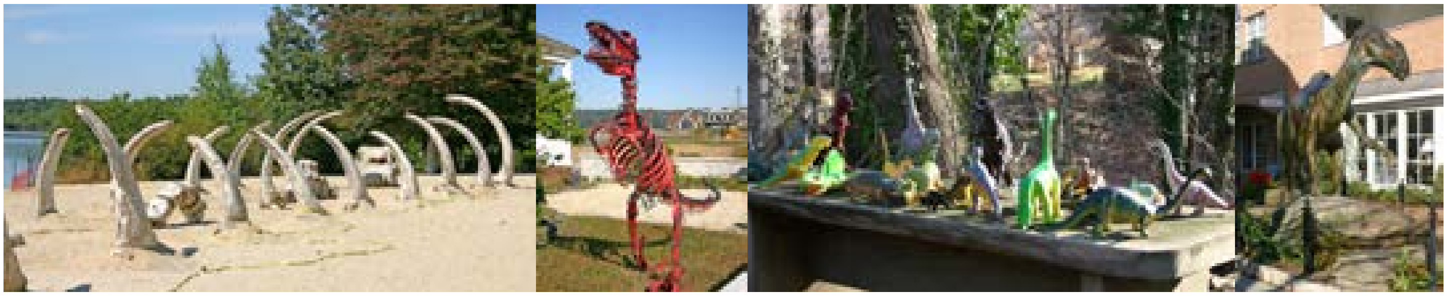

What's in a Rock? A Dinosaur Track from New Jersey at the State Museum in Trenton

Introduction

A large, red rock in front of the New Jersey State Museum (NJSM) in Trenton (fig. 1) is more than just a rock. It has a fascinating geological history. This three-ton slab, was excavated from a construction site in Woodland Park, Passaic County. It was brought to Trenton in 2010 and placed upside down to show a large dinosaur track (fig. 2) on the bottom. Most of the rock is sedimentary, sandstone from the 15,000-foot-thick Passaic Formation. The bottom part is igneous, lava from the 525-foot-thick Orange Mountain Basalt, which overspread the Passaic Formation. (The overspreading lava was originally at the top of the rock, but the rock is displayed upside down to showcase the dinosaur footprint).

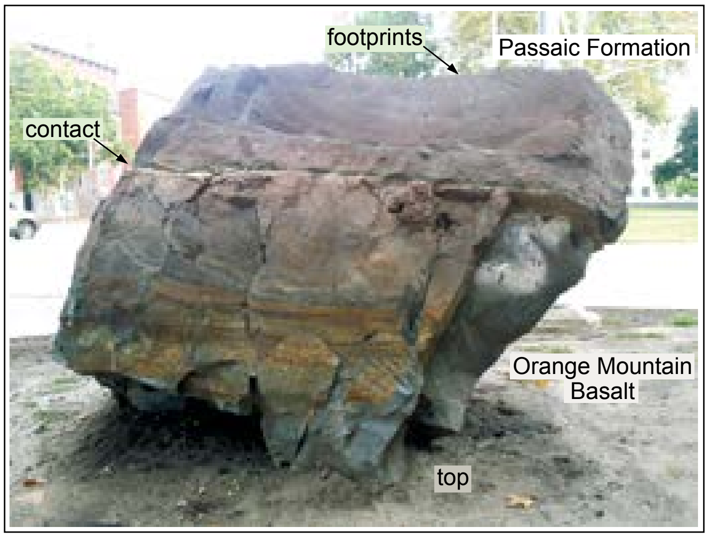

Figure 1. Rock at the New Jersey State Museum. *Photo by W. Kuehne*

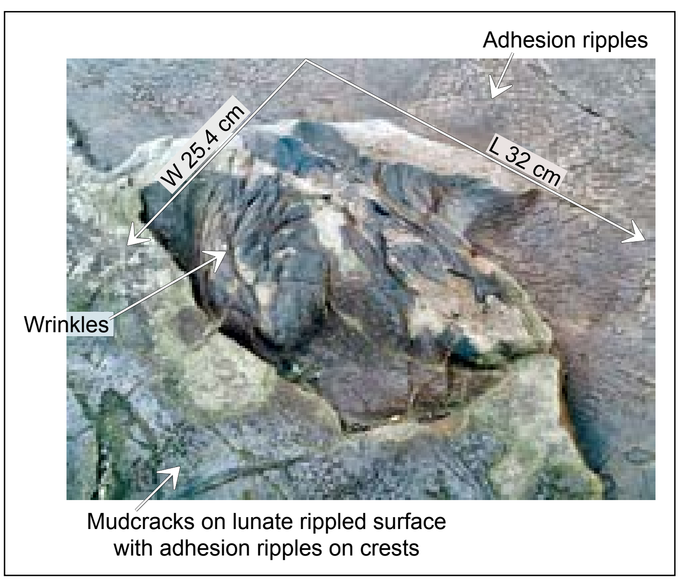

Figure 2. Close-up of the footprint showing mounding of the fill above the rock surface, three-toed structure, and the wrinkled surface of the imprint. Adhesion ripples are visible above to the left of the print. Desiccation fractures are visible below to the right. *Photo by W. Kuehne*

The rock is about 200 million years old, from the Triassic Period of geologic time. It formed in a rift valley, the Newark Basin, when Africa, positioned adjacent to the mid-Atlantic states, began to pull eastward and North America began to pull westward to open the Atlantic Ocean. The pulling and stretching caused faults to move and the rift valley to subside along border faults including the Ramapo Fault of northeastern New Jersey, about 8 miles west of Woodland Park. Sediments from erosion of higher areas west of the faults washed into the valley as it widened and deepened. Over time the sandstone was reddened from iron oxide in the sediment, forming the "red beds" characteristic of rift basin rocks (Schlische, 2015). Eventually the crust stretched and thinned enough that magma, including the Orange Mountain Basalt, welled up from the below the crust, erupted through volcanos, and spread across the sandy landscape.

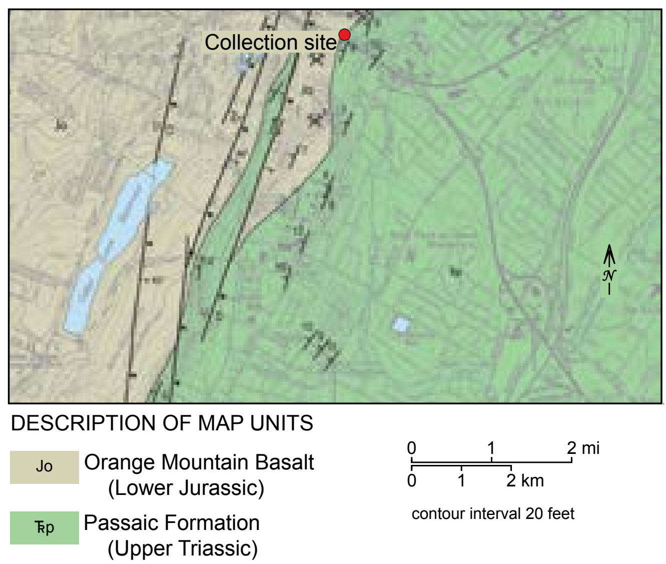

Figure 3. Bedrock geologic map of the collection area. (modified from Volkert, 2007)

The location where the rock was collected is shown on figure 3. Vertically the track is about 3 feet below the contact between the Passaic Formation and the Orange Mountain Basalt. Until recently the Triassic-Jurassic boundary was placed about 3 meters below the base of the basalt (Gallagher and Hanczary, 2006, p. 238). The boundary has been moved from just below the base of the Orange Mountain Basalt into the Feltville Formation (Olsen, 2010, p. 207). This places the track geologically within the Upper Triassic.

This was the Age of Dinosaurs, and thousands of dinosaur tracks have been collected in New Jersey. Two other sandstone slabs with dinosaur tracks are in the NJSM. The Rutgers Geology Museum in New Brunswick has a spectacular slab with dozens of prints. When the Newark Basin was subsiding, the floor of the basin often held lakes. The tracks are most often preserved on sand and mud flats bordering the lakes.

First we will examine sedimentary and igneous features of the rock, which show the environment in which the dinosaur lived. Then we will examine the footprint to see what it can tell us about the dinosaur. Finally, we will look at the layers in the rock, oldest to youngest, to reconstruct the series of geologic events they record.

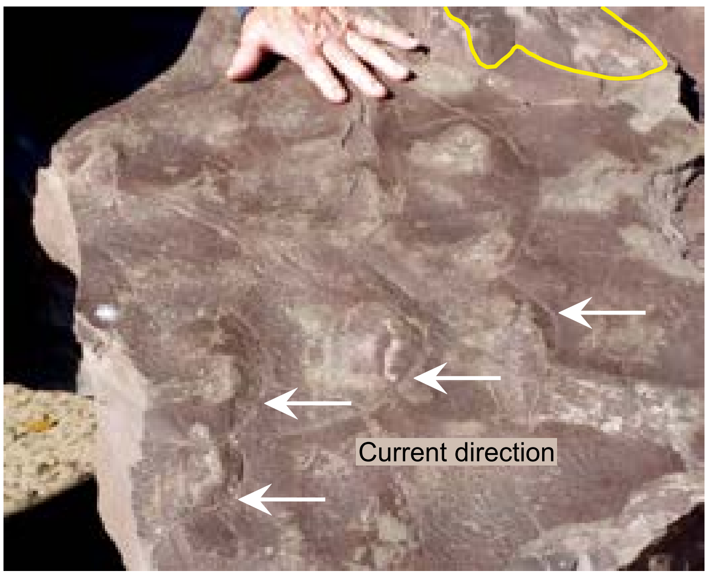

Figure 4. Top view of the slab showing footprint cast (outlined), current-rippled surface, and current direction inferred from ripples (arrows). Hand for scale. *Photo by W. Kuehne*

Features Of The Rock

At this time, New Jersey had a semi-arid climate, much like the southwestern United States today. Near the footprint, the slab is covered by ripples like those which can be seen today on a sandy stream bed. Current carries sand up the gentle (stoss) side of a ripple and deposits it on the steeper (lee) slope. From the shape of the ripples (fig. 4), we can tell that the ripples near the track were created by water flowing from right to left.

The rippled sandy layer might be from a stream which flowed vigorously for a short time following rain, then slowed down and stopped: a flash flood as is common in semi-arid climates. Alternatively, the current may have stopped because the stream channel shifted, a frequent occurrence for streams flowing across sand on the flat floors of active rift basins. Thin clay layers covering the rippled surface are from clay which was suspended in water, then settled out when it was no longer kept in motion by currents.

Overlying the clay is a surface covered with ripples different than the streambed ripples (fig. 2). They are smaller, flat-topped, and separated by narrow grooves. We interpreted these as adhesion ripples as described on beaches by Pye and Tsoar (2008, p. 184). Adhesion ripples form when wind blows sand over a damp surface. They would form on a wide, sandy streambed as easily as on a beach. Still drier conditions are evident from desiccation cracks, similar to the mud cracks in a dried puddle, on some of the bedding surfaces.

Taken together with our knowledge of the Newark Basin, evidence from the rock suggests that the rock in the slab started out as sand layers on a streambed near the shoreline of an ancient lake similar to those in our semi-arid southwest. Like our southwest, lakes in the Newark Basin expanded when rainfall was abundant and shrank in drier times, sometimes disappearing completely, leaving only a flat expanse of mud. Towards the center of the basin, near the Hackensack Meadowlands, lakes were persistent. The sediments there are rich in clay as would be expected on a lakebed. Lakes were shorter-lived towards the edge of the basin, near the Ramapo Fault, and the sediments there are gravelly, as would be expected where streams were bringing their sediment load down from highlands onto alluvial fans. The Woodland Park area is between the alluvial fans bordering the Ramapo Fault and the semi-permanent lakes at the center of the basin, and is intermediate in character. The rock is predominantly river sand. Coarse gravel was not carried this far into the basin. Thick layers of lakebed mud were not deposited.

The Footprint

The fossil we have today is not the original dinosaur footprint. In making a footprint, a dinosaur pushes sand or mud downward. The track at the museum is mounded upward rather than pushed downward (fig. 2). What we have instead of the original track is the sediment which washed into the track and filled it. The track itself, pushed downward, was on a slab lying below the slab at the museum. When the rock broke along the clay layer, the actual print was left behind.

Also, we do not know exactly which species of dinosaur made the track. Tracks are classified as ichnofossils, or trace fossils, rather than body fossils, and identification of the particular dinosaur which made the track (table 1) is inferred rather than certain. Three fairly similar kinds of three-toed tracks from carnivorous, bipedal dinosaurs are known from the Jurassic of New Jersey. The largest are named *Eubrontes,* smaller ones are *Grallator*, and an intermediate size is *Anchisauripus.* Based on size alone this print would represent an *Anchisauripus*, but because the digits are

Table 1. Dinosaur type based on length of footprints.

ICHNOFOSSIL	LENGTH (cm)	REFERENCE	REPRESENTATIVE	REFERENCE
Grallator	5 to 15	Wesleyan University, 2014	*Megapnosaurus*	Kirkland and Milner
Anchisauripus	Intermediate 20-25	Gallagher 1997, p. 49		
Eubrontes	35 to 40	Wesleyan University, 2014	*Dilophosaurus*	Kirkland and Milner
Rock at museum	32			

Figure 5. A dinosaur about the size (7-10 feet in length) and type as this one (a *Coelophysis*) made the track. *Photo by Z. Allen-Lafayette*

splayed and pad impressions are obscure, it is more likely a small *Eubrontes,* like the splayed prints illustrated in Kuban (1994, fig. 2). While we cannot be certain of the species, we do know that this was a fairly small dinosaur. "Estimates of Speeds of Dinosaurs" (Alexander, 1976) estimates hip height of bipedal dinosaurs like those which made most of the New Jersey tracks as 4 times footprint length. The footprint length is 32 centimeters (cm) giving an estimated hip height is 128 cm, similar to the dinosaur model in figure 5.

We have focused on the prominent footprint, but there is subtle evidence of a second print pointing in the same direction on the same surface (fig. 6). At first this might seem to be the next track of the same dinosaur on its trek across the flat. Assuming that this is the case we can estimate the dinosaur's speed using a formula in Alexander's article:

$$u = 0.25g^{-0.5}\ \delta^{167}h^{-1.17}$$

where

u = speed (meters/sec)
g = acceleration of free fall (9.8 meters/sec^2)
δ = stride length (in this case 0.43 meter)
and h = hip height, (estimated above as 1.28 meters)

In this instance u = 0.25 x ($9.8^{-0.5}$) x ($0.43^{1.67}$) x ($1.28^{-1.17}$) = 0.16 m/sec

This is just over 30 feet per minute, way too slow for a walking dinosaur. Also, the front print is much smaller, perhaps a quarter of the size of the prominent print, and pushed into the sand to only half the depth. Possibly the dinosaur paused and rested its front foot for balance. Perhaps the second track is a juvenile traveling close to its parent across an early Jurassic streambed. Perhaps the prints are unrelated.

The footprint surface, actually the underside, is crossed by peculiar and enigmatic wrinkles (fig. 2). While tracks may preserve skin texture: wrinkles, creases, scales and tubercles (Thulborn, 2012, p. 87), these wrinkles do not appear to be impressions of the dinosaur's skin. More likely these are in mud deformed below the surface when the dinosaur's foot sank in. The mud was there when the dinosaur walked. It broke off with the infilling sediment that left the low, mound sandstone knob we see as the fossil, but is not part of the fill. As put forth for tracks in Spain by Perez-Lorente (2015, p. 98):

> "Most of the dinosaur footprints have small, wave like structures involving ductile deformation of the mud. In this case, neither the waves nor the ruptures indicate that this area was in direct contact with the skin of the dinosaur's foot. The formation of these tracks involves a fine lamination that is not destroyed beneath the tracking surface but rather wrinkled. Wrinkled surfaces inside tracks are placed several layers below direct structures."

The squishing deformation of the finely laminated clay layers indicates that the dinosaur was walking on moist, fairly soft mud rather than on dried clay. This is further suggested by the lack of bone structure on the print. Tracks on firm ground commonly show bone structure better than those on moist, easily deformed sediment (fig. 7). The NJSM track does not show bone structure.

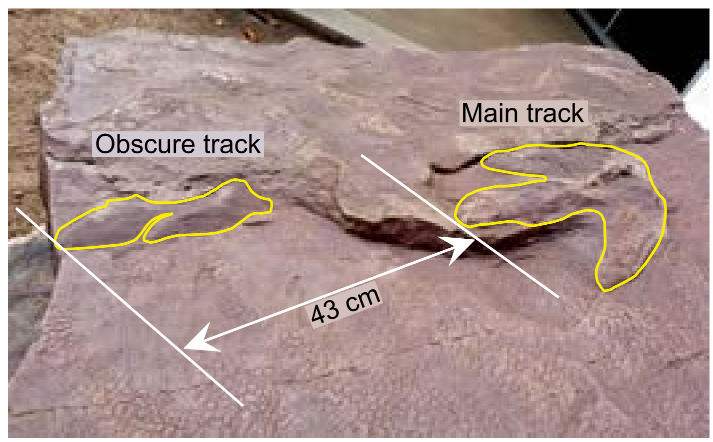

Figure 6. Dinosaur tracks separated by a stride distance of 43 centimeters, show by arrows. Adhesion ripples are visible below the tracks. *Photo by W. Kuehne*

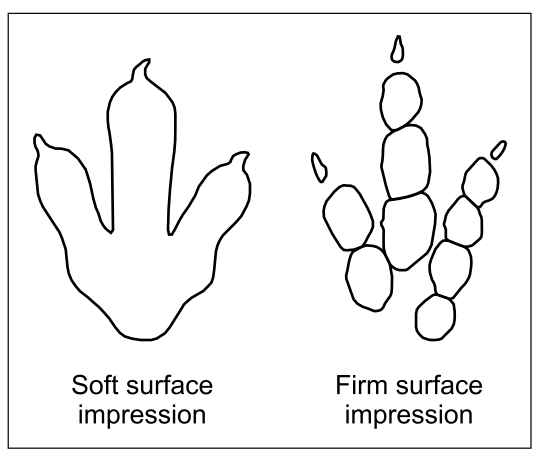

Figure 7. Dinosaur tracks in soft and firm sediment. Source: Google image gallery.

Geologic Events Recorded In The Rock

The total thickness of sediment layers in the rock is 105 cm, a short but interesting page in the 15,000 feet of sedimentary record in the Passaic Formation. Figure 8 is a geologic column diagramming this short record.

The history of the rock (fig. 8) begins with a rippled surface left by a swiftly flowing stream. The ripples were on sandstone which is no longer part of the rock. Before it was brought to the museum, the rock broke along a thin layer of clay which settled out atop the rippled surface after the stream stopped flowing. The rippled sandstone did not come to the museum. Soon after it was deposited, the clay dried and broke up along desiccation cracks. At some later time, when the sediment was again moist, stiff winds blowing across the surface created adhesion ripples. Also at a time when the sediment was moist, a dinosaur, or likely more than one, tracked across the streambed. Then the sequence repeated. The print infilled with sand as deposition recommenced, swift currents deposited an additional 15 cm of sand, ripples formed on the top of the sand, then were covered with drapes of clay which settled out of suspension. The ripples are beautifully exposed because, as with the layer near the dinosaur track, the rock split along the easily separated clay layers rather than through solid sandstone. Again, there are adhesion ripples above the clay drapes, but on this surface there are no desiccation cracks or dinosaur tracks.

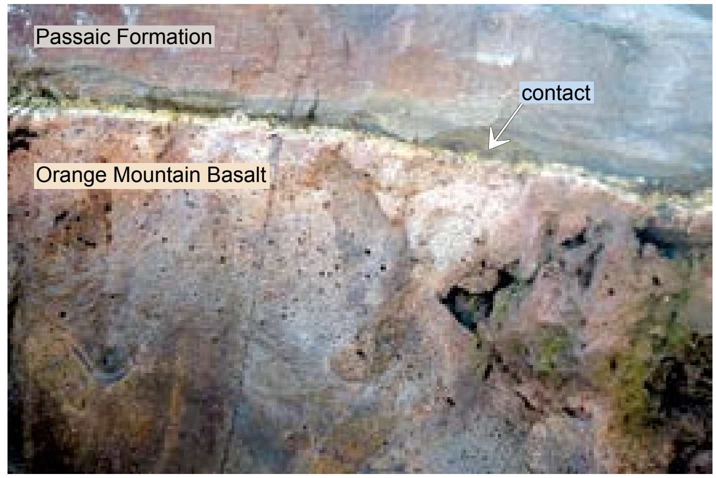

Figure 9. The contact between the Orange Mountain Basalt and the Passaic Formation. The small round holes are vesicles created by steam or other volcanic gasses that were trapped in the lava as it solidified. *Photo by Z. Allen-Lafayette*

After a few more inches of sand was deposited, there was a

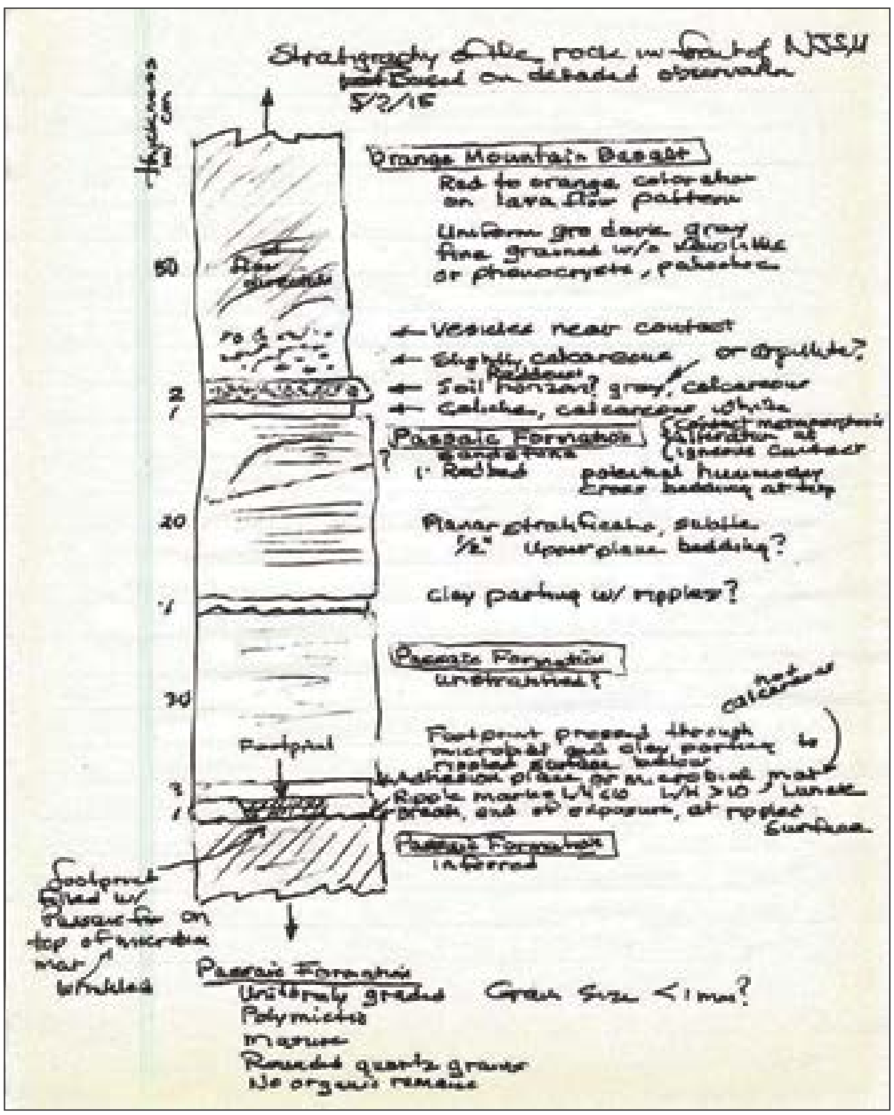

Figure 8. Stratigraphic column for the rock. The oldest layers, deposited first and buried by younger layers, are at the bottom of the column. The rock itself has been turned over, and the oldest layers are now at the top. The footprint on the top of the rock is at the bottom of the column.

major geological change. Lava of the Orange Mountain Basalt flooded across the Newark Basin. When the rock was collected, a basalt layer was at the top. The rock was turned over to show the track, and now the lava is at the bottom. Small round holes, vesicles, in the lava (fig. 9) are from gases boiling out of the lava. Some are possibly from moisture boiling up from the sediment below.

The basin continued to subside for a few million years after the eruptions began. Sediment continued to wash in and volcanoes continued to erupt, eventually leaving the rock at the museum buried 5,000 or so feet deep. Then, in another major geologic change, the basin stopped subsiding and the area was uplifted exposing the rock to erosion. 5,000 feet of rock wore away, leaving the museum rock once again at the surface, where it was broken loose during construction, and brought to the NJSM.

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Banner Photos: For the Love of Dinosaurs, left to right:

Pseudoconcretosaurus, fossil dinosaur sculpture, Parvin Lake, Parvin State Forest, Salem County.

Adipiscing metalli dinosaurum, spotted near Sea Bright Boro, Monmouth County, is a reminder that these magnificent beasts once roamed what are now our suburbs.

Tokens of appreciation left at the *Hadrosaurus foulkii* discovery site, Haddonfield Boro, Camden County.

Hadrosaurus foulkii sculpture, by John Giannotti, Haddonfield Boro, Camden County. New Jersey declared "Haddie" our state fossil in 1994.