THE PROVENANCE OF EXOTIC FOSSILIFEROUS PALEOZOIC BOULDERS EMBEDDED IN QUATERNARY SEDIMENTS OF THE NEW JERSEY ATLANTIC COASTAL PLAIN

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ABSTRACT - A field of more than 200 exotic boulders scattered over an area of 150 hectares, was discovered in a suburban residential area in Southwestern New Jersey, USA on the unconsolidated Quaternary deposits of the Atlantic Coastal Plain (ACP). Half of the boulders are overtly fossiliferous, harboring tentatively identified Devonian fossils dominated by Plantae, *Archaeopteris* and *Psilophyton* but include vertebrates; Antiarch placoderms cf. *Pterichthes*, Ostracoderm cf. *Cephalaspis,* invertebrates; gastropod cf. *Pleurotomaria tuboides* and ichnofossils; *Chondrites* fabrics and *Helicodromites* correlative with formations in southcentral New York State. Observed boulder dispersal was eight clasts per hectare but Ground Penetrating Radar (GPR) reconnaissance revealed higher density in the subsurface. Borehole stratigraphy failed to reveal the suspected Pleistocene boulder-bearing stratum. The boulders exhibit faceted, plate and block shapes, some with polished faces and striations, suggesting glacial derivation even though the field is more than 150 kilometers south of the terminal moraines of Pleistocene glaciation crossing the northern part of the state. Comparison of generally accepted fluvial with glacial transport modes concludes that the boulders were ice-rafted into the study area and deposited as melt out dropstones during a sea level highstand when the regional lithosphere was glacioisostatically depressed below the eustatic drop in sea level associated with glacial epochs. The age of the host sediments indicates emplacement during the Middle Pleistocene. These observations have important implications for continental glaciology particularly in areas proximate to sea coasts.

INTRODUCTION

A field of more than 200 exotic boulders, residing within a 1.5 square kilometer area, was discovered in a residential area of southwestern New Jersey on the ACP approximately five kilometers distant from the three major regional waterways, Pensauken Creek, Cooper River and the Delaware River. The area is also within the relict periglacial region of Pleistocene glaciation, which interceded 150 kilometers away in the northern part of the state. The unweathered complexion of the boulders and their prominent situation on residential properties suggests that they were originally subsurface, exhumed during home basement excavation and the more attractive stones retained for landscaping. A typical boulder, a section of the field and the study area of this report are shown (**Figure 1)**.

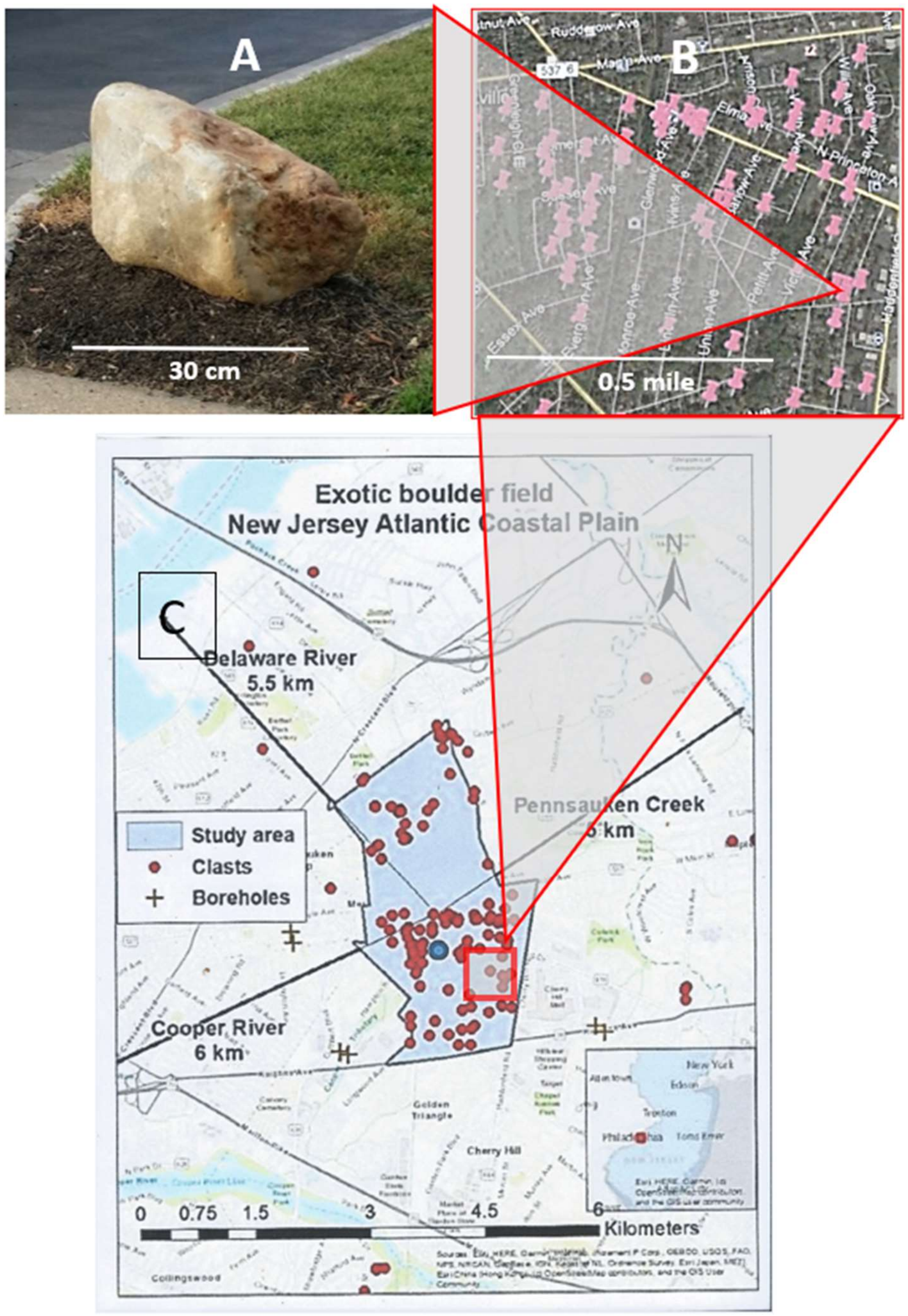

Figure 3. Exotic boulders within the study area and broader area of interest showing proximate major waterways and existing boreholes used to assess subsurface stratigraphy. The blue circle marks the location of the GPR survey. A. Typical boulder lodged in front of a residential property; B. Section of the boulder field (Google Earth) and C. Boulder distribution over the study area and surrounding area of interest. ArcMap by author.

Boulders on the ACP are reported to be embedded within, or have eroded out from, the remnants of the Bridgeton, Pensauken and Cape May surficial geology formations that once overspread much of the ACP but have since been eroded away to scattered remnants on higher elevations including the study area of this report (Salisbury and Knapp, 1917; Owens and Minard, 1979; Newell et al., 2000; Demitroff, 2016). These investigators, however, do not clearly specify whether the boulders are native or exotic, whether in-situ or merely associated with the formation in which they are found or the geochronological age of the boulders. Salisbury and Knapp (1917) do note, however, the presence of Paleozoic clasts and Devonian fossils on chert nodules in the Quaternary formations of New Jersey but otherwise do not comment on the paleontology of the boulders found in these formations.

Salisbury and Knapp (1917) assigned the Pensauken and Bridgeton formations to the Pleistocene Epoch based on composition resembling glacial till. Richards (1945) also designated the Pensauken-Bridgeton Complex as Early Pleistocene in age. Bowman and Lodding's (1969) studies of lateritic weathering and other evidence suggest that the Pensauken Formation was deposited during a warm interglacial period. More recent studies, however, based on paleobiology, revised the stratigraphy, repositioning the Pensauken and Bridgeton formations into the earlier Neogene Period but kept the Cape May Formation in the Pleistocene (Owens and Minard, 1979; Newell et al., 2000).

Newell et al. (2000) postulated that high-discharge rivers of the Neogene Period outwashed clasts from northern New Jersey and beyond into the Pensauken and Bridgeton Formations on the ACP. Owens and Minard (1979) concurred that these formations were deposited in a fluviatile environment. Additionally, Bowman and Lodding's (1969) studies concluded that the deposits in the Pensauken Formation were fluviatile. Other investigators, however, argued that the presence of some large boulders associated with these formations could only be explained by ice-rafting (Salisbury and Knapp, 1917; Kummel, 1940; Richards, 1945; Jordan, 1964. Widmer, 1964; Bowman and Lodding, 1969).

Only clasts larger than 256 millimeters largest diameter, defined as boulders on the Wentworth Scale, are included in this study (Wentworth, 1922). In this report, "Exotic" applies to clast of a lithology foreign to the region in which it resides. "Erratic" applies to a glacially derived clast residing within a glacier catchment area or proximate drift. "Host" is the geological formation residence of an exotic boulder. "Parent" is the geological formation from which an exotic boulder was extracted. "Periglacial," in the context of this report, is literally applied as "close to a glacier," more specifically to the glacioisostatically depressed region at or around Last Glacial Maximum. To distinguish "periglacial" from current usage, as the surface condition after retreat of a glacier, the term "periglacial" is preceded by the word, "relict."

METHODS

Exotic boulders within the area of interest were recognized by a street-by-street visual prospecting survey documenting location, coordinates, size, elevation, lithology and distinctive features. As more boulders were discovered, a study area was defined ultimately encompassing 150 hectares and incorporating 165 clasts visible from the street. No clasts were removed from their locations, but property owners, where available, were interviewed concerning the history of the clasts residing on their property. The following characteristics guided the survey in distinguishing exotic boulders from endogenous and commercial landscaping varieties.

- Conspicuously placed, isolated
- Too large to have been easily hand-carried
- Rounded, smooth surfaced
- Not as attractive as commercial landscaping stones
- Longest dimension >250 millimeters
- Lodged on a residential property
- Commonly quartzite, conglomerate or sandstone
- Not obviously endogenous ironstone, conglomerate or silcrete

Of the 217 boulders surveyed over the broad area of interest, (**Figure 1**), 84 were photographed and studied, scrutinizing lithology, fabric, shape, fossils, weathering pattern and surface features on site and later from closer examination of enlarged photographs. GPR reconnaissance was used to explore the subsurface distribution of objects at a central location in the study area, marked as a blue circle in **Figure 1** (Gardener, 2020). NJDOT borehole logs in the vicinity of the study area (crosses) were reviewed to assess the subsurface stratigraphy (NJDOT, Geotechnical Data Management System, online). The compiled information was mapped and analyzed by Geographical Information System (GIS) methods using surficial and bedrock geology from the New Jersey Geological and Water Survey (NJGWS) and the United States Geological Survey (USGS).

RESULTS

The subset of 84 boulders, photographed and selected for detailed study, was grouped into eight shape classes, with representatives illustrated (**Figure 2**).

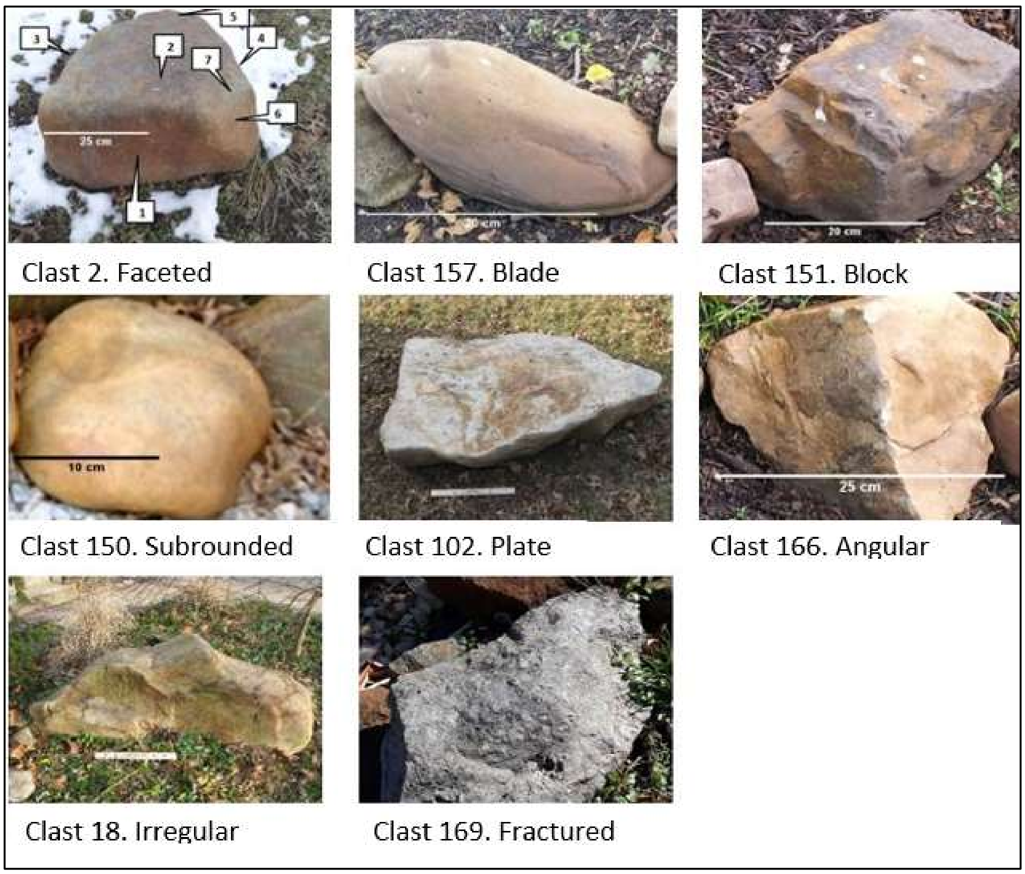

Figure 4. Shape classes of boulders within the area of interest.

It seems reasonable to expect an orderly shape progression of glacially transported clasts starting from plucked and quarried bedrock plates with sharp edges (Clast 102), planed to a faceted shape (Clast 2), further abraded to subrounded (Clast 150) and eventually comminuted to rock flour if long entangled in the glacier traction zone, more than 35 kilometers (Goldthwait, 1951).

These shapes are more typical of glacial derivation than the rounded and half-rounds of boulders transported fluvially over significant distances considered to be >100 kilometers (Boulton, 1978; Chatanantavet et al., 2010).

Clast 150 is smooth surfaced, possibly fluviatile, but has five subtle faceted faces. It is notable that there are no boulders in the collection which are clearly of fluviatile derivation. See Data Repository of this report for photographs of the complete inventory.

In addition to distinctive shape, striations on clasts are evidence of glacial derivation. In the study area, eight out of the 84 boulders selected for detailed study exhibit wavy, bedrock-type striations impressed on polished surfaces (**Figure 3**). Five other boulders exhibit planar-type striations typical of clasts which have passed through the glacier traction zone. The most prominent four are shown (**Figure 4**).

Figure 5. Clast 18: polished and striated face on plucked bedrock, enlargement on the right. White line traces the track of the striations. Ruler is 30 cm.

Finding striations of both types on 13 out of 84 (15%) boulders studied is significant evidence of glacial derivation. The absence of striations does not preclude glacial origin, however, because weathering and post-glacial erosion may have erased all traces (Salisbury, 1902).

Figure 6. Planar type striations on exotic boulders in the study area. Enlargements adjoining on right. White lines show direction of striations.

This boulder field has probably escaped notice because of the of the sparseness of the boulders visible on the surface, only one per hectare, but, from the footprint of an average home basement excavation, suggests that there are about eight clasts per hectare expected if the entire area was excavated to a depth of four meters. Except for a limited GPR survey (Gardener, 2020) no estimate can be made for the number of boulders that were removed from the premises or that were not be visible from the street-by-street survey. The GPR survey at one property indicates that the subsurface density is probably several orders of magnitude greater than those visible on the surface. Many properties in the study area display numerous boulder-sized clasts in their landscaping supporting the notion that there is a large population of boulder-sized clasts in the undisturbed subsurface of the study area. No clasts, however, were observed on undeveloped tracts in the area of interest, tentatively verifying that the clasts now exposed were originally subsurface

PALEONTOLOGY

More than half of the boulders in the study area are fossiliferous, approximately equally divided between fossils and ichnofossils. Fossils are more evident on the fracture-faced clasts which are more numerous and available for study on the property where the GPR survey was conducted. Attrition and abrasion may have erased traces on most of the rest as there are only ephemeral traces of fossils on surfaces of abraded clasts. Mostly, the discernable fossils on the abraded clasts are densely packed, overlapping, macerated, without a preferred orientation and not sufficiently isolated for identification. Accordingly, the identifications that follow are tentative. The fossil suite is dominated by Devonian Plantae, *Psilophyton* and *Archaeopteris*, but includes *Archaeosigillaria*, *Lepidodendron* and an unidentified lycopod. Notable fossils are pictured in the figures below.

Suite	Clast	Figure
Devonian fossils	127, 118, 13	**5**, A-C
Devonian plant fossils	200	**6**, A-F
Various fossils	117	**7**, E, G, L, O
Gastropods	189	**8**
Ichnofossils, Chondrites fabrics	16, 9, 189	**9**

Table 4. Key to Figures of fossil photographs.

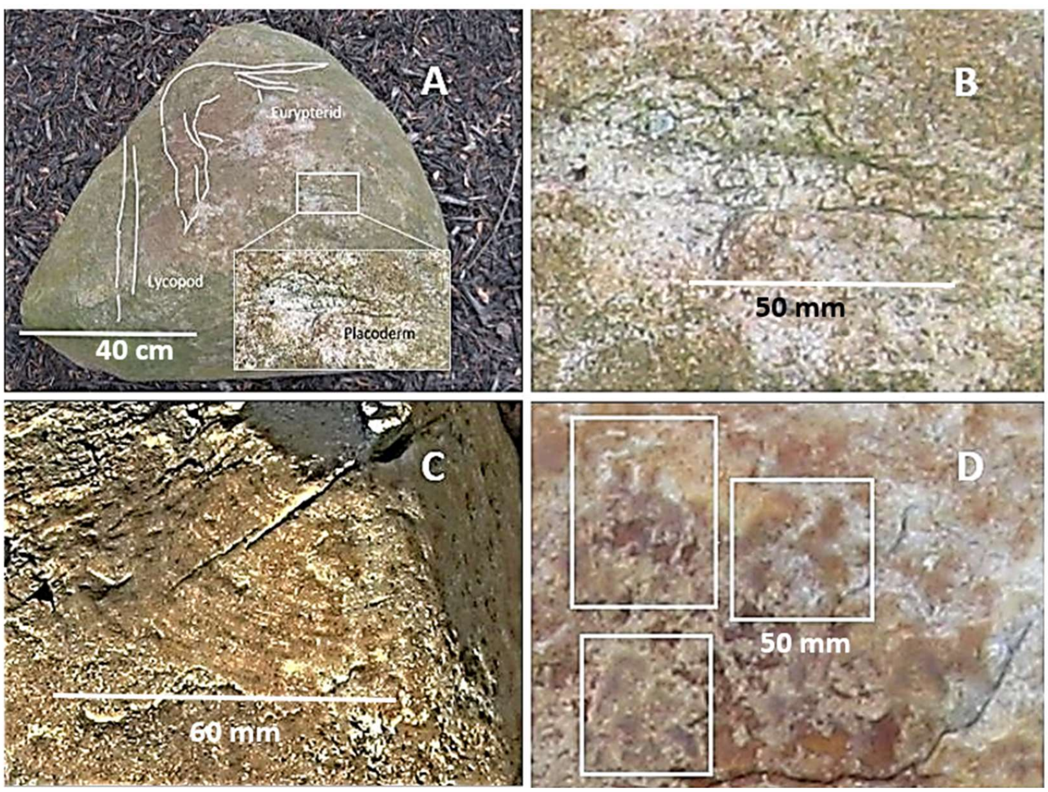

Figure 7. Devonian fossils. A. Clast 127. Fossil traces include eurypterid, lycopod and placoderm, see inset and enlargement adjoining for the placoderm traces. B. Clast 127. placoderm tail and pectoral appendage detail, scaled tail indicates *Pterichthys*. C. Large bivalve on Clast 118. D. *Archaeopteris* leaf groups on Clast 13.

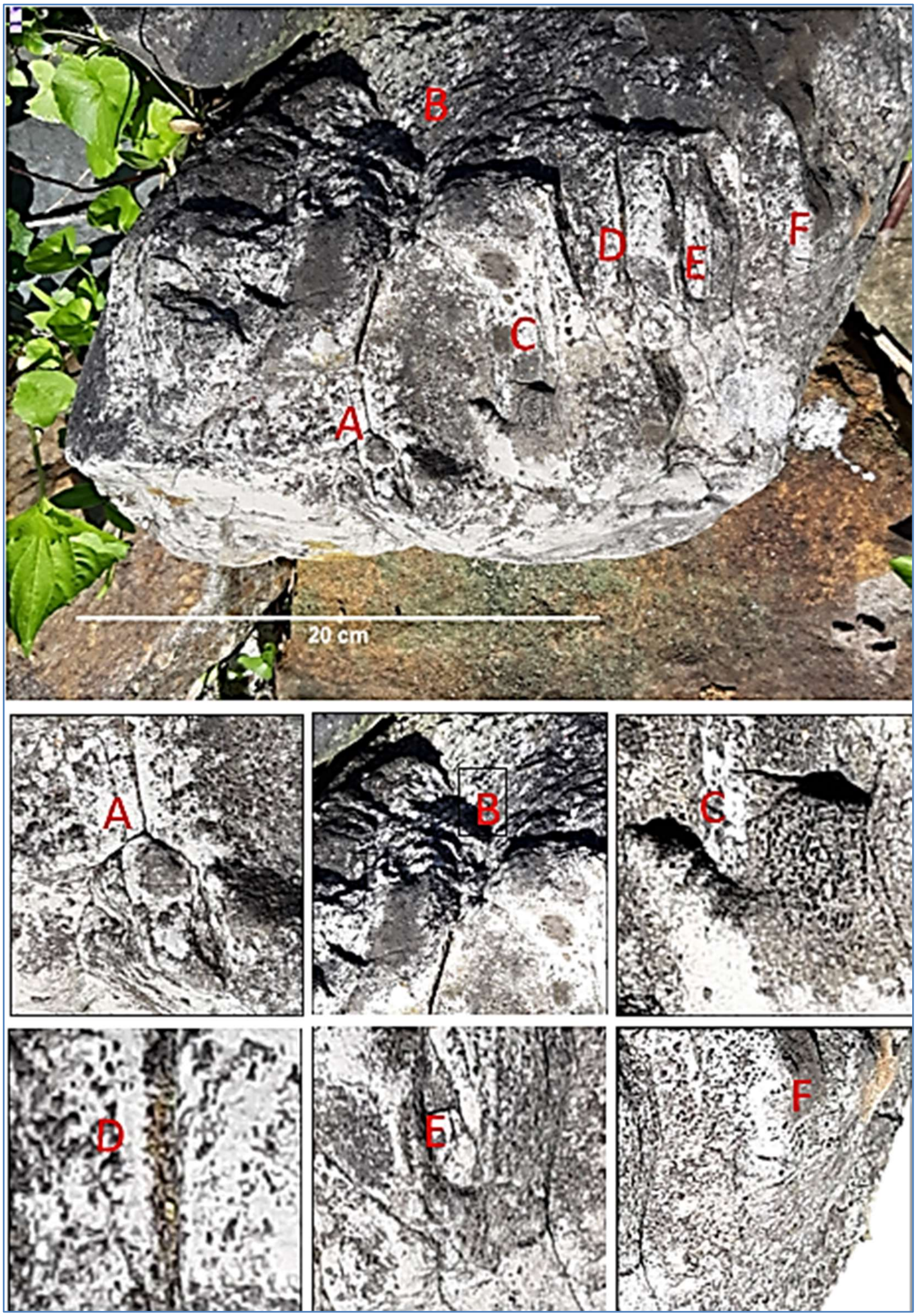

Figure 8. **Devonian plant fossils on Clast 200. A. Plantae or crinoid? B, C. *Psilophyton* carbonized leaves, D. *Archaeosigillaria*, E. *Lepidodendron*, F. *Archaeopteris* pinnules.**

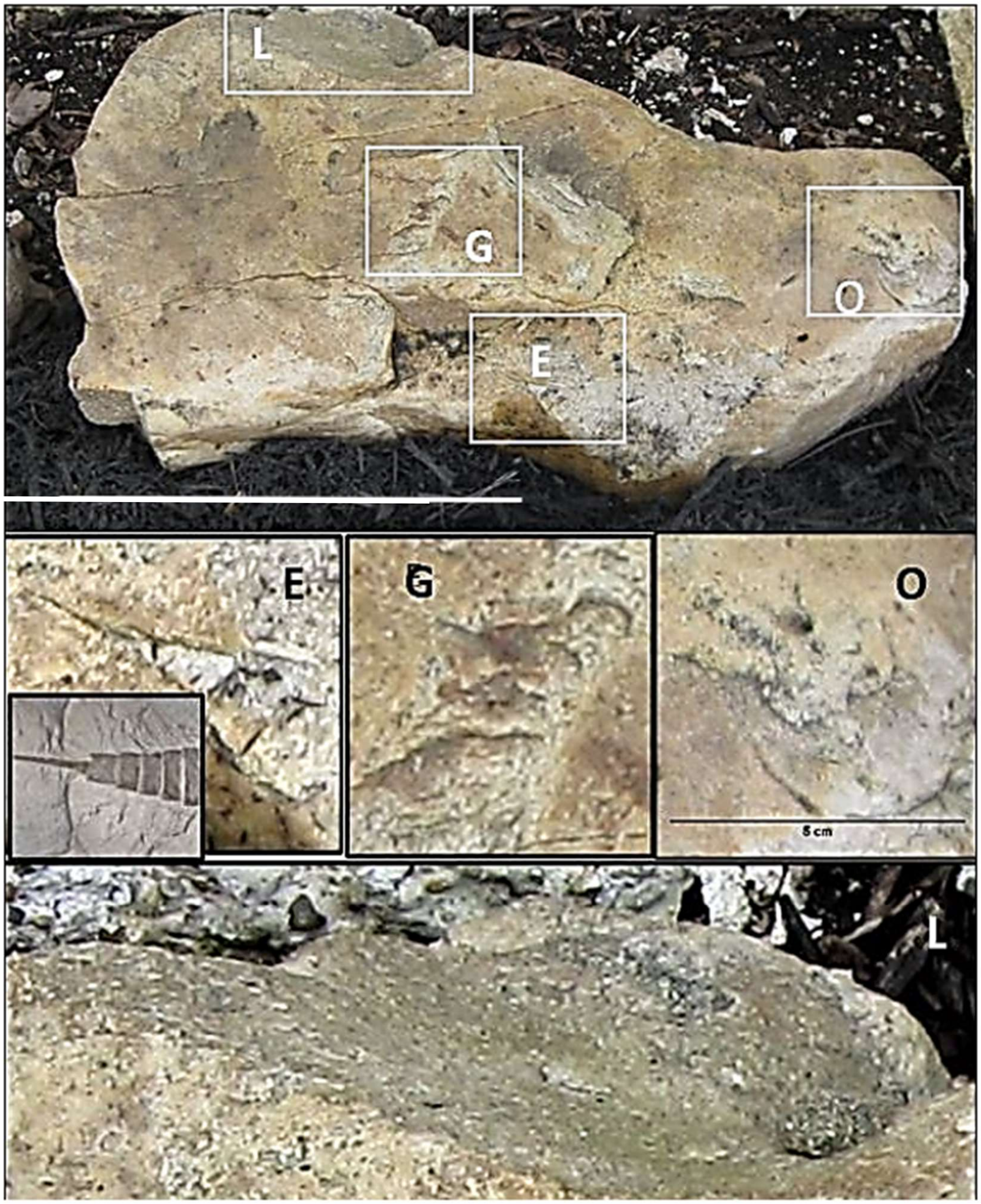

Figure 9. **Clast 117. E. Eurypterid, inset for comparison, G. *Gyrolithes*, L. *Archaeopteris* pinnules, O. Ostracoderm.**

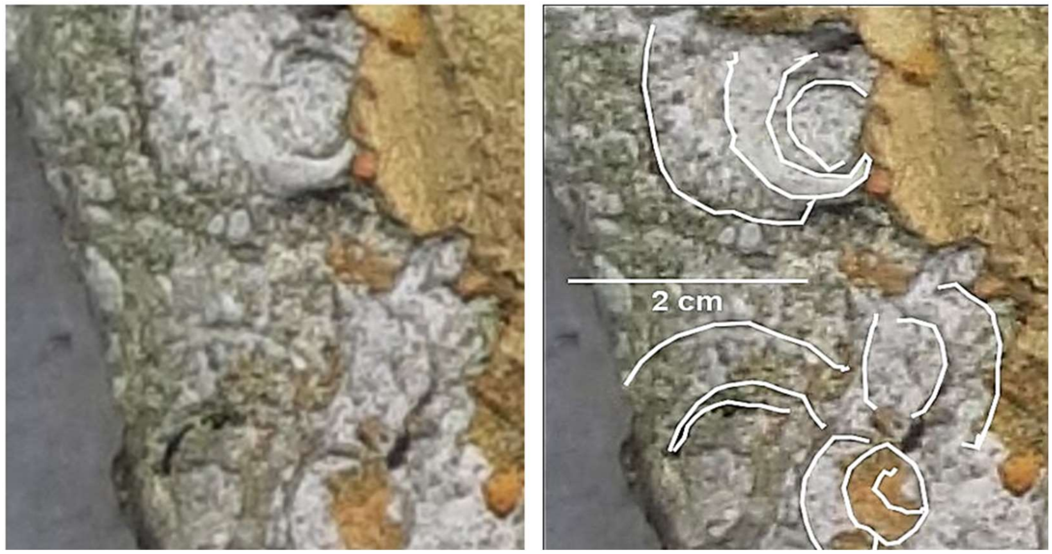

Figure 10. Gastropod group on limestone Clast 189, cf. *Pleurotomaria tuboides*. L. image, R. traced gastropods on the image.

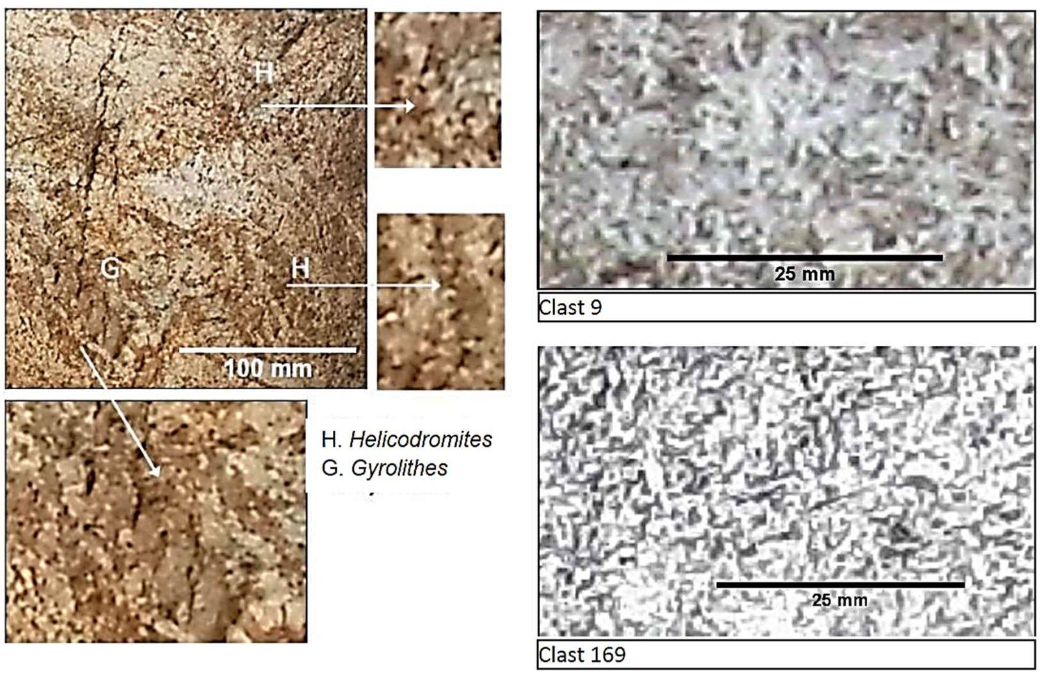

Figure 11. Left, Ichnofossils *Gyrolithes* and *Helicodromites* on Clast 16. Right, *Chondrites* fabrics on Clasts 9 and 169.

Combined, the fossil suite (**Table 2)** and paleontology profile of the boulders (T**able 3)** are presented below.

Taxon	Clast No.	Abundance
Plantae		
Psilophyton	200	Common
Archaeopteris	13	Common
Lepidodendron	200	Rare
Archaeosigillaria	200	Rare
Unidentified lycopod	127	Singular
Vertebrata		
Ostracoderm cf. *Cephalaspis*	127	Singular
Eurypterid	127	Rare
Placoderm cf. *Pterichthys*	127	Rare
Tetrapod	140	Rare
Mollusca		
Bivalve, cf. *Cypricardella*	118	Rare
Gastropods cf. *Pleurotomaria tuboides*	189	Rare
Anthozoa		
Tabulata cf. *Romingeria*	169	Rare
Ichnofossils		
Chondrites	16	Abundant
Helicodromites	16	Abundant
Gyrolithes	117	Uncommon

Table 5**. Fossil suite by taxonomic class with relative abundance.**

Category	Quantity
Total clasts studied	84
Fossils other than ichnofossils	27
Ichnofossils only	31
No discernable fossils or ichnofossils	26

Table 6**. Paleontology profile of boulders.**

PARENT ROCKS

Correlating the lithology of exotic boulders in the study area to specific bedrock in the glacial catchment area is formidable involving such tasks as thin sectioning, petrographic analysis and a comprehensive rock library, exercises beyond the scope of this investigation but a possibility for future research. A less definitive approach to identifying parent rocks is correlation through paleontology and geochronological age. Many of the 84-boulder subset selected for detailed study harbor fossils tentatively identified as Devonian age. Pleistocene glaciation overran and could have quarried such rocks and carried them south. Two Devonian-age bedrock formations lay in the Pleistocene glaciation catchment area, the Green Pond Mountain Outlier in New Jersey and New York State and the Catskill Formation in Pennsylvania and New York State (**Figure 10**)

(Dalton et al., 2014; Bedrock Geology of New York**,** online**;** Bedrock Geology of Pennsylvania, online). The Green Pond Mountain Outlier bedrock Devonian facies are very limited in extent and are mostly sandstone and shale, which contain marine invertebrates and a single conglomerate formation, the Skunnemunk, which is not known to contain fossils (Weller, 1903). Therefore, the Green Pond Mountain Outlier is unlikely to be the source of the boulders in the study area which display terrestrial plants and marine vertebrates. Rocks of the Catskill Formation, however, contain Devonian plant and vertebrate fossils at numerous sites (**Figure 10**) (Dennison, 1985; Broussard, 2018; Daeschler and Cressler, 2011; Downs et al., 2011). Except for Franklin, New York (uppermost green circle), these sites are located in the red bed facies of the Catskill Formation in west-central Pennsylvania, not likely to contribute elements into the area of interest of this report. The boulders in the area of interest are also predominately gray sandstone, unlike the redbeds farther to the west, suggesting their parent source is in the eastern section of the Catskill Delta in New York State where gray facies predominate (Bedrock Geology of New York**,** online**)**. Although unable to identify specific parent rock, some generalizations can be drawn. Plant fossils indicate a shallow marine paleoenvironment adjacent to terrestrial strata. Bioturbation indicates full marine. Dennison (1985) showed shallow Catskill marine strata adjacent to the Arcadian orogeny in southeastern New York State in the Lower Devonian. As the southeastern region of New York State contains many sites with Devonian plant fossils, this region is a candidate source for those clasts in the study area exhibiting plant fossils.

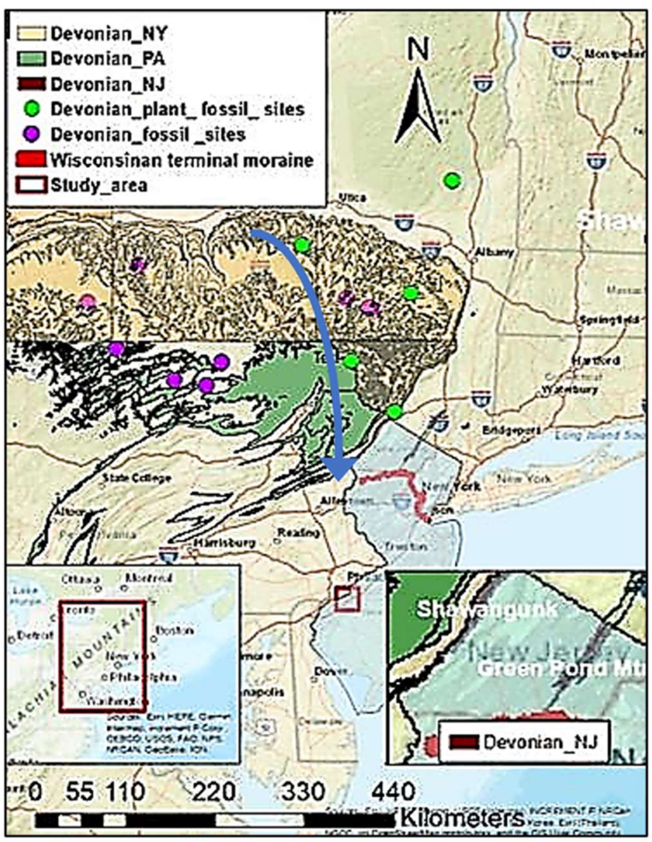

Figure 12. Devonian rocks and fossil sites in the Pleistocene glaciation catchment area. The arrow marks the general path of glaciation towards the study area. ArcMap by author. Details of Devonian plant fossil sites are included in Table 4.

Locality	Coordinates	Elevation, meters	Taxa	Formation	Clast(s) Displaying	Reference
Cairo, New York	43.300238° N 73.999625° W	107	*Eospermatopteris, Archaeopteris*	Presumably Catskill Formation *	13, 116, 153, 163, 168, 188, 190	(Stein et al., 2019)
Gilboa, Schohane County, New York	42.388139° N 74.458448° W	441	*Archaeosigillaria*	Catskill Formation	200	(Stein et al., 2019)
Lebanon, Madison County, New York	42.782025° N 75.652094° W	458	*Psilophyton*	Windom Shale, Moskow Formation, Hamilton Group	2, 8, 125, 143, 146, 150, 177, 191	(St John, online
Huguenot, Madison County, New York	41.418125° N 74.632947° W	148	*Archaeosigillaria*	Mount Marion Formation, Hamilton Group	200	(St John, online

Table 7. **Devonian plant fossil sites in southeastern New York State (Figure 10).**

* Located in the Adirondack region which does not include Devonian bedrock (Bedrock Geology of New York, online).

The plant fossils presented (**Table 4)** are found in the Devonian rocks of southeastern New York State, over160 kilometers distant, far exceeding the Goldthwait 35-kilometer limit for boulder survival (Goldthwait, 1951). The Delaware River watershed, however, extends up into the Devonian bedrock region where plant fossil sites are located (**Figure 10**), providing an alternate pathway to channel boulders to the study area. This route would be open especially during glacier retreat when the Devonian source rocks were within the Goldthwait 35-kilometer survival limit and the land was still glacioisostatically depressed allowing meltwater outwash to flow out into the Delaware Valley.

SUMMARY

This investigation of the provenance of exotic boulders residing in an area of interest on the Atlantic Coastal Plain in southwestern New Jersey concludes the following:

- Originally subsurface, exhumed during construction activity
- Lodged in Quaternary Pleistocene age sediments of the ACP
- Identify as glacially derived by size, shape and striations
- Ice rafted into the study area and deposited as glacial dropstones
- Derived from fossiliferous Devonian age bedrock in southeastern New York State

DISCUSSION

Various media portray spectacular boulders in the glacier track, designated as, ”erratics” but largely overlook, “exotic” boulders downglacier in the relict periglacial region, even though, as this study has demonstrated that the boulders there are likely similarly derived and share shape and surface features with their counterparts lodged within the till of the glacier catchment area. Such disinterest is not surprising as most exotic boulders in the relict periglacial region are buried in the subsurface, smaller than their erratic counterparts in the glacier track and not lodged in bounded depositories such as till, drumlins and eskers. Scholars also found the presence of apparent glacially derived boulders in relict periglacial regions problematic and offered explanations such as erratics of a rogue glacier lobe advancing beyond its recognized final terminus or an unidentified earlier ice age event, tabling the matter for future research (Ray, 1969).

DATA REPOSITORY

A database and photographic plates of all boulders, 10 plates, 85 photographs of boulders in the area of interest, are available at

https://doi.org/10.17605/OSF.IO/6ZSNT

To view, go to doi.org, enter this doi credential into, "Resolve a doi name" and submit to open the document.

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GEOLOGY AND PALEONTOLOGY OF A NEW UPPER CRETACEOUS (MAASTRICHTIAN) PALEOGENE TRANSITION SITE (K-Pg) DISCOVERED NEAR MULLICA HILL, GLOUCESTER COUNTY, NEW JERSEY

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Abstract - The Turtle Creek tributary of Raccoon Creek near Mullica Hill, Gloucester County, New Jersey, exposes the contact between the Upper Cretaceous (Maastrichtian) Navesink Formation and the overlying Paleogene Hornerstown Formation, a nominal K-Pg transition site. The stratigraphy at Turtle Creek is disturbed. In some sections the Kirkwood makes an appearance, but the expected intermediate Vincentown Formation is entirely missing. Although the site is near the historic prolific Mullica Hill Pond site, fossils native to the same formations exposed at Turtle Creek are relatively sparse. *Cucullaea* sp. steinkerns and fragments that appear to be bone were recovered just above the K-Pg contact at the expected horizon of the Main Fossiliferous Layer (MFL) characteristic of K-Pg sites on the Coastal Plain. The Navesink and Hornerstown Formation exposures yield fossils typically associated with these formations including *Cucullaea* and *Pycnodonte* bivalves as steinkerns, an indurated Exogyra and other bivalves, *Peridonella dichotoma* and lithified *Thalassinoides* burrows. Silicified wood fragments found in the stream bed gravel correlate with the Kirkwood Formation which outcrops in a downstream section. All fossils at this site are poorly preserved except the silicified wood and the sponge *Peridonella dichotoma*. Stratigraphy reveals an unexpected layer of gravel with embedded cobbles and boulders with Paleozoic fossils above the Hornerstown and Kirkwood Formations attributed to the Bridgeton Formation several kilometers outside of its mapped bedrock range. Some of the clasts exhibit striations and other evidence of glacial derivation. The site is unique for abundant Paleozoic fossils representing Cnidaria anthozoans: tabulata and rugosa, porifera, crinoidea and brachiopoda taxa traced to the tentative Bridgeton Formation hosting layer. Systematics and photographs for all invertebrate native fossils recovered from the site and representative Class taxa of the Paleozoic fossils are included.

INTRODUCTION

Sites in New Jersey exposing the Upper Cretaceous (Maastrichtian)-Paleogene, K-Pg, contact have long attracted much attention from geologists who believe the transition reveals a great mass extinction event ostensibly caused by an asteroid impact in the Yucatan Peninsula at the end of the Cretaceous Period. Faunal and lithology changes across this transition at such sites support this extinction hypothesis. Gallagher (1993) provided a rather complete overview of New Jersey sites where the transition is exposed. Gallagher, Parris and Spamer (1986) earlier discussed the paleontology, biostratigraphy and depositional environments of this transition and the role of glauconite across the New Jersey Coastal Plain. Rowan University is conducting a major investigation of the transition and the MFL which are well exposed at their research site at the former Inversand glauconite quarry in Sewell, New Jersey (Rowan, 2021). The aim of this report is to add Turtle Creek in Mullica Hill to the list of known K-Pg sites in New Jersey and to investigate the exposures there for faunal and lithology changes across the transition which could reflect on the postulated K-Pg extinction event.

Site location and description

East sidewall of the inner ravine of Turtle Creek, a small tributary of Raccoon Creek, near Mullica Hill in Gloucester County, New Jersey, located on the Inner Coastal Plain, typical exposure **Figure 1**, Left, site map**,** Right, topography including the Mullica Hill Pond site. The inner ravine is 5 meters deep, 50 meters wide and the upper surface elevation 21 meters. A highlighted blue line impressed on the topography traces the relevant section of Turtle Creek. Site details are included in **Table 1**.

Site	Turtle Creek, tributary of Raccoon Creek
Accessibility	Private
Municipality	Harrison Township
County	Gloucester
Altitude, meters	21
Coordinates, dd	Latitude: 39.783166º N, Longitude: 75.209007º W
Site description	Small underfit stream, unconsolidated bedrock exposures along east bank
Surficial geology	Qwcp, Weathered Coastal Plain Formations (Stanford 2000).
Surficial alluvium	Decomposition residue of Quaternary and Tertiary age on other sedimentary rocks (Fullerton et al., 2016)
Bedrock geology	Formations: Navesink, Lower Hornerstown, Lower Member Kirkwood, Bridgeton
Source of fossils	Exposures of formations and loose in stream bed gravel
Collecting method	Hand pick in-situ or screen gravel in stream bed
Residence of fossils	Spears personal collection
Age	Upper Cretaceous (Maastrichtian), base, Paleogene to Holocene, upper

Table 8. Turtle Creek fossil site details.

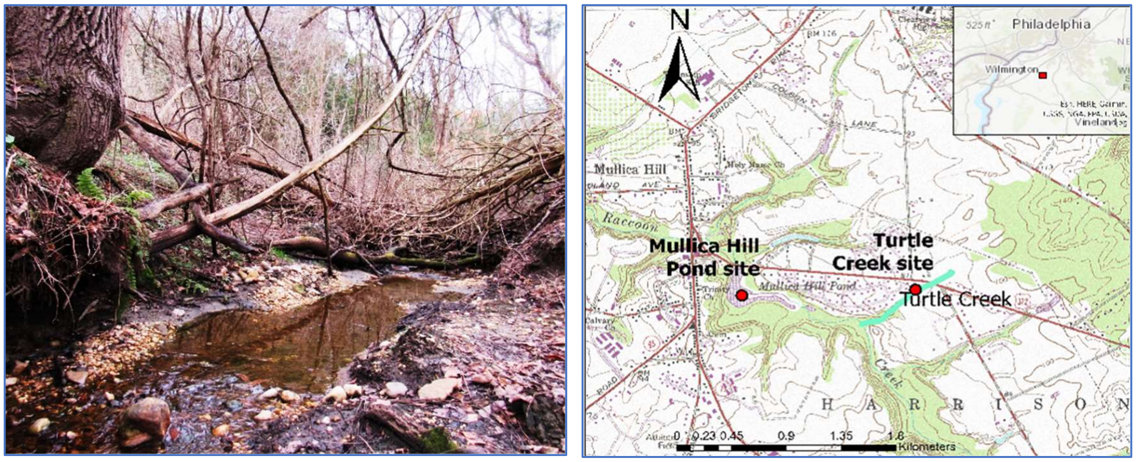

Figure 13. Left. Typical stretch of Turtle Creek showing boulders, cobbles and gravel in the stream bed from which most of the fossils were recovered. View is upstream with formation exposures on the right (east) bank. Photograph by author. Right, Location section of UISGS topographic map of the Turtle Creek site relative to the more familiar classic Mullica Hill Pond site. Turtle Creek is highlighted. The Rowan University Edelman Fossil Park site (former Inversand) is off the map to the right. ArcGIS map by author.

RESULTS

Geology

On the bedrock geology map, **Figure 2**, Left, the Turtle Creek site when viewed from above is situated where the Paleocene Hornerstown Formation adjoins the Miocene Kirkwood Formations without the sequential intermediate formations, Vincentown, Manasquan and Shark River. As the formations generally dip to the southeast and the underground stratigraphy is disturbed, **Figure 3**, the Upper Cretaceous Navesink Formation intrudes only the central part of the site profile so that it was necessary to construct two columns to completely describe the stratigraphy at Turtle Creek. Stratigraphic Section B includes the Navesink-Hornerstown Formations and Section C the Hornerstown-Kirkwood Formations with the Bridgeton Formation overlying both sections. The surface of the formations is overlain with Qwcp, Weathered coastal plain deposits, thickness at site discontinuous and less than 10 ft. (Thickness of Surficial Deposits in New Jersey, online reference) but the description of Qwcp notably does not report cobbles or boulder sized clasts which are abundant in the stream bed and in the apparent layer of Bridgeton Formation central to the site stratigraphy, **Figure 3**. The Weathered coastal; plain deposits, Qwcp, is described as:

Exposed sand and clay of Coastal Plain bedrock formations. Includes thin, patchy alluvium and colluvium, and pebbles left from erosion of surficial deposits (Stanford, 2000)

It is enigmatic that the apparent Bridgeton Formation appears in these sections as surficial geology shows only its outliers on higher elevations not closer than two kilometers, **Figure 2**, Right. Apparently, the Bridgeton Formation extends outward from these elevated exposures, under the weathered surface plain deposits. The Turtle Creek watershed extends northeast into one of the exposures. Owens and Minard (1979), however, show Bridgeton and Pensauken Formation blanketing the region, Gallagher, Parris and Spamer (1986) review of the

Inversand site (now Rowan University Edelman Fossil Park) also assert that:

> The yellowish-orange gravel that unconformably overlies the Hornerstown greensand is the Pensauken Formation, a Pleistocene outwash deposit containing fossiliferous chert pebbles derived from Paleozoic strata in the Appalachians.

Their article does not, however, provide support for this assertion, and, for purposes of the present report, we will assume that it is the Bridgeton Formation which overlies the Hornerstown Formation at Turtle Creek as in **Figure 3**, based on bedrock geology (Gallagher, Parris and Spamer, 1986).

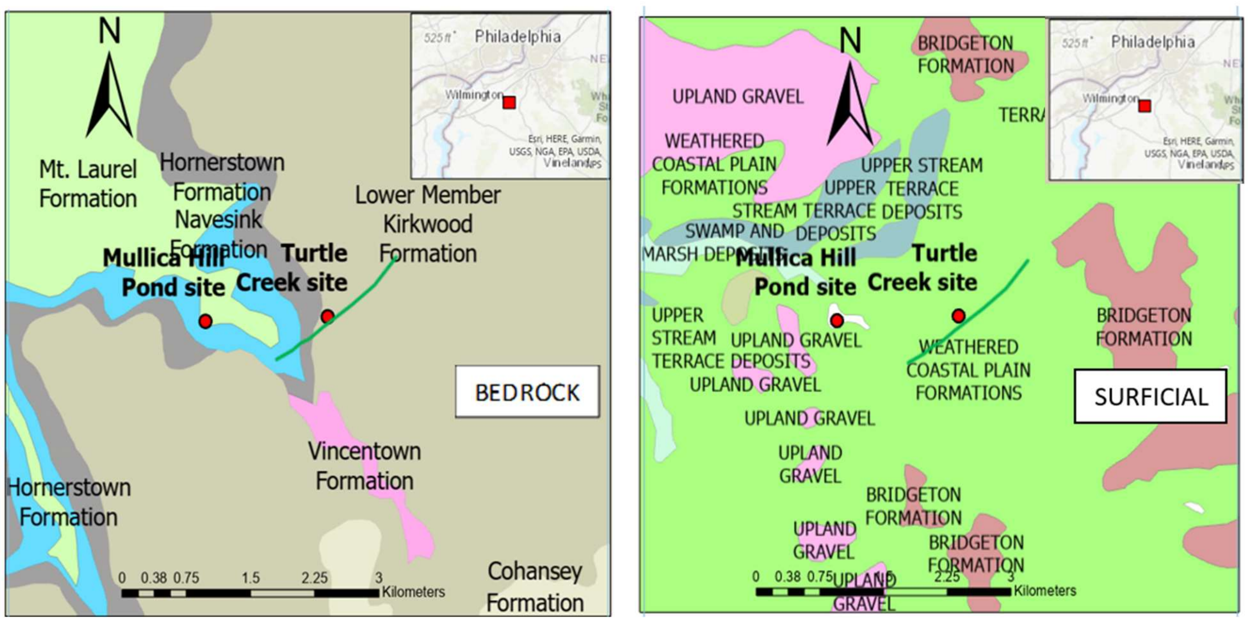

Figure 14. Geology of the Turtle Creek fossil site. Left, bedrock (Sugarman, P., Castelli, M. and Kopcznski, K., 2021), Right, surficial (Fullerton, D., Bush, C. and Pennell, J., 2016), Blue line is the approximate position of Turtle Creek. ArcGIS maps by author.

Stratigraphy profile

The profile of the stratigraphy at Turtle Creek as inferred is sketched in **Figure 3** illustrating the disturbed strata at the site.

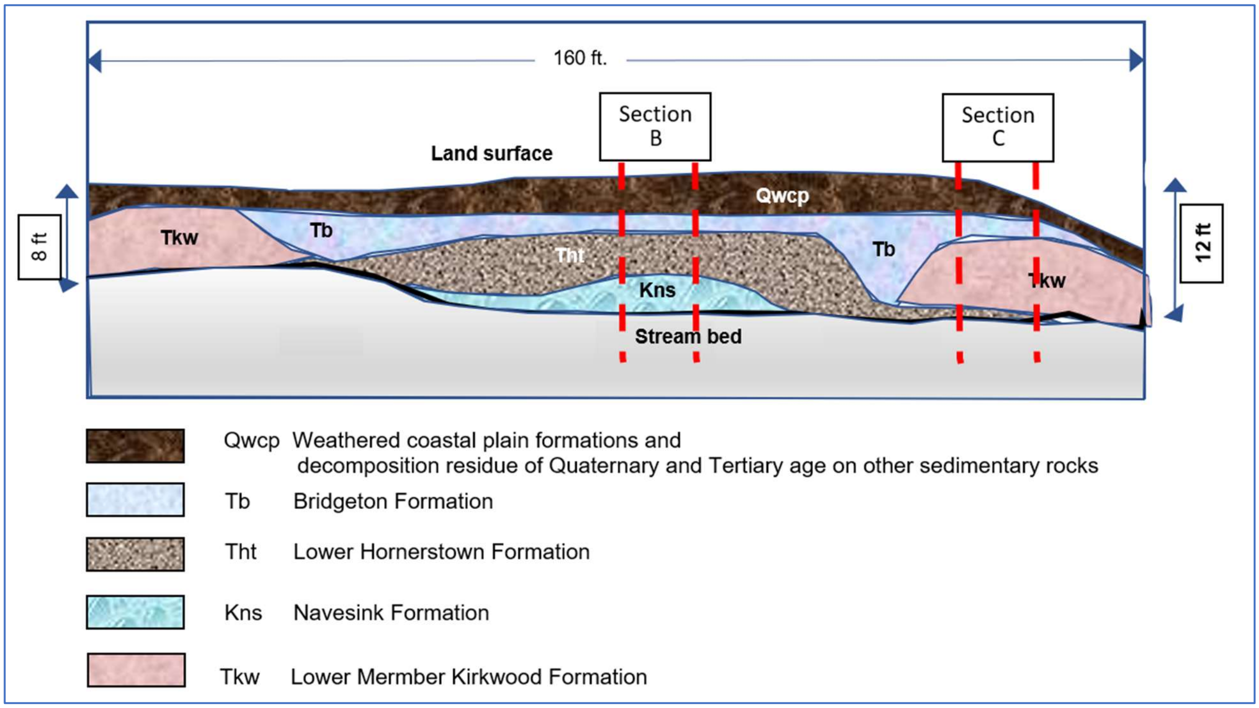

Figure 15. Subsurface geology profile sketched as interpreted along the east bank of the Turtle Creek site, downstream to the right. Sketch by author, MS Word.

Stratigraphy

Sketches and descriptions of the two stratigraphic columns constructed in the positions shown in the site geology profile **Figure 3** are presented below. Sections include lithology symbols for recovered fossils at approximate levels as found in the column. Section B, **Figure 4** and Section C, **Figure 5**.

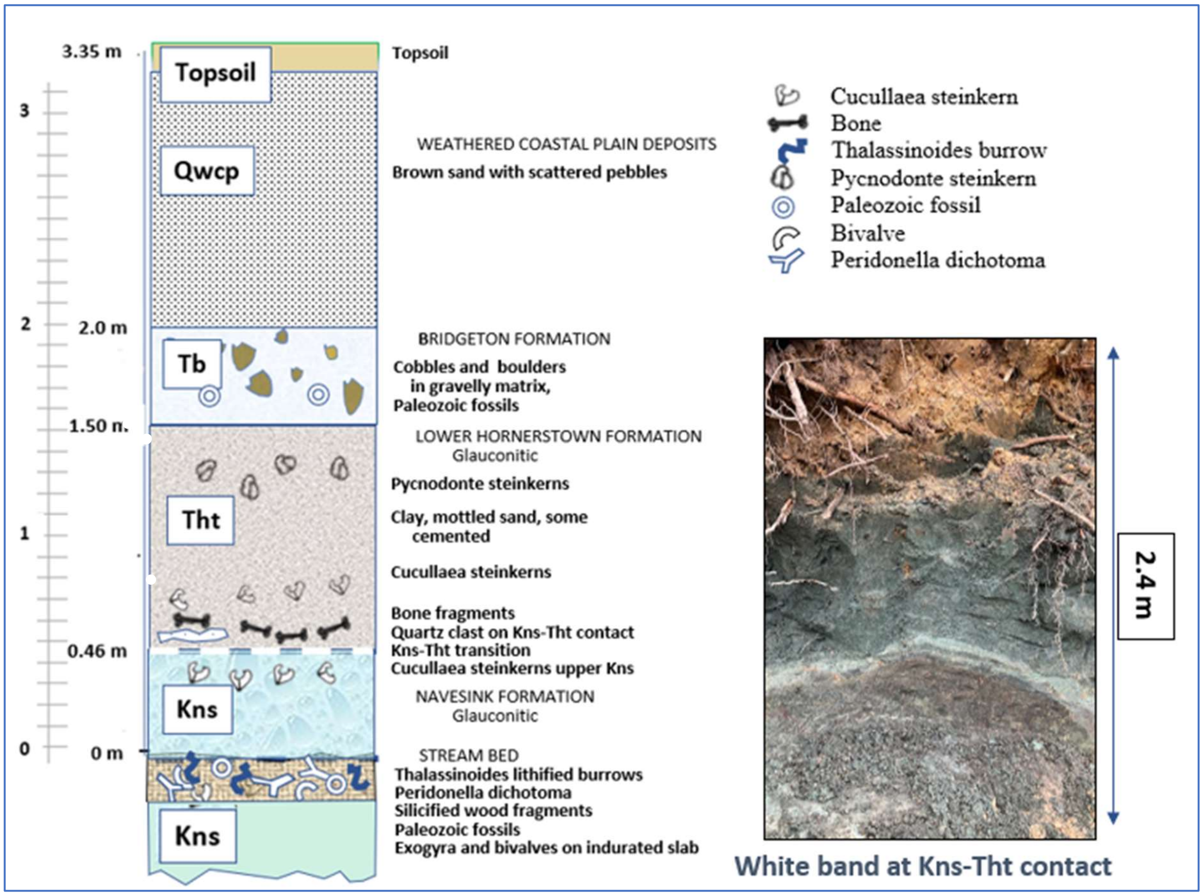

Figure 16. Stratigraphic Section B Turtle Creek site. See site profile Figure 3 for location. The white band at the Kns-Tht contact ranges from 10 cm to 46 cm in width. The bones were recovered from the thicker section of this band off to the right. Sketch by author, MS Word. Photograph by author.

Turtle Creek site, description of stratigraphy at Section B, **Figure 4**. This section is representative of a part of the profile which is only about three meters wide but contains the only exposure of the Navesink along this part of the ravine. Reading from the stream bed upward in section. <u>0</u> Stream bed gravel. Fossil sponges cf. *Peridonella dichotoma,* Indurated mollusks, *Exogyra* and other unidentified bivalves, lithified *Thalassinoides* burrow fillings, oolites, and free form Paleozoic fossils.

<u>0 to 0.46 m</u> Navesink formation: Dark greenish black glauconitic sand with clay content. In the top of this section a few *Cucullaea* sp. steinkerns reside. At the 0.46 m level there is a distinct color change in the glauconitic sand from the Navesink to the Hornerstown. Also, at this contact there appears to be a thin concretion layer cemented with iron oxides.

<u>0.46 to 1.50 m</u> Lower Hornerstown, the basal part of this section appears to be a very complex. In some parts the glauconitic sand appears to be a lighter color, almost white and partly cemented possibly by the clay content. There is also a mix of glauconite grains that range from bluish-black to dark green. The following fossils came from the lighter glauconitic sand that appears to be cemented by the clay content, a few *Cucullaea* sp. steinkerns and some bone fragments which may trace to the MFL. The contact with underlying Navesink Formation appears gradational marked by a distinct color change, a white band and a quartz slab which may be a cemented part of the band of medium to coarse-grained quartz sand which is known to

occur at the Kns-Tht contact. In the upper part of this section the glauconitic sand, appears to be almost pure glauconite, dusky green in color. At about midway in this section some *Pycnodonte* steinkerns.

1.5 to 2 m This appears to be the Miocene Bridgeton formation gravel resting on the Hornerstown Formation at this site. 0.5 m layer of gravel, with fine clay, a few cobble size rocks of quartzite, schist, bits of gneiss and a least one boulder size sandstone rock. At some areas of the contact with the Hornerstown there is a thin concretion layer with iron oxides.

2 to 3.35 m Surface. Layer of brown sand with scattered pebbles up to six centimeters with topmost layer of topsoil

The Turtle Creek site exposes what appears to be the contact of the Lower Hornerstown Formation with the Navesink Formation in Section B, but near the base of the Lower Hornerstown Formation the expected MFL which is reported to stretch across the state (Rowan 2021, online reference) contains only *Cucullaea* sp. steinkerns and a few bone fragments. The ichnofossil, *Thalassinoide*s, has been used to place the MFL at K-Pg exposure sites (Weist et al., 2016). Gallagher, Parris and Spamer, 1986) reported burrows hanging down from the contact but, unfortunately, no lithified burrows or tunnel traces of this taxon have been observed in-situ across this boundary at the Turtle Creek site. Also, the rich faunal content of the Navesink Formation exhibited at the Mullica Hill Pond site (Gallagher, 1993) and at the Rowan Inversand site (Rowan, 2021, online reference) 64 invertebrate taxa recovered from Mullica Hill Pond (Gallagher 1993), six present at Turtle Creek (this report). Although the Vincentown Formation is the next Formation above in the Paleogene stratigraphic sequence above the Hornerstown, it is missing in the Turtle Creek section probably eroded away and replaced by the Miocene Bridgeton Formation. Neither is the diagnostic brachiopod *Oleneothyris harlani* (Morton) present in the stream bed, another indication that the Vincentown Formation was never present in the Turtle Creek upstream watershed. Nor is there any evidence of this taxon at the nearby Mullica Hill Pond site. In Section C, **Figure 5** below, the Kirkwood Formation overlies the Upper Hornerstown Formation without the Vincentown formation. No silicified wood was found in-situ in the Kirkwood, but some fragments were recovered from the stream bed gravel providing evidence of its presence somewhere along the upstream reach of Turtle Creek.

Note that Cross Section B of the Pitman West bedrock geological map shows the Cohansey Formation above the Kirkwood at higher elevations in the vicinity of Raccoon Creek and does not include the Bridgeton Formation (Sugarman, P., Castelli, M. and Kopcznski, K., 2021). The description of the Cohansey does not include any clasts larger than gravel, maximum size 6 centimeters (Pebble gravel, Udden-Wentworth scale) except ironstone which does not appear at Turtle Creek (Cohansey Formation, online reference). As Cohansey lithology does not differ markedly from the surficial weathered coastal plain deposits, Qwcp, it is conceivable that some Cohansey may be mixed in with the surface deposits. The Cohansey Formation is also a source of Paleozoic fossils (Kuehne, Hajzer and Spears, 2022).

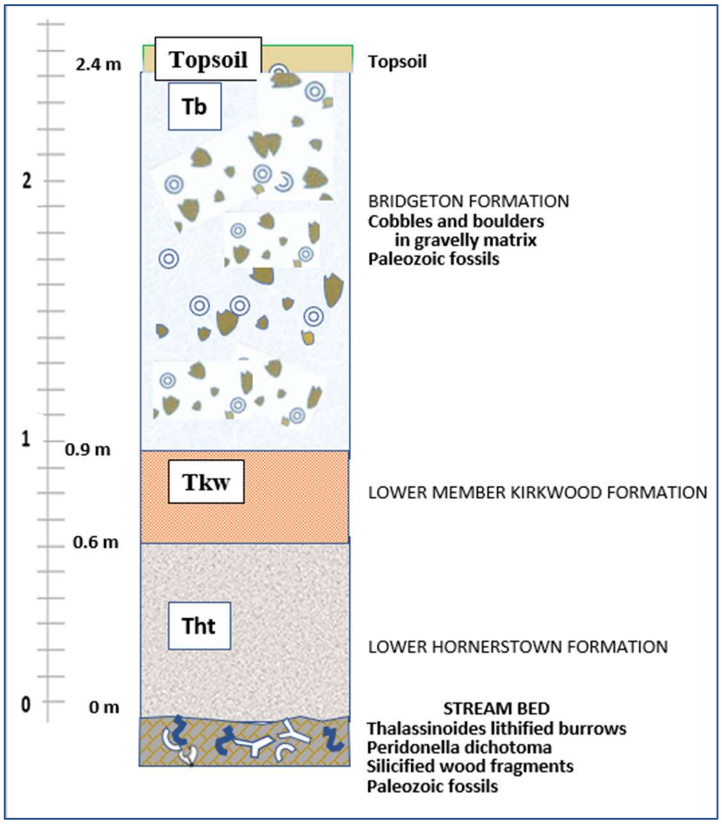

Figure 17. Stratigraphic Section C, showing the layer of Kirkwood Formation, Turtle Creek site. See site profile Figure 3 for location of this section. Sketch by author, MS Word.

Description of stratigraphy at Section C, **Figure 5**. Reading upward from stream bed

<u>0 – 0.6 m</u> Hornerstown Formation, glauconitic sand, dusky green, almost pure glauconite

<u>0.6 to 0.9 m</u> Kirkwood Formation, mix of light gray sand and clay. Note, In this area of Mullica Hill, the Kirkwood is deeply weathered in the outcrop to shades of orange, dark yellowish orange, grayish orange and light gray.

<u>0.9 to 2.4 m</u> Bridgeton Formation, red gravel with small pebbles throughout with some small cobbles.

<u>0.3 m</u> Layer of topsoil at top

The paucity of fossils in the Navesink at Turtle Creek compared to Rowan Inversand and Mullica Hill Pond is probably because fossils are more abundant lower in the Navesink Formation, clear from stratigraphic columns at these sites and from Sugarman, Castelli and Kopcznski (2021) description of the Navesink Formation.

White and glauconitic oolites are present on some indurated molluscan slabs recovered from the stream bed at the Turtle Creek site at Section B **Figure 4**, white form pictured in **Figure 6**. Ooids form in shallow seas in warm, wave agitated water. The basal Hornerstown Formation is characterized by transgressive and regressive sequences which may be favorable to oolite formation (Hornerstown Formation, online reference).

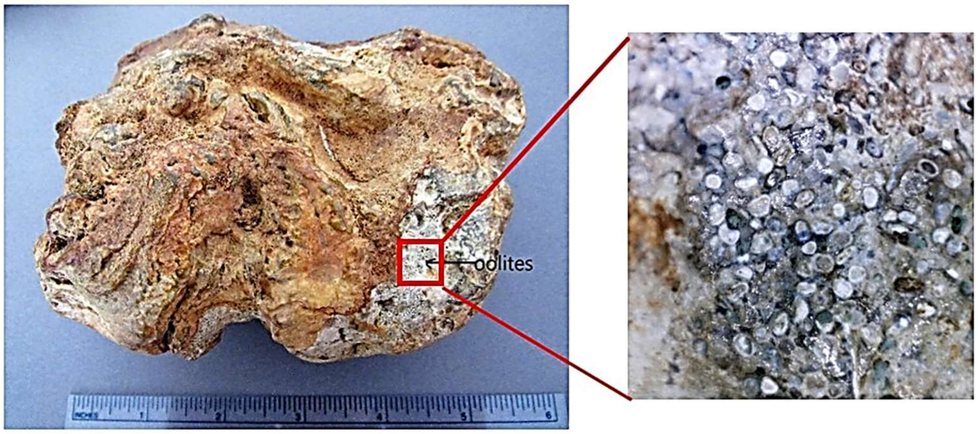

Figure 18. Indurated Mollusca slab from stream bed at Section B, Figure 4 with interior oolites. Photographs by author.

Paleontology

The assemblage of fossils found at the Turtle Creek site is presented in **Table 2** below and systematics, descriptions and photographs in the Appendix, complete for native fossils except bones but only representative Class assignments for the exotic Paleozoic fossils. Except for *Peridonella dichotoma* and silicified wood, all fossils are poorly preserved. Three vertebrate fossils which appear to be bone were recovered from the expected location of the MFL in the lower Hornerstown Formation, symbolized on Section B, **Figure 4**. These vertebrates are highly pyritized, encrusted and poorly preserved. Because of their poor quality, photographs of these vertebrates are not included in the Appendix.

Salisbury and Knapp (1917) speculate that that the chert containing the Paleozoic fossils is in the Miocene Bridgeton Formation and that the fossils there are Devonian, consistent with conclusions at Turtle Creek. The source of Paleozoic fossils on the New Jersey Atlantic Coastal Plain is discussed in Kuehne, Hajzer and Spears (2022). It is remarkable that these Paleozoic fossils, weathered out of probably Devonian diagenic limestone at least 150 kilometers north, have survived with minimal attrition and weathering, another indication of possible ice rafting transport.

<u>Formation</u>
<u>Taxon</u>

Weathered coastal plain deposits, Qwcp.
No in-situ fossils found.
Bridgeton
Representative Classes of Paleozoic fossils in stream bed, two Rugosa fossils recover in-situ
Tabulata
Rugosa
Brachiopoda
Bryozoa
Crinoidea
Kirkwood
Plantae: silicified wood in stream bed, none in-situ
Hornerstown
Cucullaea sp. steinkerns

Bone fragments
Pycnodonte dissimilaris steinkerns
Navesink
Cucullaea sp. (steinkern)

Stream bed gravel
Peridonella dichotoma Gabb
Thalassinoides lithified burrows
Indurated Mollusca slab in stream bed
Exogyra mold cf. *Exogyra costata*
Bivalves unidentified

Table 9. Fossil assemblage Turtle Creek site

BOULDERS

Clasts up to cobble and even boulder size litter the bed of Turtle Creek at the site location. Striations, facets and chatter marks mark some of these clasts as glacially derived indicating Pleistocene age but enigmatically appear to reside in the Miocene Bridgeton Formation with many downwashed into the stream bed. Only the surficial weathered coastal plain deposits (Qwcp) are reported to contain materials of Pleistocene age but no glacial derivatives have been noted in the Turtle Creek exposures of Qwcp, Figure **1**. Apparent striations appear on one cobble recovered from the stream bed **Figure 8**. The surface above the bedrock formations is overlain with Qwcp, Weathered coastal plain deposits, thickness at site discontinuous and less than 10 ft. (Thickness of Surficial Deposits in New Jersey, online reference) but notably does not contain cobbles or boulder sized clasts which are plentiful in the stream bed and in the apparent layer of

Bridgeton Formation central to the site stratigraphy profile, **Figure 3**.

An assortment of stream bed clasts is pictured in **Figure 7**. Many lithologies are represented consistent with the description of Newell et al. (2000) including red shale, schist (cf. Manhattan Schist) and gneiss forms representing bedrock found at least 150 kilometers north in the Newark Group and Ridge and Valley provinces of northern New Jersey or farther into New York State. From Sternberg's law of exponential downstream attrition Chatanantavet, et al., (2010), however, it is unlikely that these irregular clasts have transgressed any significant distance (>100 kilometers) by fluvial transport, suggesting ice rafting along the Delaware River glacial outwash channel. (Kuehne, 2021, online reference). The Bridgeton Formation was deposited by east flowing wash across the coastal plain opposite to the present direction of flow of the Mullica River and its tributaries (Owens and Minard, 1979). Additionally, in fluvial transport, the degree of roundness increases by the logarithm of the distance traveled, so that over a reach of 100 kilometers, only rounds and half-rounds (broken rounds) are expected to survive. None of the large clasts in the bed of Turtle Creek are rounded in this fashion **Figure 7**. Apparent glacial striations on one clast are illustrated in **Figure 8**.

Figure 19. Cobble sized clasts from Turtle Creek stream Bed pictured in Figure 1. Scale bar is 12 inches. Photographs by author.

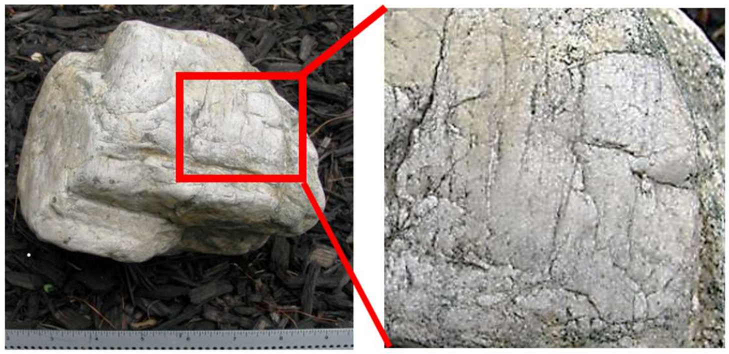

Figure 20. Large cobble from the Turtle Creek site, 10 x 18 centimeters. Appears to have striations on the right side, adjoining inset. Photograph by author.

DISCUSSION

Although Turtle creek is not a spectacular fossil site when compared to the prolific vertebrate and invertebrate discoveries at Mullica Hill Pond and former Inversand site (Rowan, 2021, online reference), the findings at the Turtle Creek site do add to the body of scientific knowledge of the paleontology of New Jersey particularly about the K-Pg transition and the associated extinction event. The site is unusual, however, in many respects including:

1. Unexpected and unexplained sparseness of native fossils in formations exposed at Turtle Creek correlative with Mullica Hill Pond and Inversand (Rowan, 2021).
2. Only a few bone fragments and *Cucullaea* sp. steinkerns were found at the expected location of the usually fossil rich MFL, an exception to the perceived ubiquitous nature of the MFL across the New Jersey Coastal Plain (Gallagher, 1993).
3. Discovery of Paleozoic fossils in-situ in the tentatively identified Bridgeton Formation
4. Large number of Paleozoic fossils lodged in stream bed gravel of Turtle Creek.
5. Incongruous outlier of the Bridgeton Formation in the Turtle Creek site stratigraphy
6. The presence of apparent glacially derived clasts in the stream bed

DATA REPOSITORY

The complete assemblage of Paleozoic fossils recovered from Turtle Creek is included in the data repository at DOI: 10.13140/RG.2.2.10504.70405 Resolve doi name at https://www.doi.org/

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APPENDIX

Paleontology systematics and description

Plate reference key

1	2	3
4	5	6
7	8	9
10	11	12

Plate I, Native fossils from Turtle Creek

1. Porifera. *Peridonella dichotoma* Gabb. Individuals collected from stream bed.

2. Porifera**.** *Peridonella dichotoma* collected from stream bed.

3. Crustacea: Ichnofossils, *Thalassinoides*. Lithified burrows recovered from stream bed. Outside diameter ranges from 1.3 to 2 cm. minimal branching, Light gray exterior indicates Navesink Formation host, reddish sediment filling suggests Hornerstown Formation.

4. Crustacea: Ichnofossils, *Thalassinoides* lithified burrow end view, reddish sediment filling suggests oxidized glauconite filling (Hornerstown Formation, online reference).

5. Crustacea: ichnofossils, *Thalassinoides* lithified burrow end view green filling, probable pure glauconite from the Hornerstown Formation (Hornerstown, online reference).

6. Mollusca, Bivalvia: *Pycnodonte dissimilaris* poorly preserved pyritized steinkerns.

7. Mollusca, Bivalvia: Exogyra. cf. *Exogyra costata*. traced outline on indurated slab of mollusks.

8. Indurated bivalves. Opposite side of No. 7.

9. Mineral, Oolites on No. 8, enlarged view.

10. Mollusca, Bivalvia: *Cucullaea* sp. cf. *vulgaris*, poorly preserved steinkern with some thin patches of shell material. Found in-situ in the basal Hornerstown Formation. From on-line research, *Cucullaea* fossils are often only internal molds.

11. Mollusca, Bivalvia. *Cucullaea* sp. from Hornerstown Formation, poorly preserved steinkern. Opposite side view of No. 10.

12. Plantae: silicified wood fragments from stream bed.

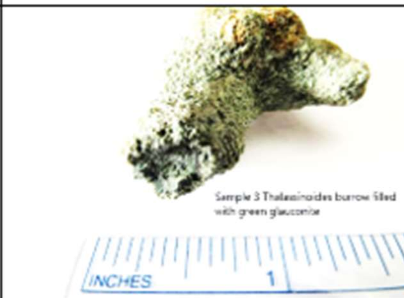
Plate I - Native fossils of Turtle Creek.

Peridonella dichotoma

Peridonella dichotoma

Thalassinoides

Thalassinoides

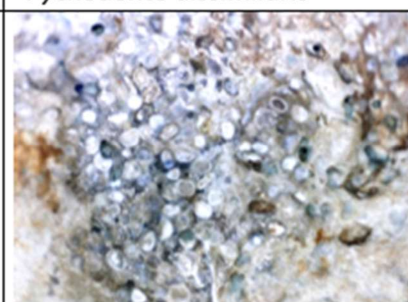


Thalassinoides


Pycnodonte dissimilaris


Exogyrid. cf. *Exogyra costata*


Indurated bivalves


Oolites on No. 8,

Cucullaea sp. cf. *vulgaris*

Cucullaea sp. cf. *vulgaris*


Silicified wood fragments

Plate 2 Paleozoic fossil Classes with representative specimens. References **[n]** follow plate.

Plate reference key

1	2	3
4	5	6
7	8	9
10	11	12
13	14	15

Brachiopoda

1. MH 101. Brachiopoda, cf. *Leptaena rhomboidali*s, 24 mm wide, buff, Ordovician (Llanvirn) Devonian (Pragian)[**2**], [**1**](p. 38,pl. 132, figs. 16-20), found in Devonian of New York and Pennsylvania
2. 2nd view, *Leptaena rhomboidali*s
3. MH 172. Brachiopod, spiriferid, 10 mm, tan, external mold on poriferid fossil.

Porifera

4. MH 110. Porifera, Demospongea, cf. *Hindia* sp., 32 mm wide, white, spherical, with narrow canals that radiate from the center of the sphere, found in New York, New Jersey, Ordovician through Permian, [**5**].
5. MH 112. Porifera, Stromatoporoid, cf. *Labechia* sp., 45 mm long, buff. Silurian, Earlton, Ontario [**6**].
6. MH 113. Porifera, Schlerosponges, cf. *Chaetetes* sp., length 50 mm, width 22 mm, buff. colony of long slender tubes that radiate from center, corallites polygonal to rounded, septa absent in calices, widespread in North America, Middle Devonian through Permian [**5**].

Rugosa

7. MH 107. Rugosa, cf. *Heliophyllum canad*ense, 31 mm long, buff, horn shape, calice 23 mm wide, Devonian, Onondaga limestone of Mendon, Ontario [**3**].
8. MH 103. Rugosa, cf. *Heliophyllum* sp., 10 mm long, white. small solitary, conical, calice 15 mm wide with septa, widespread in eastern North America, Lower and Middle Devonian [**5**].
9. MH 108. Rugosa, cf. *Hexagonia* sp., colonial, irregular shape, buff, corallites averaging 2 to 3 mm in diameter, some with faint septa, found in the Devonian Limestone of Genesee County, New York [**1**].

Tabulata

10. MH 147. Tabulata, favositid, *Favosites turbinatus*, 25 mm, buff.
11. MH 166. Tabulata, cf. *Favosites* sp., corallites 3 mm wide, white, widespread in North America, Upper Ordovician through Middle Devonian [**5**]..
12. MH 148. Tabulata, favositid, cf. *Favosites* sp., 20 mm wide, white. oval, corallites 1 mm wide, polygonal, white, widespread in North America, Upper Ordovician through Middle Devonian [**5**].

Miscellaneous

13. MH 177. Crinoidea in chert matrix on MH 174.
14. MH 170. Porifera, Archaeocyathid, cf. *Archaeocyatha* sp., partial specimen in chert clast, buff, found in the Cambrian [**3**].
15. MH 111. Tabulata, favositid, cf. *Favosites* sp., 48 mm wide, buff, mound shape with bottom center stalk, tightly packed corallites, less than 1 mm wide, widespread in North America, Upper Ordovician through Middle Devonian [**5**].

Plate 2. Paleozoic fossils Turtle Creek site

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5. Thompson, 1994, National Audubon Society Field Guide to North American Fossils. National Audubon Society.

6. Fossilarium. Available online at: https://www.fossiles.ca/en/learn/local-fossil-classification/stromatoporoids-rough-sponges/