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)**.

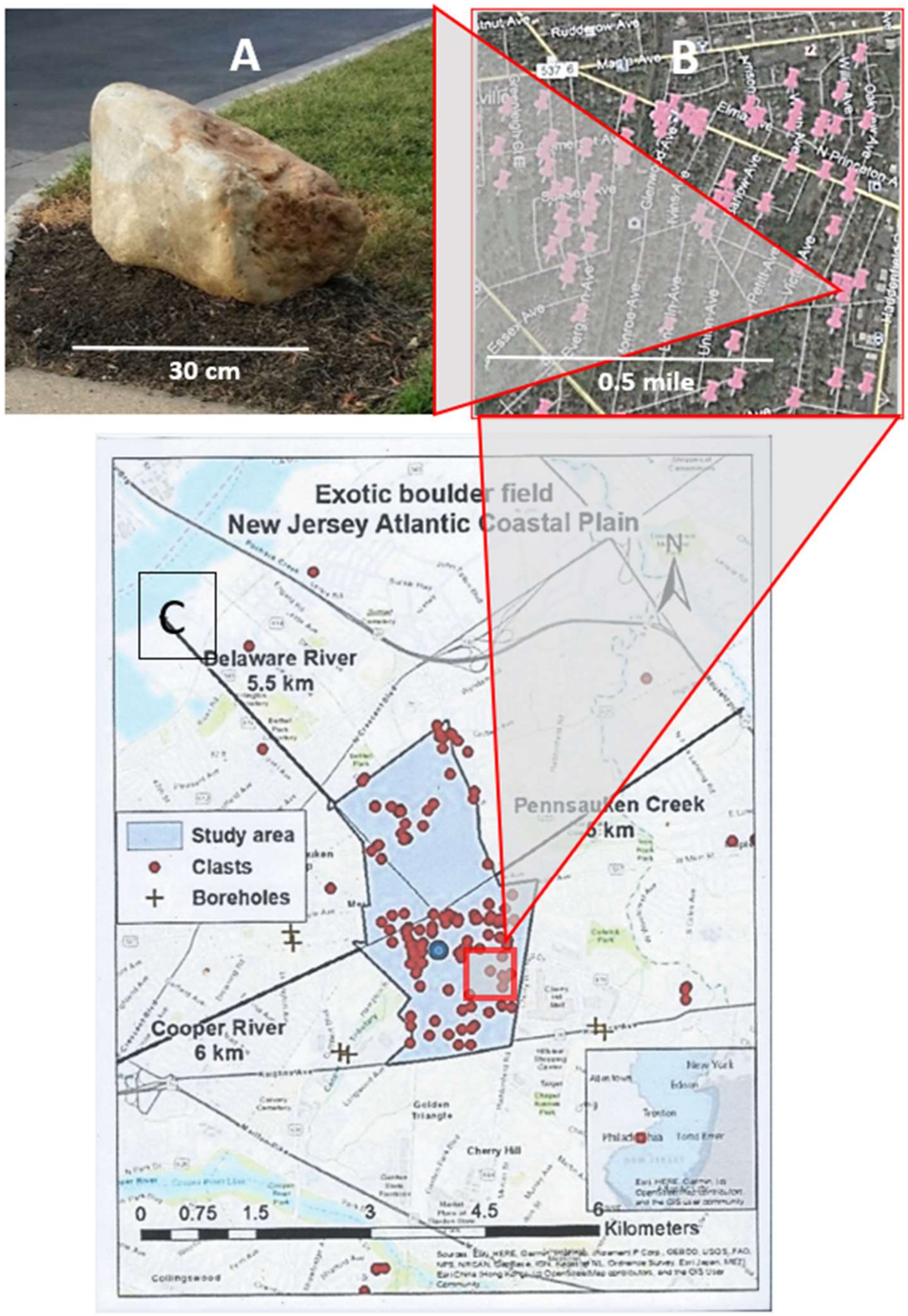

Figure 3. Exotic boulders within the study area and broader area of interest showing proximate major waterways and existing boreholes used to assess subsurface stratigraphy. The blue circle marks the location of the GPR survey. A. Typical boulder lodged in front of a residential property; B. Section 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**).

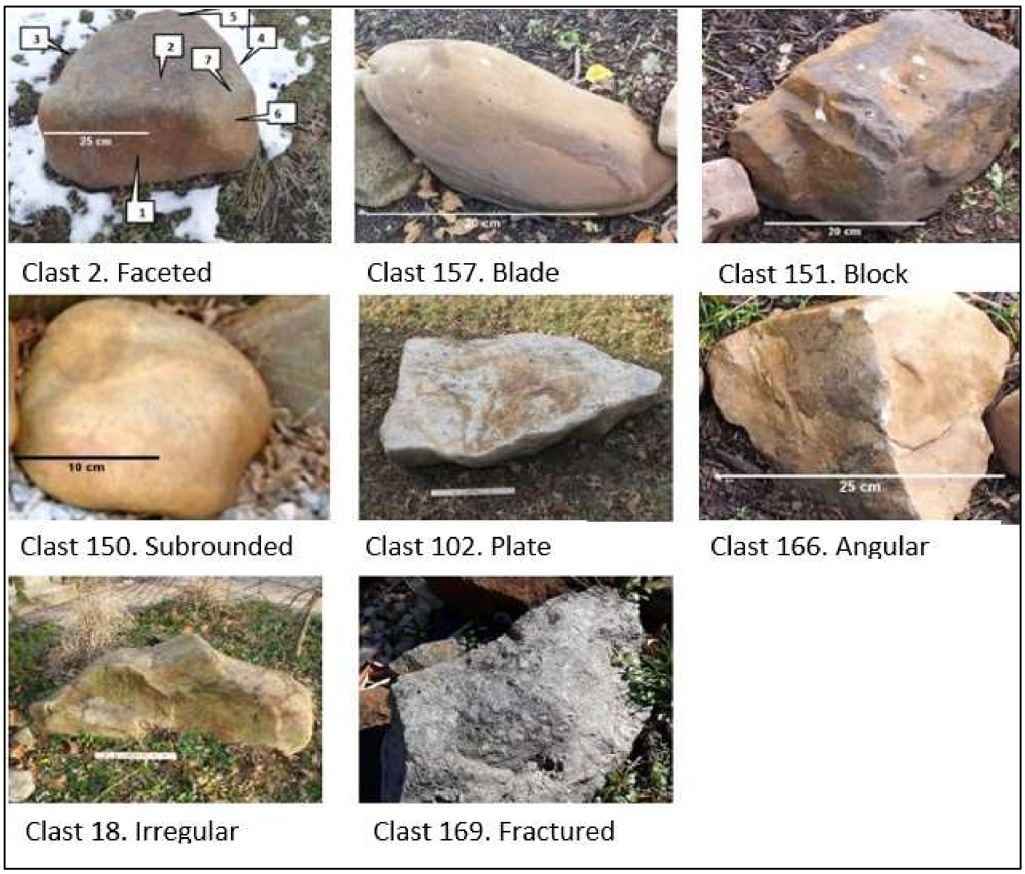

Figure 4. Shape classes of boulders within the area of interest.

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.

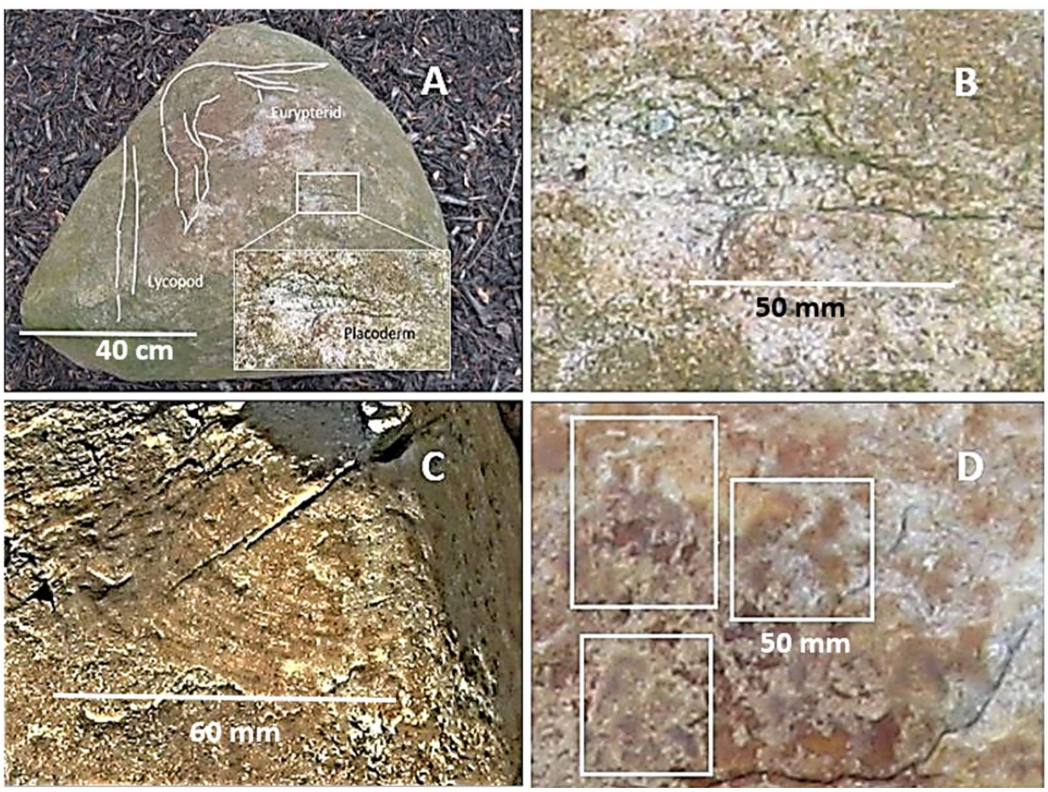

Figure 7. Devonian fossils. A. Clast 127. Fossil traces include eurypterid, lycopod and placoderm, see inset and enlargement adjoining for the placoderm traces. B. Clast 127. placoderm tail and pectoral appendage detail, scaled tail indicates *Pterichthys*. C. Large bivalve on Clast 118. D. *Archaeopteris*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

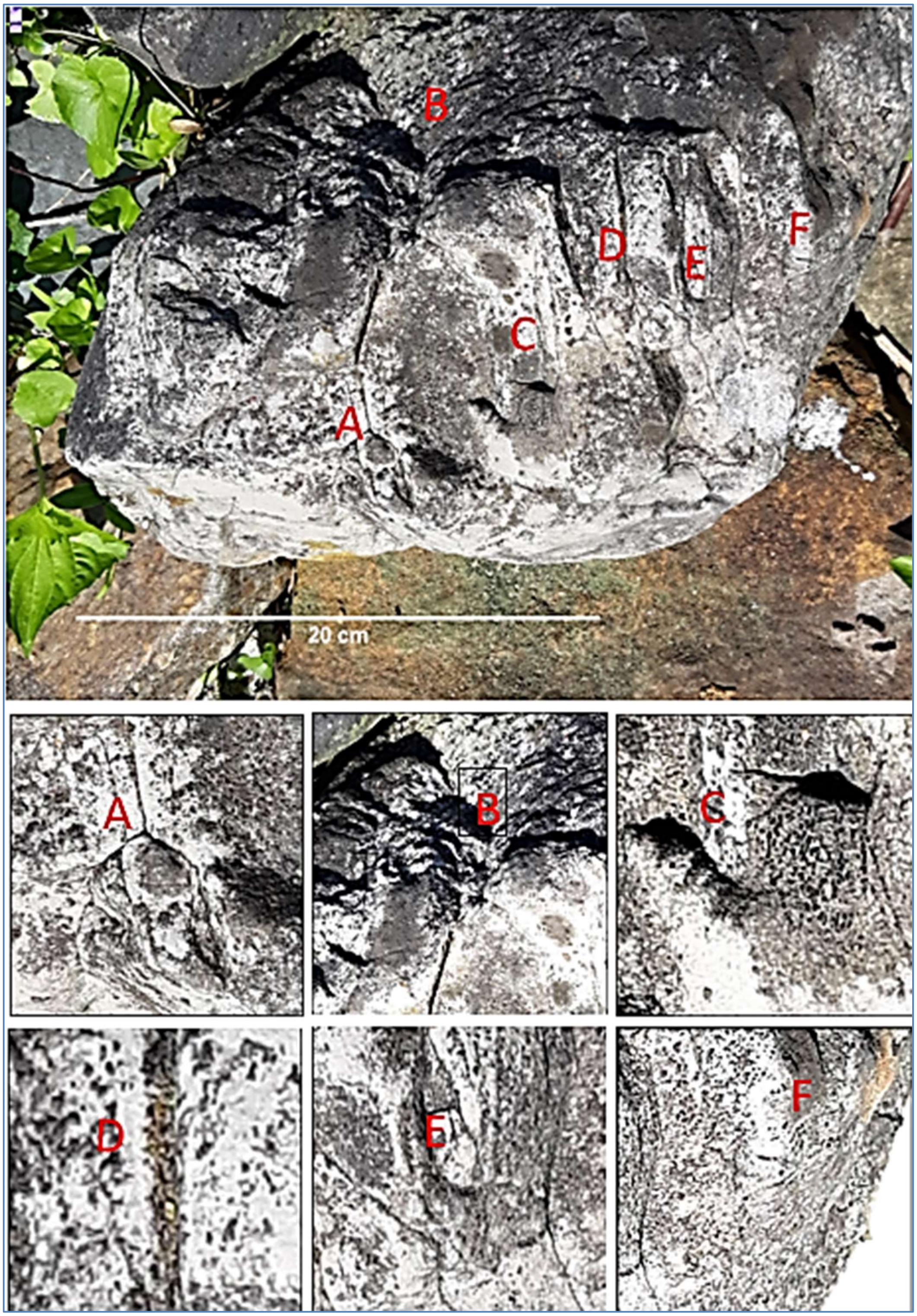

Figure 8. Devonian plant fossils on Clast 200. A. Plantae or crinoid? B, C. *Psilophyton* carbonized leaves, D. *Archaeosigillaria*, E. *Lepidodendron*, F. *Archaeopteris* pinnules.

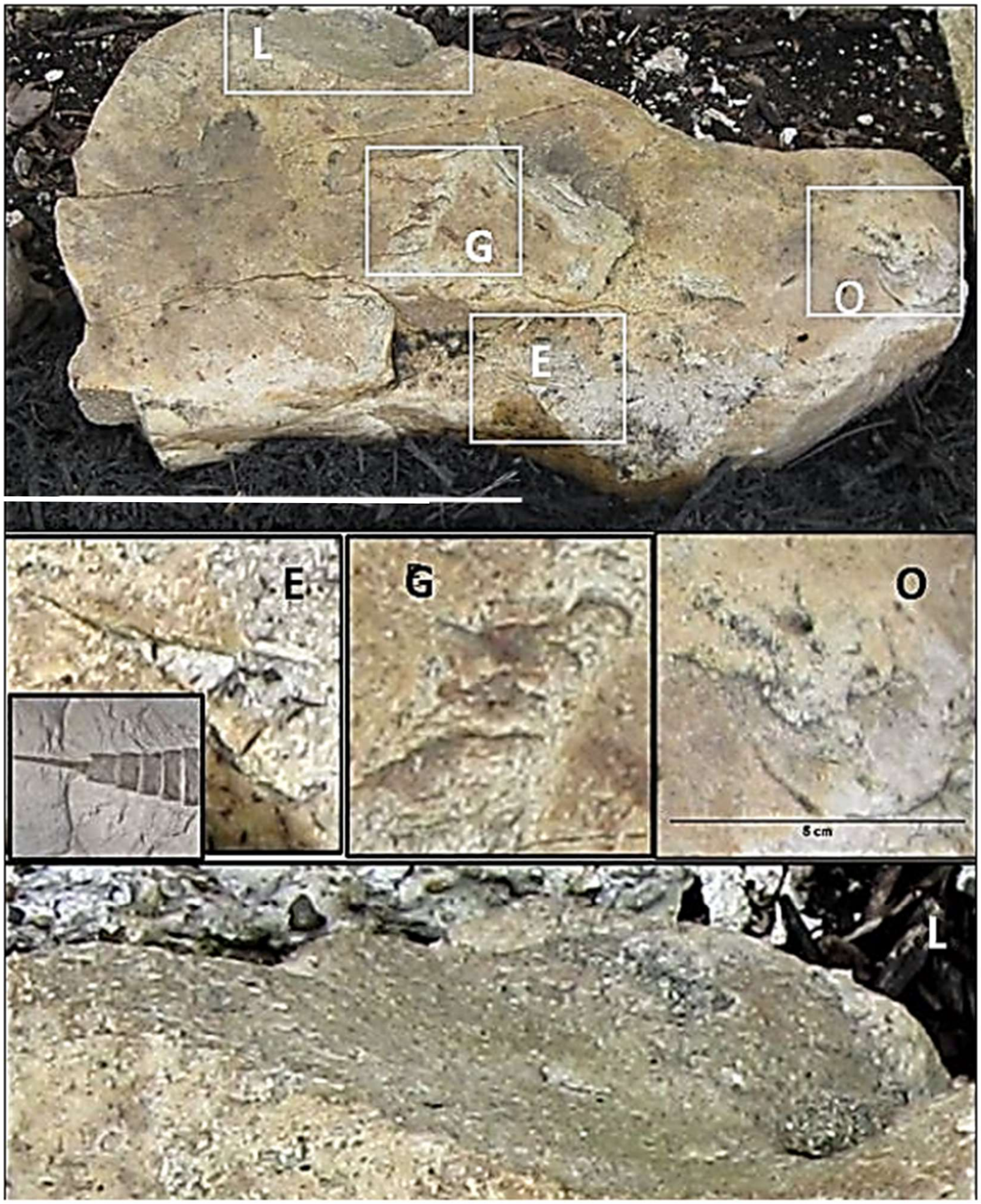

Figure 9. **Clast 117. E. Eurypterid, inset for comparison, G. *Gyrolithes*, L. *Archaeopteris* pinnules, O. Ostracoderm.**

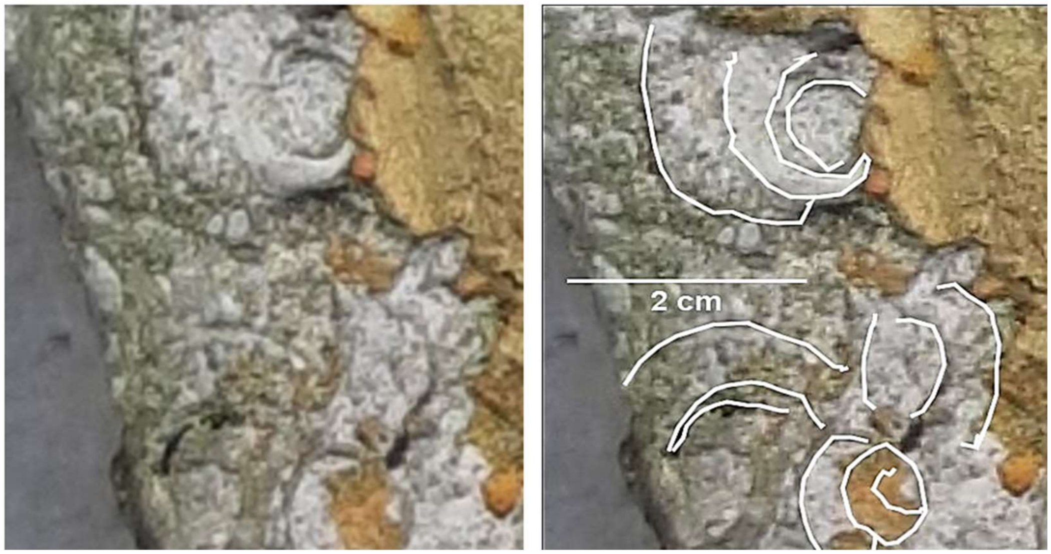

Figure 10. Gastropod group on limestone Clast 189, cf. *Pleurotomaria tuboides*. L. image, R. traced gastropods on the image.

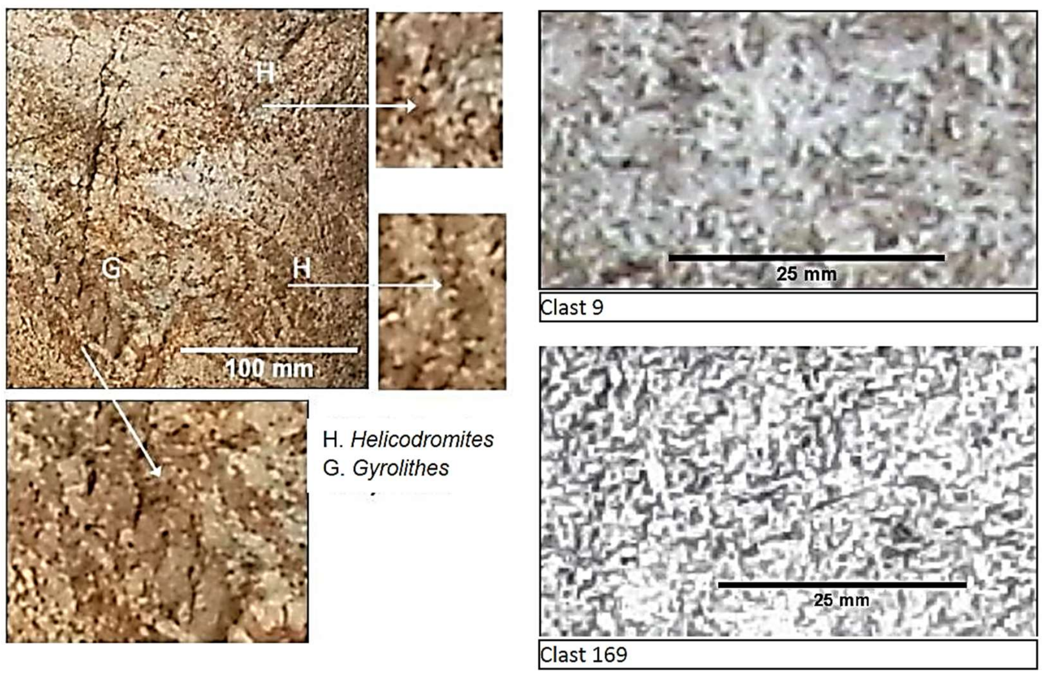

Figure 11. Left, Ichnofossils *Gyrolithes* and *Helicodromites* on Clast 16. Right, *Chondrites* fabrics on Clasts 9 and 169.

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.

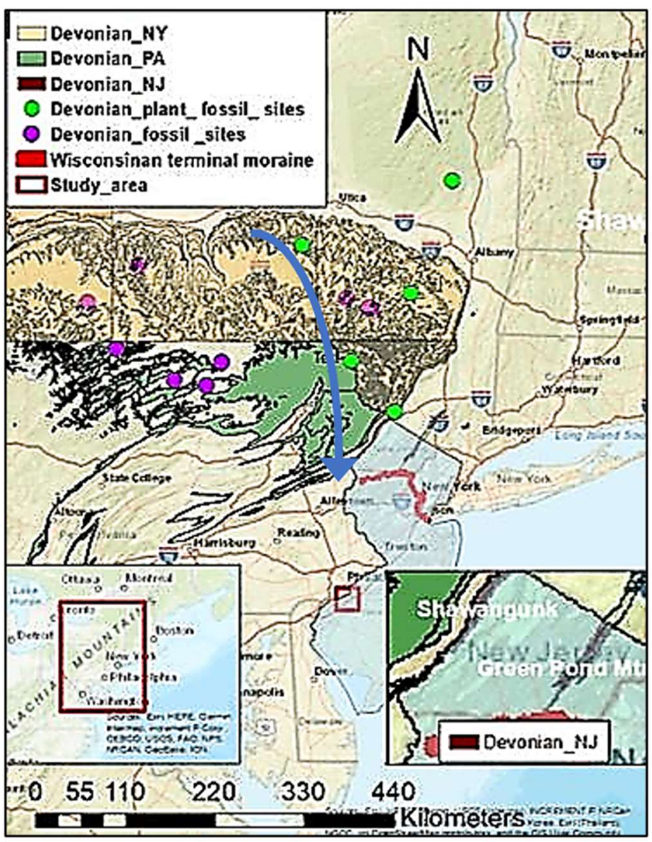

Figure 12. Devonian rocks and fossil sites in the Pleistocene glaciation catchment area. The arrow marks the general path of glaciation towards the study area. ArcMap by author. Details of Devonian plant fossil sites are included in Table 4.

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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