal plain sediments allowing erosion to take place.

The Shark River Formation also crops out along the Manasquan River (fig. 3). The base of the formation is a medium-to coarse-grained glauconite sand, locally cemented, and somewhat clayey and silty. Fossil mollusk impressions (mainly of *Venicardia perantiqua*) can be found in the lower cemented layer near the railroad tracks along the Manasquan River (site 1 in fig. 3; see directions to Geologic Site 1).

At the Allaire State Park core hole, the Shark River Formation is about 70 feet thick and consists of two layers. In each, glauconite sand occurs at the base and clay or silt at the top. These two layers are separated by a hiatus of about 3 million years, from 44 to 41 mya (Browning and others, 1996). Although somewhat similar in appearance, these two layers were deposited at different depths. The lower layer, which is dated at 44.5 - 43.4 million years (m.y.), was deposited at a water depth of 500 feet. The upper layer, dated at 41.2 - 40.5 m.y., was deposited at a depth of 164 - 246 feet.

About 19 million years passed between the end of deposition of the Shark River Formation and initial deposition of the Kirkwood Formation in early Miocene time, 21 mya (Sugarman and others, 1993). During this 19-million year hiatus, sea level around the world rose and fell about 8 times (Haq and others, 1987). This caused a major unconformity which can be observed along the Manasquan River directly downstream from the railroad bridge (fig. 3 and Geologic Site 1) at the park. This unconformity is readily identified by the difference in the color below and above it. Below the unconformity, the Shark River Formation exhibits shades of green and gray. Above it, the Kirkwood Formation is predominantly dark brown. The unconformity is marked by a 2- to 3-foot thick bed of coarse sand and gravel.

The Kirkwood Formation was deposited in shallower water than the Shark River Formation. At Allaire State Park, the Shark River was deposited at depths of 150-500 feet, whereas the Kirkwood was deposited at depths of less than 100 feet not far from the shoreline, and in marshes, bays, and channels (Isphording, 1970).

At Allaire State Park, the lower beds of the Kirkwood Formation consist of a dark gray or brown, woody, massive-to thin-bedded clay-silt. In sand and gravel pits throughout the park, the upper part of the Kirkwood consists of sands that are white, yellow, or gray; massive or cross-bedded, micaceous, and commonly iron oxide stained.

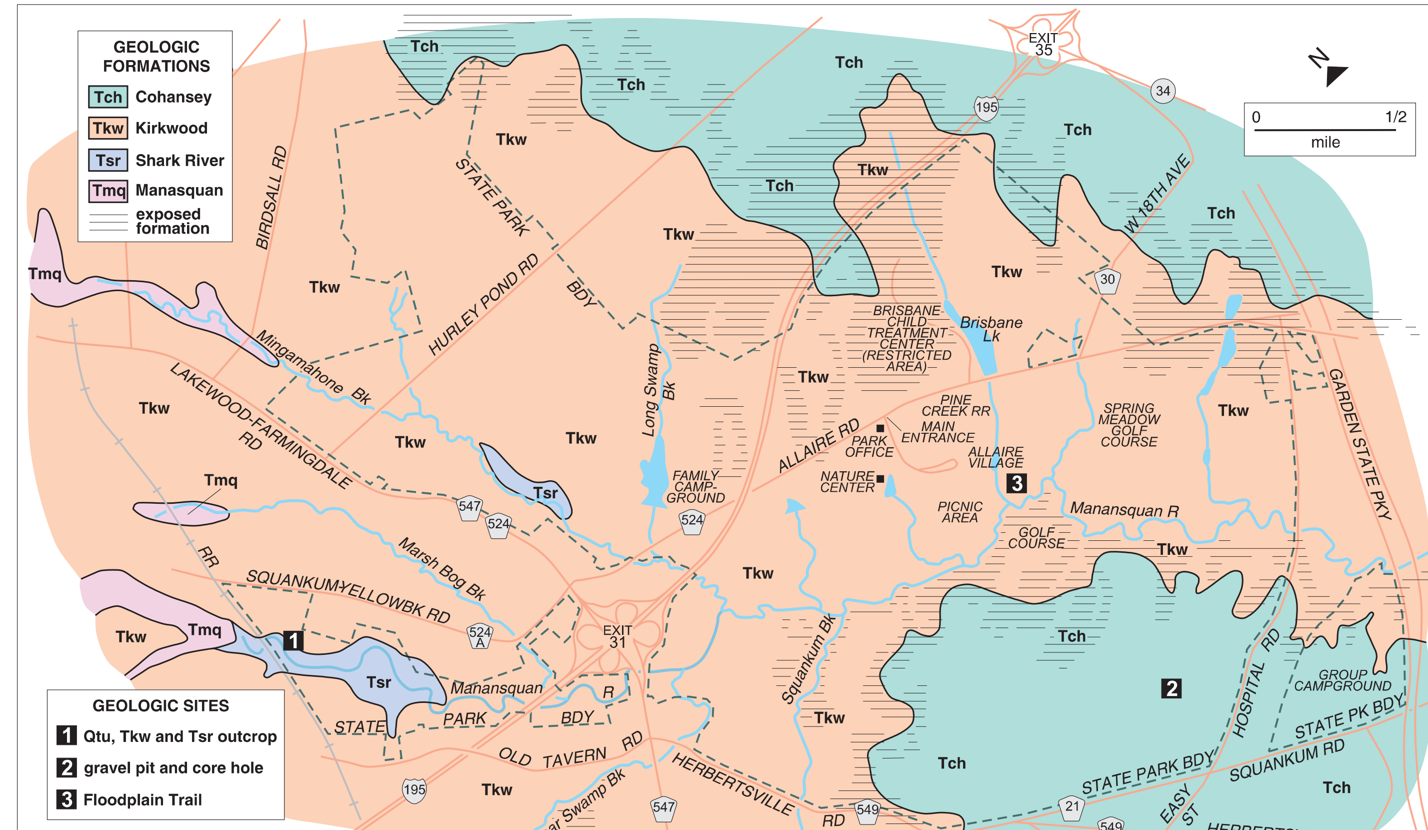


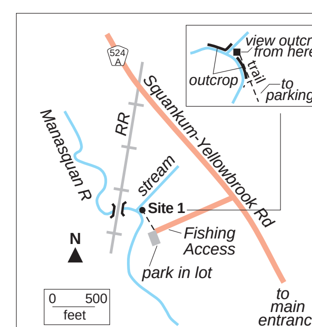
Figure 3. Geologic map of Allaire State Park

The Kirkwood Formation is overlain by the Cohansey Formation in the park. The Cohansey is estimated to be about 12 million years old, so an estimated 10 million years is represented by the hiatus between the two. After the deposition of the Kirkwood, global sea level changed at least six times prior to the beginning of deposition of the Cohansey.

The Cohansey Formation is a loose, white to yellow sand; it commonly is stained red or orange by iron oxides. Most of the sand is crossbedded indicating that the Cohansey sand was deposited in shallow water adjacent to barrier beaches at or near Allaire State Park.

Surficial Deposits and Landforms of Allaire State Park

Following deposition of the Cohansey Formation, the Antarctic ice sheet grew during the middle to late Miocene and global sea level dropped (see fig. 2). Since then the New Jersey Coastal Plain, with the exception of the Cape May peninsula and a strip along the modern coast, has been continuously above sea level. Stream and hillslope processes have been shaping the landscape throughout this time. The present form of valleys, plains, and hills is the result of the progressive action of these erosional and depositional processes.



Directions to Geologic Site 1

1) From Allaire State Park main entrance, turn left onto Route 524.

2) Travel 2.3 miles.

3) Turn left onto Manasquan River Fishing Access Road.

4) Park in lot at end of access road.

5) Walk to outcrop (see map). ***Climbing and digging on outcrop is prohibited.***

Thin deposits of sand and gravel overlie the coastal-plain formations in most of the park (fig. 4). These are generally less than 10 feet thick and were deposited by streams and by downslope movement of material on hillslopes. The stream deposits include upland gravels, which cap hilltops and ridgetops, terrace deposits, which cap plains in the valleys of the Manasquan River and Mingmahone Creek, and flood-plain deposits, which cover the low ground along streams that are regularly flooded. Hillslope deposits, known as colluvium, thinly cover most slopes in the park.

The upland gravels are the oldest surficial deposits in the park. They were deposited by an older network of streams from late Miocene to early Pleistocene time. Because they occur on the tops of hills and ridges, above present-day valleys, they are older than the terrace and flood-plain deposits and. They consist mostly of white and yellow quartz pebbles and sand eroded from the Cohansey and Kirkwood Formations and from an even older, topographically higher river deposit known as the Beacon Hill Gravel. This gravel was eroded from the park area, but small patches remain on higher hilltops in northern and western Monmouth County. In the park, upland gravels remain atop the high ground south of the Manasquan River, on hilltops around the Brisbane Child Treatment Center (fig. 4), and on a ridgetop adjacent to the family campground north of Allaire Road. The upland gravels were previously dug for construction material from the now-abandoned gravel pits along Allenwood and Hospital Roads (see directions to Geologic Site 2).

With renewed global decline of sea level in the late Pliocene (fig. 2) due to the growth of ice sheets in North America, Greenland, and Eurasia, downcutting by streams intensified. At this time the general location of the modern Manasquan and Mingmahone Valleys and adjoining uplands was established. After the streams deepened their valleys, seepage of ground water and stream-bank processes along the valley sides slowly eroded sand of the Cohansey and

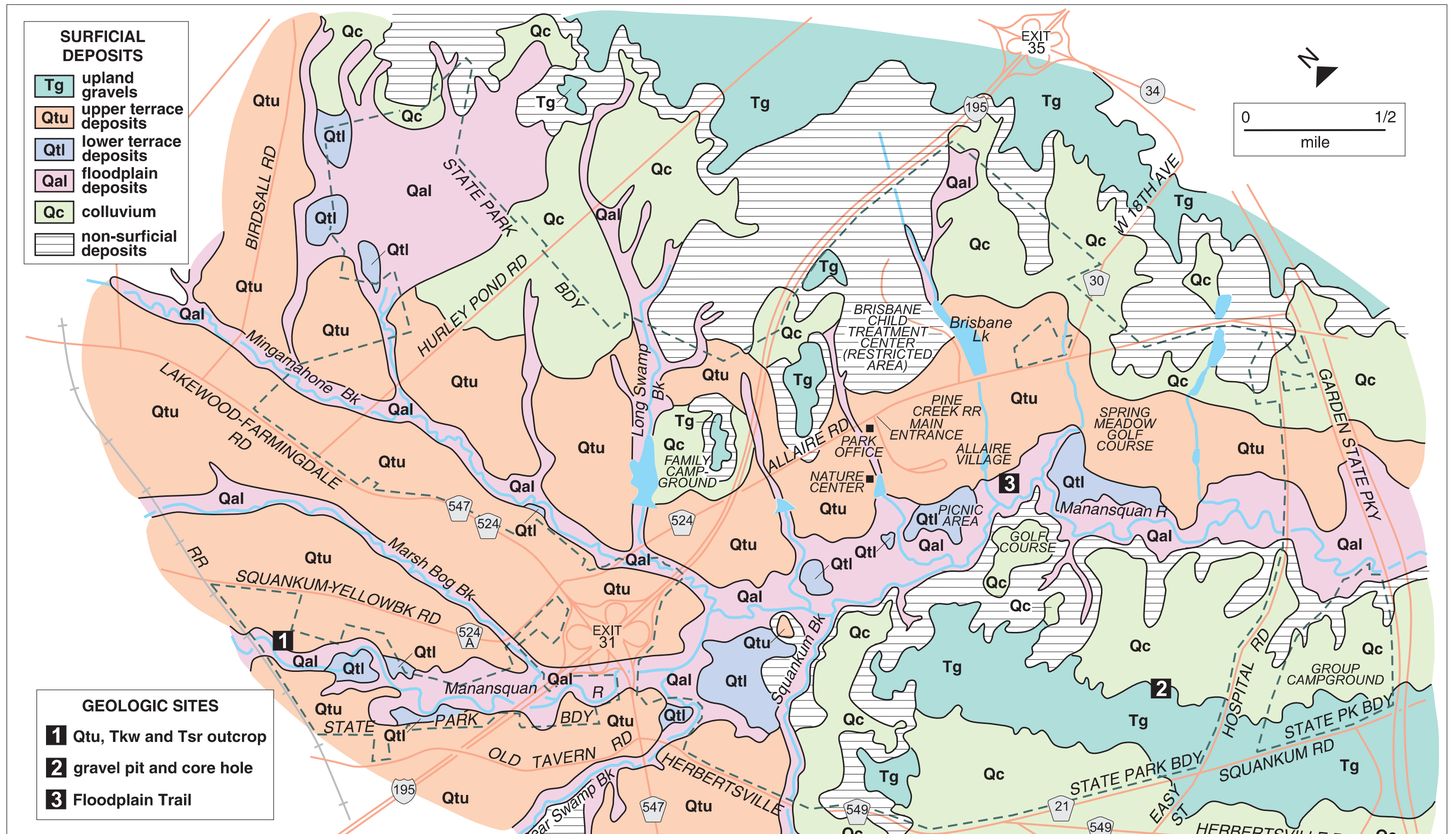
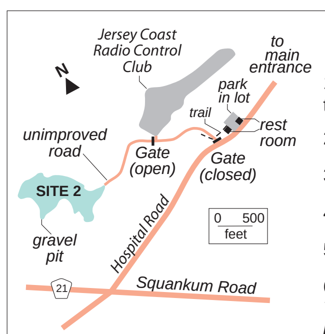


Figure 4. Surficial deposits map of Allaire State Park

Kirkwood Formations and the overlying upland gravels. This widened the valleys and enabled the streams to deposit sand and gravel over a broad flood plain in the valley bottom. This flood plain sediment today forms the upper terrace deposits, which are 20 to 40 feet above the modern flood plain, and are as much as 1.5 miles wide. These deposits include quartz and glauconite sand not only from the Cohansey and Kirkwood Formations, but also from the older Hornerstown and Vincentown Formations (fig. 2) that crop out upstream in the Manasquan Basin and that were exposed during valley deepening. The gravel is largely from the older upland gravels. Allaire Village, the Pine Creek Railroad, and the park nature center are all on this terrace deposit. The terrace deposits can be seen along streambanks of the Manasquan and its tributary streams. Perhaps the best exposure is downstream from the railroad bridge near Squankum (Geologic Site 1), where several feet of terrace sand overlie the Kirkwood and Shark River Formations.

During the most recent glaciation, which reached its maximum about 20,000 years ago, global sea level again fell and rivers again deepened their valleys. The Manasquan and Mingmahone and their tributaries cut into the upper



Directions to Geologic Site 2

1) From Allaire State Park main entrance, turn right onto Route 524.

2) Travel 1.4 miles.

3) Turn right onto Hospital Road.

4) Travel 1.0 miles.

5) Park in lot on right.

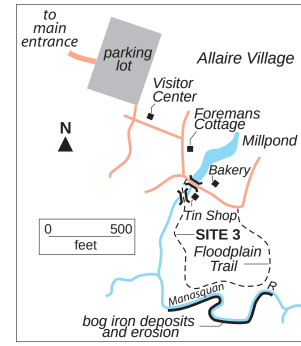
6) Walk to gravel pit (see map). ***Yield to bicycles and horses on multi-use trail.***

terrace and deposited a much smaller terrace in the narrow, deepened valleys. This lower terrace, now about 5 to 10 feet above the modern flood plain, has been largely eroded but is preserved in a few places. Its deposits are similar to those of the upper terrace, but are richer in glauconite because the streams cut deeply enough to erode into the glauconitic Shark River and Manasquan Formations. Part of the picnic area at Allaire Village is on the lower terrace, as is part of the Spring Meadow Golf Course.

At the last glacial maximum the vegetation in the coastal plain was likely a mixture of tundra and boreal forest and much of the ground was perennially frozen. Subsoil ice prevented rain and snowmelt from soaking into the ground. The surface soil became waterlogged and gradually crept downhill; water running over the ground surface also moved sediment downhill. These processes likely deposited much of the colluvium in the park. Some gravelly material at the top of the Cohansey Formation and the upland gravel may also have formed in place as smaller sand particles in those deposits were washed downslope or into the subsoil, leaving the larger gravel particles concentrated at the surface. This concentration process continues today, especially in unvegetated areas.

As the climate warmed and the ground thawed, first spruce, then pine, and finally the present oak-pine forest, covered the coastal plain. Tree roots stabilized slopes and less sediment entered streams. This decrease in sediment volume enabled streams to erode into the lower terrace and form the modern flood plain. The modern flood-plain deposits are mostly reworked from the older terrace sediments and consist chiefly of silt, sand, and a little gravel with some wood and plant debris. Flood plains are areas where ground water commonly discharges at the land surface. Here, iron dissolved in the ground water precipitates as its acidity and oxygen content changes. The flood plain deposits host bog iron, the

raw material for southern New Jersey's historic iron industry. The flood plain deposits and bog iron (visible as an orange film on wet surfaces) are best seen on the Floodplain Trail at Allaire Village (see directions to Geologic Site 3). Deposition of sediment during floods and accumulation of bog iron along the major streams in the park continues today. In places, slope and streambank erosion are also active, especially along the steep south bank of the Manasquan River, where ground-water seepage and stream cutting continue to erode into the Kirkwood Formation.



Directions to Geologic Site 3

1) From Allaire State Park main entrance, proceed to Allaire Village parking lot.

2) Park in lot.

3) Walk past Allaire Village Visitor Center to Millpond.

4) Floodplain Trail (yellow trail) begins below Millpond. ***Trail is packed clay with many exposed roots. It may be muddy, slippery and wet.***

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GEOLOGY AND SEA-LEVEL CHANGES AT ALLAIRE STATE PARK, MONMOUTH COUNTY, NEW JERSEY

Manasquan River, Allaire State Park.

Introduction

Allaire State Park is located in the New Jersey Coastal Plain, a low-lying region composed largely of unconsolidated sediments that form flat to gently rolling terrain. New Jersey's Coastal Plain is the emerged western margin of a large sedimentary basin called the Baltimore Canyon Trough (fig. 1) that underlies the continental shelf along the Middle Atlantic States. In general, sediments thicken southeastward into the trough.

The history of this area is related to the rifting of the Earth's crust and the opening of the Atlantic Ocean, which began in Late Triassic time 230 million years ago (mya) and continued into the Late Jurassic Age (150 mya). Rift valleys formed on faulted continental crust and then filled with sediment from rivers and streams. The Newark Basin is the largest of these exposed ancient rift valleys (fig. 1), which also contained many lakes. By Late Jurassic time the Atlantic Ocean was established as marine waters invaded the rift valley.

New Jersey Coastal Plain sediments range in age from Cretaceous (125 mya) to Quaternary (recent time). The Early Cretaceous was a time when large deltas built well out into the ocean; they consist predominantly of sand, silt, clay, and gravel. The Upper Cretaceous sediments typically consist of marine (shelf) and nonmarine (deltaic) deposits which are cyclic in nature, and record several changes in sea level during this time. A major cycle of sea level rise began about 100 million years ago in the Baltimore Canyon Trough and spread into