The Mosasaur

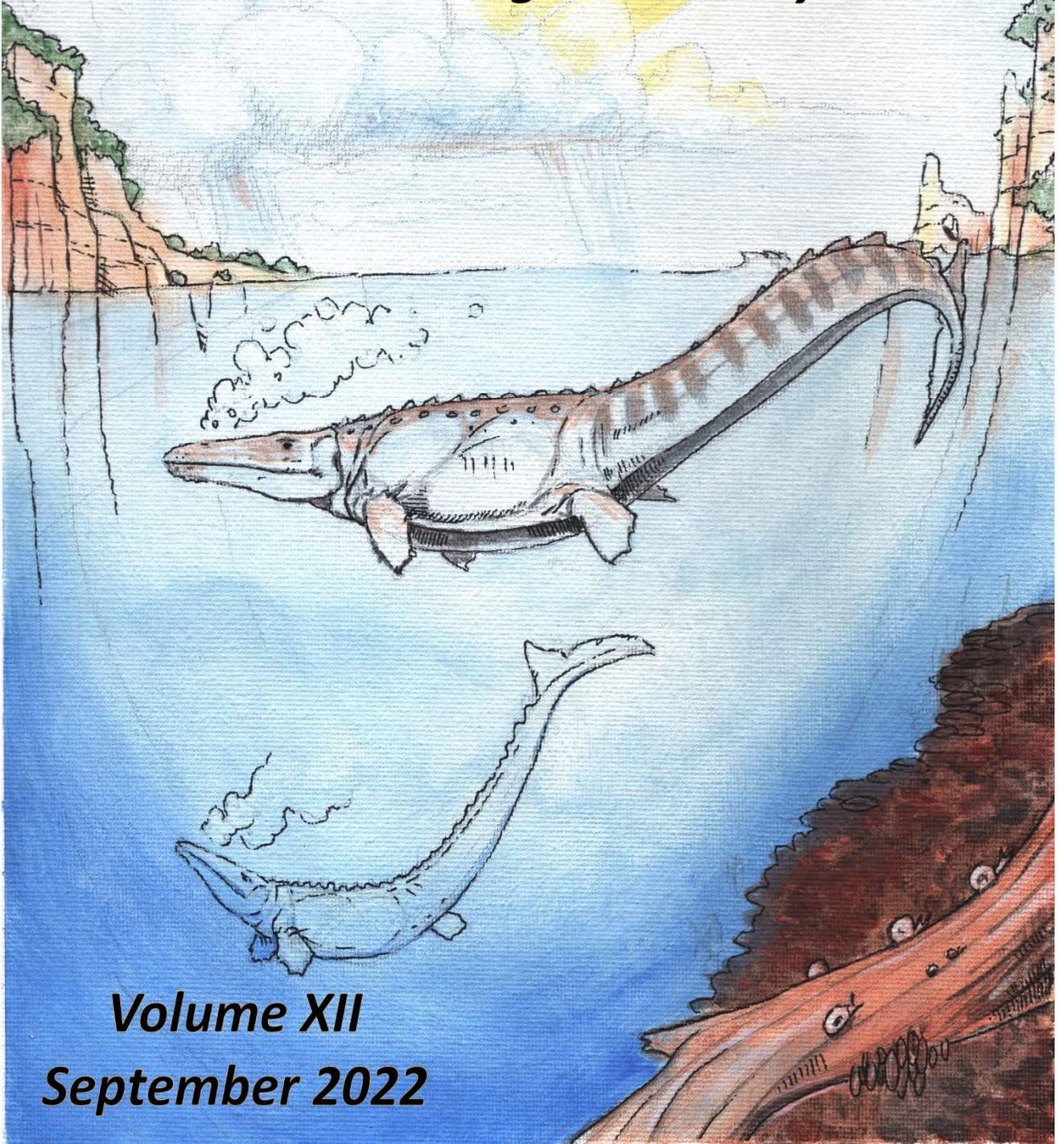## The Journal of the Delaware Valley Paleontological Soceity

Volume XII

September 2022

The Mosasaur

Volume 12, July 2022

The Journal of the Delaware Valley Paleontological Society

COVER ART – The cover art was painted by Jason Poole and depicts a school of Mosasaurs.

NEW BIOSTROMES DISCOVERED AT THE UPPER CRETACEOUS (CAMPANIAN) STONE BRIDGE FOSSIL SITE IN CAMDEN COUNTY, NEW JERSEY

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Abstract - This report describes and analyzes two newly discovered biostromes, one calcareous and the other concretions leached of calcareous content, found lower in section and downstream from the historic biostrome investigated by previous studies of this Upper Cretaceous (Campanian) Stone Bridge fossil site in Cherry Hill Township, Camden County, New Jersey. The paleontology, taphonomy and ecology of the overall site is reinterpreted and addresses the newly discovered biostromes. A faunal assemblage of 129, many new to the site, was recovered with 23 exotic Paleozoic fossils, mostly corals, collected from alluvium in the stream bed. Derived from bedrock geology and paleontology, the site appears to be in the Englishtown Formation, however, lithology suggests that the site rests in the Woodbury Formation consistent with conclusions of other site investigations. The bivalve suite is dominated by *Cyprimeria depressa* at 61% of the class in a *C. depressa*-Turritellid association. Bivalve trophic mode and relative abundance suggest that the historic biostrome was originally an ecological community displaced by a light taphonomic process interpreted as a storm event. Recovering both *Cucullaea* and *Lucina* assemblages together challenges Weller's stratigraphic water depth proposition that these assemblages do not overlap. Photographic plates of all good quality specimens are included.

INTRODUCTION

Site history

Over time, many fossil collectors have visited the Stone Bridge site, but vertebrates were usually their primary interest and, as far as known, their specimens have never been reported. The first known published description of the paleontology of the Stone Bridge fossil site was provided by Kuehne, D. (1993), but he continued to collect fossils from the Stone Bridge site up until 2003 (pers. obs.). In 2016, his entire home-based Stone Bridge fossil collection was donated to the New Jersey State Museum (NJSM) where it was inventoried by Lauren Jamel (unpubl. data) and curated by us at NJSM 2016 to 2018. Following curation and review of field notes, we described Kuehne, D.'s work at the site, adding photographs of identifiable specimens, more detailed geology of the site and correlation with five other similarly situated sites along the New Jersey Upper Cretaceous, Woodbury-Englishtown contact strike including Haddonfield (Kuehne, W. and Kuehne, A., 2018). In the interim, Oman et al. (2016) did an intensive investigation of the Stone Bridge site describing many new vertebrate taxa and interpreting site taphonomy and ecology. Coincident with Oman et al.'s work, Stringer et al. (2016) described seven new families of parrot fish from the 1800 otoliths recovered from the site by Oman et al. After Kuehne, D. passed in 2003, we ourselves independently collected fossils from the historic exposure and from two previously

unreported biostromes discovered downstream and now add our findings and conclusions to the paleontological record of the site. All three collections now reside at NJSM except the otoliths and a few of Kuehne, D.'s vertebrate specimens which reside at the Academy of Natural Sciences of Drexel University in Philadelphia, PA.

Highlights of this report:

• Description and analysis of two newly discovered biostromes, below the historic biostrome, one calcareous and the other a concretion layer leached of calcareous content.

• Complete fossil assemblage of 129 taxa including 28 vertebrates, 54 bivalves and 22 gastropods.

• Photographs of all recognizable, good quality specimens, 6 plates with 144 photographs.

• Extended description of the site geology and stratigraphy to include the two newly discovered biostromes.

• Reinterpretation of the overall site taphonomy and ecology with insights from the additional biostromes.

• Correlation of the three major investigations of the Stone Bridge site.

Explanations

Fossiliferous exposures in this report are designated "biostromes" rather than "lags" because of the absence of debris in the matrix, however, in mapping, the biostromes are referenced simply as, "beds."

To avoid confusion (Kuehne, 1993) and Kuehne, 1999) in text reference citations will include the author's initial as (Kuehne, D., 1993) and (Kuehne, D., 1999) to distinguish from (Kuehne, W. and Kuehne, A., 2018). Note also that the report, (Kuehne, W. and Kuehne, A., 2018), was built on Kuehne, D.'s collection from the Stone Bridge site.

METHODS AND MATERIALS

Study Area

Though the Stone Bridge site has already been well described in the earlier reports outlined in the Introduction to this report, a brief overview may be expedient as a refresher and for new readers. Located in Cherry Hill Township, Camden County, New Jersey, the site is situated along a small east to west trending, unnamed tributary of the south branch of the Cooper River. From the bridge, for which the site is named and which marks the eastern limit of the site, the tributary flows westward about 0.42 kilometer to Wallworth Lake in Cooper River Park. Downslope from the site, the stream gradient is shallow, ranging from 5 meters elevation at the historic exposures near the bridge to 4 meters at its confluence with Wallworth Lake. The entire stream reach is punctuated with a discontinuous chain of gravel bars and intervening scour pools. Although moderately ephemeral, in this report the principal gravel bars have been numbered for orientation, from 1 at the Wallworth Lake base to 11 at the bridge which, for simplicity, are prefixed with, "G." Previous workings are all associated with G11, designated as the "historic" site. This report now adds findings from Gravel bars G10, G9 and G8, with G10 a newly discovered calcareous biostrome, G9 principal collecting site for fossils outwashed from the upstream calcareous biostromes on G11 and G10 upstream and G8, the newly discovered downstream leached fossiliferous concretion bed. All known exposures where fossils have been collected at Stone Bridge are indicated on the site plan **Figure 1.**

Prospecting east upstream from the bridge an additional 600 meters to 9 meters elevation did not reveal any additional fossils or traces even though dark clay was well exposed in the stream banks. Outside of the historic exposures, from the south bank fossils spill down from an unidentified source above G11 and vertebrates from upstream and higher indicating that fossiliferous exposures lie beyond the limits of the study area but not upstream from the bridge. A typical gravel bar, G9, is illustrated in **Figure 2.**

On G9, several bioturbated, thin siderite plates appear to be from a hardground, but the position in the stream bank was not evident, see Hardground section of this report for more details. Oman et al.'s (2016) excavation on G11 penetrated vertically 70 cm into the formation revealing two stacked 15 cm thick fossil beds separated by 10 cm of silt, clay and lignite, and a potential third bed below. It is possible then that the shell bed investigated by Kuehne, D. (1993), Kuehne, W. and

Kuehne, A. (2018) and our work on G11, described in this report, correspond to Oman's upper shell bed and the newly discovered lower shell bed on G10 correspond to Oman et al.'s lower shell bed (see Stratigraphy section of this report for details). Because Oman et al. penetrated 70 cm, their lowermost, third layer, may correspond to the leached bed discovered on G8.
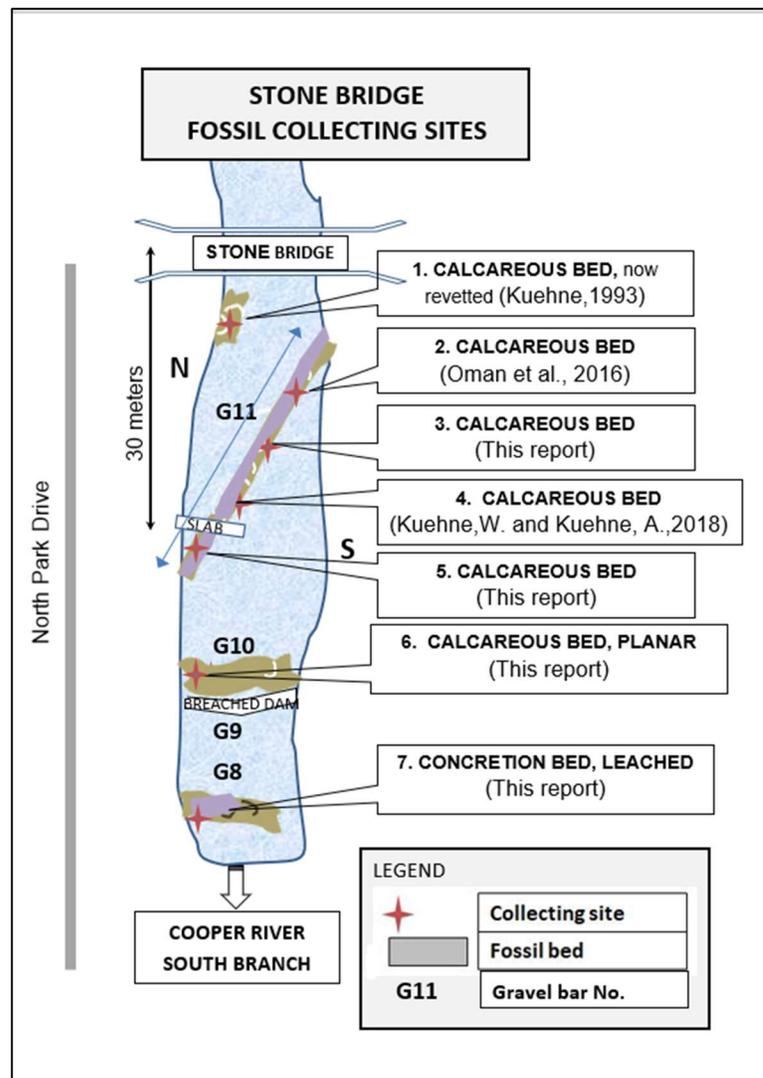

Figure 1. Stone Bridge fossil site with numbered fossiliferous formation exposures.
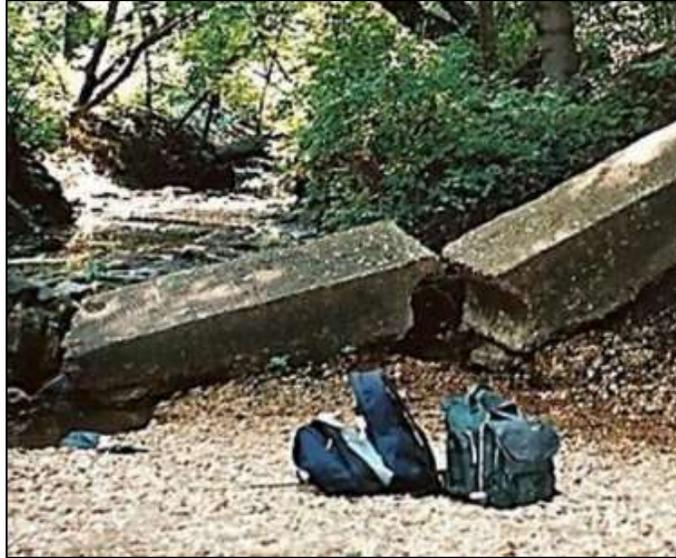
Figure 2. A typical Stone Bridge gravel bar, G9. View is upstream to G10 just across the breached dam towards G11 in the distance. Note unsorted float gravel catchment for fossils downwashed from upstream fossiliferous exposures on G10 and G11.

Field work

Specimens were collected at the site by random sampling of calcareous fossiliferous outcrops on G11 and G10, approximately two kilograms each. Screening offsite tended to fragment most of the calcareous material, but a few small articulated bivalves, *Breviarca haddonfieldensis* and *Corbula crassaplica,* survived intact. Larger taxa, however, were often identifiable from the shattered remains. Fossiliferous concretions from the leached bed G8 were split and fragments exhibiting good quality fossil molds were recovered and preserved by impregnating with a polyvinyl acetate solution (Elmer's glue mixed 50% with water) and cured. Objects identifiable on the surface of these shards were used in the paleoecology analyses of this report, see Ecology section. A few molds were taken directly from the dark clay formation exposed outward from the exposures on G11 and downstream below G8. Vertebrate fossils though were recovered from the Stone Bridge site mainly by surface collecting and screening of stream bed float gravel downstream from the fossiliferous exposures on G11, G10 and G8. Also, some in-situ vertebrates were recovered in the

screens from sampling of the calcareous beds on G11 and G10. On the leached bed, some concretions contained embedded vertebrates. See **Plate 1**, fig, 20, in **Appendix 2** for an example of a pristine *Scapanorhynchus texanu*s lateral tooth embedded in a concretion from G8.

RESULTS

Geology

Previous investigations of the Stone Bridge site assign the geology to the Woodbury Formation even though, the New Jersey Geological and Water Survey map of bedrock geology shows the Stone Bridge site in the Englishtown Formation **Figure 3 (**Stanford et al., 2004). Lithology, however, indicates the fossil beds are in the Woodbury Formation. The differences between mapping and lithology suggests that the site is in the transitional zone.

Fortuitously, the tributary hosting the fossil site is almost exactly aligned with the NW-SE dip of the Upper Cretaceous formations of New Jersey. From the surface at Wallworth Lake the Woodbury Formation dips down at a 0.44° degree angle so that

the contact with the Englishtown Formation calculates 4.2 meters below the fossiliferous Stone Bridge exposures. Weller (1907) reports the Englishtown Formation as predominately quartz sand with the lower few meters transitional with the underlying Woodbury Formation.

The differentiation of the formation (Englishtown) from the subjacent Woodbury clay is rather sharp, the transition from the clay to the sand being accomplished in a thickness of two or three feet at the most. The formation passes upward by a somewhat rapid transition into the overlying glauconitic or sandy clay, so that its upward limit can be easily recognized.

The United States Geological Survey (USGS) reports that the Englishtown Formation sand is interbedded with thin to thick beds of dark clay (Englishtown Formation, online). These features are evident at Stone Bridge, sand lenses or layers between the clay interbeds contain the calcareous fossils. A sedimentation test of a sample of the biostrome on G11 showed no clay (pers. obs.). The geology at the Stone Bridge site more resembles the USGS description than Weller (1907), the differences illustrating along strike variability of the Woodbury-Englishtown transition.

Feature	Stone Bridge	Haddonfield
Formation as mapped (Stanford et al., 2004)	Englishtown	Woodbury
Marine vertebrates	Common (Kuehne, D.,1993, Oman et al., 2016), (this report)	Rare (Kuehne, D., 1993), (Kuehne, W. and Kuehne, A., 2018)
Association	*Cyprimeria depressa* (61%)-Turritellid (18%) association, at 79% dominance (this report)	None (Kuehne, W. and Kuehne, A., 2016)
Life position	None reported	(Kuehne, D., 1993) *Gervilliopsis ensiformis* and *Pinna laqueata*
Simpson's Similarity Index (Kuehne, D., 1999)	40.1%, less than expected if Stone Bridge and Haddonfield are both in the same formation	

Table 1**. Comparison of geology and paleontology, Stone Bridge-Haddonfield fossil sites.**
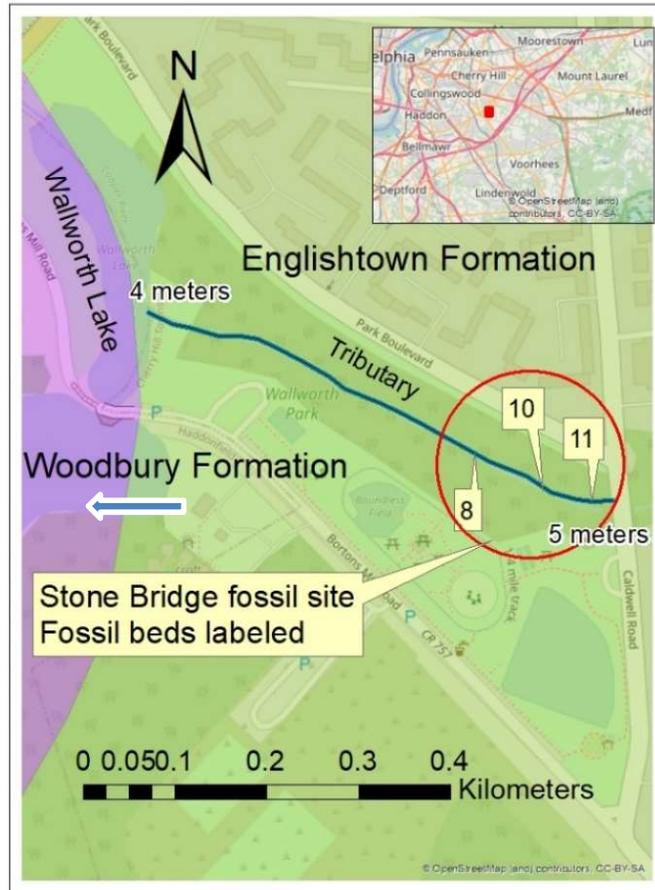
Figure 3. Bedrock geology Stone Bridge fossil site showing principal collecting exposures and stream terminal elevations (Stanford et al., 2004). ArcMap by authors.
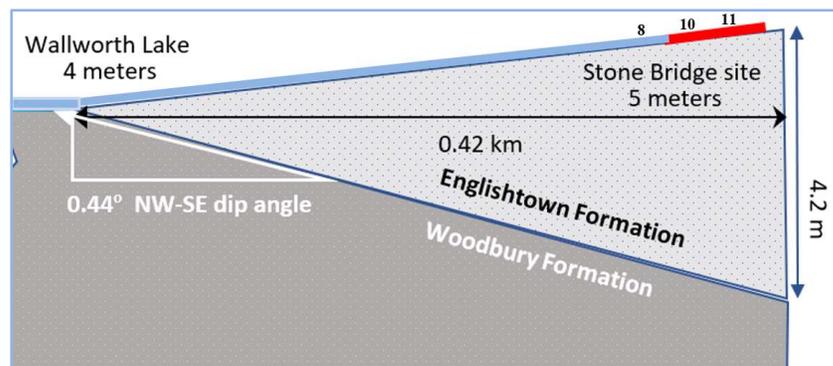
Figure 4. Subsurface stratigraphy along the Stone Bridge tributary. Dip 0.44° of the Englishtown-Woodbury Formation contact is approximately colinear with the NW-SE trending tributary. The site is shown in red showing principal gravel bar collection sites covered in this report, G11, G10 and G8.

Stratigraphy

A composite stratigraphic section was synthesized from observations at G11, G10, G8, at the stream bed and along the banks over the reach of the tributary **Figure 5.** The narrow horizontal stringer on G11 (**Figure 1)** may have a limited vertical dimension, 15 cm, if equivalent to Oman et al.'s shell bed 1 (Oman et al., 2016). Bed G10 appears more tabular than the narrow band of the historic site, G11. Bed G8 has a horizontal exposed trace and appears planar but of unknown vertical extent unless it corresponds to Oman et al.'s shell bed 3, then may be limited vertically. A significant silt fraction, however, is evident from the infaunal to epifaunal ratio I/E of bivalves close to 2, infaunal, I; muddy or silty substrate, epifaunal E; sandy substrate. The matrix of the leached concretionary bed appears to be coarse sand, loosely cemented. Shell beds, G11, G10, G8, may correspond to Oman et al.'s three shell bed site stratigraphy from their excavation on G11, **Figure 6**.
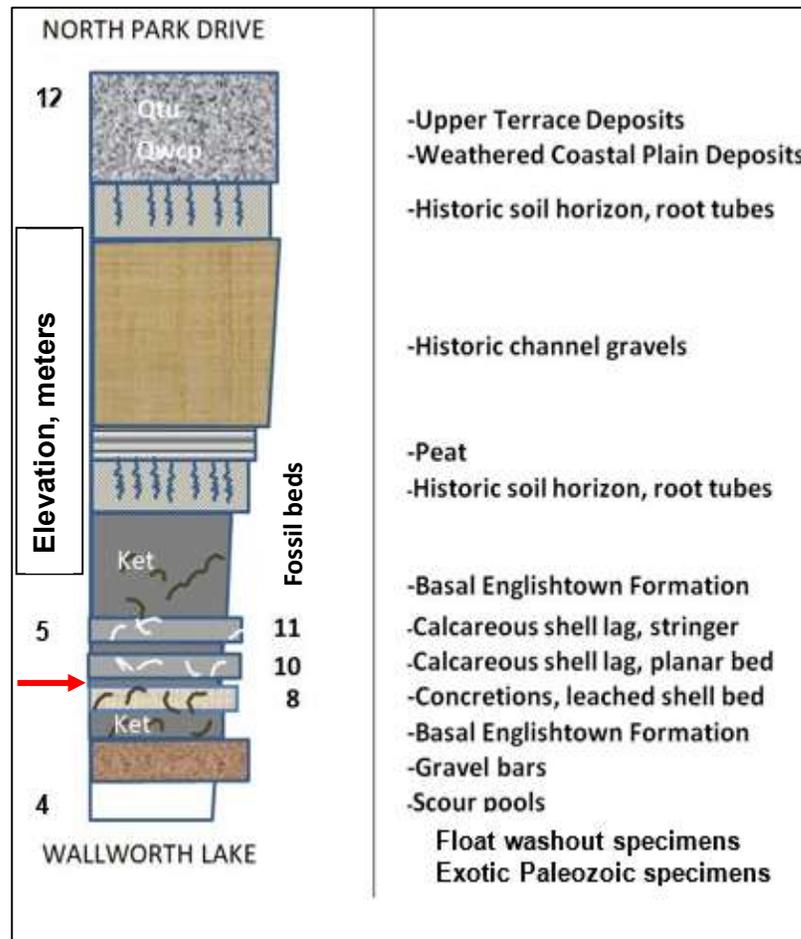

Figure 5. Composite stratigraphy of the Stone Bridge fossil site from the upper surface at Park Drive 12 meters down to Wallworth Lake at 4 meters. Red arrow marks the speculative position of a hardground diastem boundary on G9 separating the calcareous beds G11 and G10 from the leached bed G8. See Hardground section of this report for details.
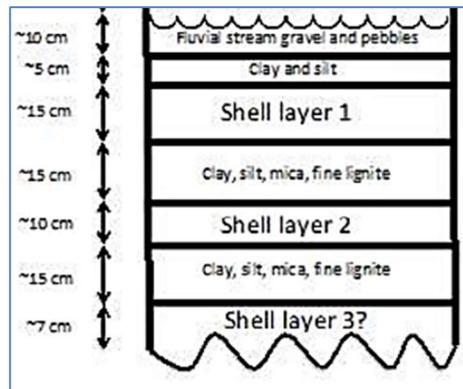
Figure 6. Section of Oman et al.'s (2016) stratigraphic column showing the vertical sequence of shall layers on G11.

Historic calcareous shell bed G11.

The fossil bed on G11 appears on or near the surface of the stream bed as a narrow band of densely packed molluscan fossils, a linear stringer feature on the order of 10 cm wide and at least 10 meters in visible length, traced SE-NW until it disappears under the north bank of the tributary **Figure 1**. A block cut from this feature, preserving its in-situ orientation, is shown in **Figure 7**. The bivalve, *Cyprimeria depressa,* is visually dominant, with intact but disarticulated valves, imbricated, tilted back at approximately 15 degrees from vertical towards the southwest and the external surfaces of the valves facing up northeast. Orientation of the stringer feature is about 130° east of magnetic north and, with the external surfaces of *C. depressa* valves facing northeast, suggests deposition by a current flow that direction, NE. Transverse sampling perpendicularly across this feature, calcareous mollusks appear in diminishing concentrations outward grading into sparse molds leached of calcareous material beyond 0.5 meter.

Figure 7. Narrow band of imbricated, concave up, disarticulated but complete Cyprimeria depressa valves with associated molluscan taxa on G11. Breakage is due to attempts to expose the mollusks.

Newly discovered calcareous bed on G10

Differing from the narrow-bounded fossil orientation on G11, on G10 the entire stream bed, some 4 meters wide at this point, is nearly level, underlain by a calcareous biostrome of unknown depth or horizontal extent and extending visually up the north bank. This bed is just upstream from the breached dam in **Figure 1** and covered by only a few centimeters of sediment. Derived from limited sampling, the bed lacks the dense concentration of *Cyprimeria depressa* valves so evident on G11. Although the calcareous taxa in general are more randomly dispersed with fewer, if any, vertebrates present, the faunal mix appears similar to the exposures on G11. As with G11 molluscan taxa appear intact in-situ, but so fragile that it is nearly impossible to recover a complete specimen over 5 millimeters. This bed may correspond to Oman et al.'s, lower shell bed, which is some 25 cm below the surface on G11, **Figure 6**. (Oman et al., 2016).

Notable that not many microvertebrates or otoliths were recovered on G11, or G10 as Oman et al. (2016) reported even screening shell bed concentrate to 1/16 in. mesh. Possibly shallow sampling did not penetrate to the deeper vertebrate concentration bed referenced to by Oman et al. (2016).

Newly discovered concretion leached bed G8

A second type of preservation, concretions leached of calcareous content, resides in a newly discovered biostrome downstream from the calcareous beds on G11 and G10 described above. This bed shows on **Figure 1** site plan and **Figure 5** stratigraphy as G8. Fossil taxa much resembles that of the calcareous bed on G11, including a compact concentration of randomly oriented, imbricated band of intact but disarticulated *Cyprimeria depressa* valves. A block cut from the *C. depressa* concentration concretion shows in **Figure 8,** compare to the calcareous block cut from the stringer on G11, **Figure 7.** The concretion matrix is coarse grained, lightly cemented, reddish stained externally but gray in the interior. The orientation of this bed appears nearly horizontal, the upper level is sharply bounded with only a few centimeters of formation above, then alluvium and surficial formations higher up. As with the calcareous beds G11 and G10, the downward extent of this leached bed of concretions is unknown as it is right at the water line. Molds on the surfaces of the concretions, however, were identifiable with much less difficulty than the fragile taxa in the calcareous beds on G11 and G10. No shell hash is visible in **Figure 8,** but there are occasional burrow fillings, possibly *Skolitho*s, as the diameter of the filling is much smaller than that of *Ophiomorpha nodosa* burrows. A final note, a leached layer beneath a calcareous layer is unusual and underscores the complex taphonomy of the Stone Bridge site. This leached bed G8 may represent an earlier event deposit covered by additional sedimentation and so older than the beds above on G10 and G11.

Figure 8. Leached imbricated Cyprimeria depressa valves from the fossilferous concretion bed on G8. Note concave up orientation of the valves.

Ichnofossils

Loose *Ophiomorpha nodosa* burrow fillings were found in float on the gravel bars but their source is unknown. Their external molds, however, appear on the siderite plate shown in **Figure 9.** Sparse, possible *Skolithos,* burrows are evident in some of the concretions on G8, filled with darker colored sediment. Overall, bioturbation activity at Stone Bridge is low, not observed in the massive dark clay lithology outside of the sandier shell beds. The possible hardground siderite plates, however, are extensively bored, an indication of more bioturbation above or below in stratigraphy. Because no significant bioturbation was otherwise observed, post depositional reworking of the deposit is evident.
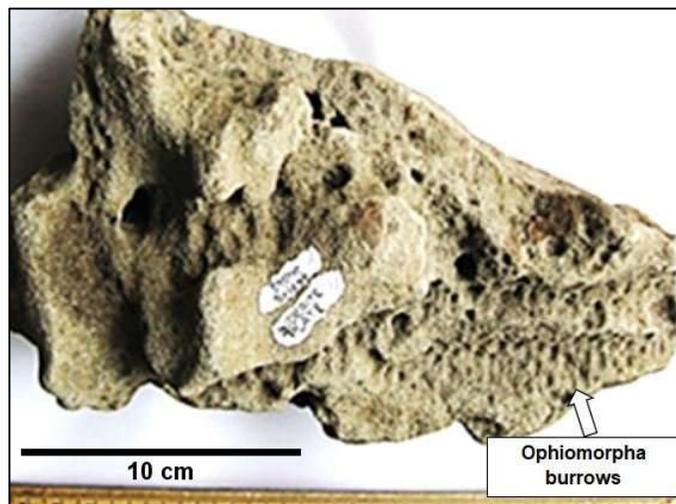

Figure 9. External molds of Ophiomorpha nodosa burrow fillings on one of many siderite hardground plate found on G9, hypothetical stratigraphic position marked by red arrow in the stratigraphic column Figure 5. Thickness of the plate is about 5 cm.

Hardground

In addition to the bioturbated siderite plate (**Figure 9**) other siderite plates litter G9. These plates are evidence of a breakup of a diastem which may mark the boundary between calcareous shell beds above on G11 and G10 and the leached bed on G8 below. Oman's excavation on G11 did not penetrate any hardground even though 70 centimeters penetration should have reached it if the bed on G8 was horizontally extensive (Oman et al., 2016).

Paleozoic fossils

Within the gravel bar float are rare, silicified Paleozoic fossils. Most are free form, but some are embedded in chert nodules, including crinoids, bryozoans, rugose and tabulate corals, brachiopods and others described in detail in our report (Kuehne, W. and Kuehne, A. 2020) with some specimens reconfigured. Two examples show in **Figure 10**, the complete suite described and illustrated in **Appendix 2, Plate 6**, of this report.

Brachiopod, cf. *Atrypa reticularis*.

Tabulate coral, cf. *Emmonsia emmonsii*
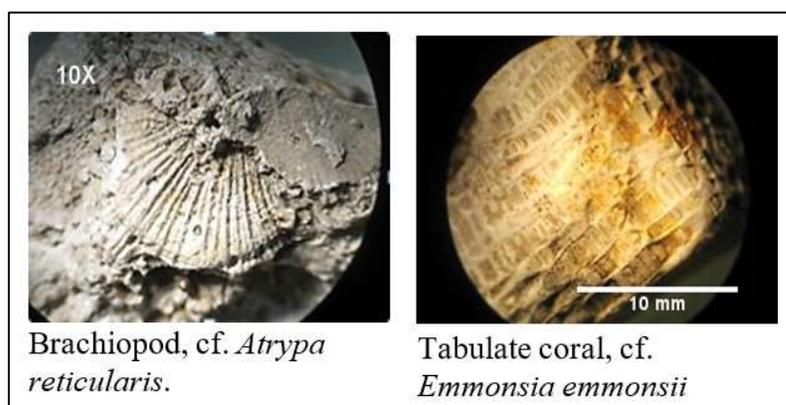
Figure 10. Exotic Paleozoic fossils, Stone Bridge site, from stream bed float.

PALEONTOLOGY

Vertebrates

Vertebrate taxa at the Stone Bridge site are dominated by Chondrichthyes and Osteichthyes fish fossils, their relative abundance shown in **Figure 11**, but include marine reptiles and Chelonia and terrestrial, *Hadrosaurus*, all mostly expressed as teeth. Examples are shown in **Appendix 1**, **Plates 1** and **Plate 2** of this report. The abundances are based on a suite of nearly 1500 specimens. Most specimens are worn even in-situ from formation exposures on G11, but there is also a fraction of unworn, pristine specimens. Shark teeth are also embedded in concretions from G8, for an example, see **Plate 1**, fig. 20, a pristine lateral *Scapanorhynchus texanus* tooth. A random sample of *Scapanorhynchus texanus* exhibits a wide size range from a few millimeters to 50 millimeters suggesting a calving ground, Extremes of *Scapanorhynchus texanus* and *Squalicorax kaupi* sizes show in **Appendix 1, Plate 1**.
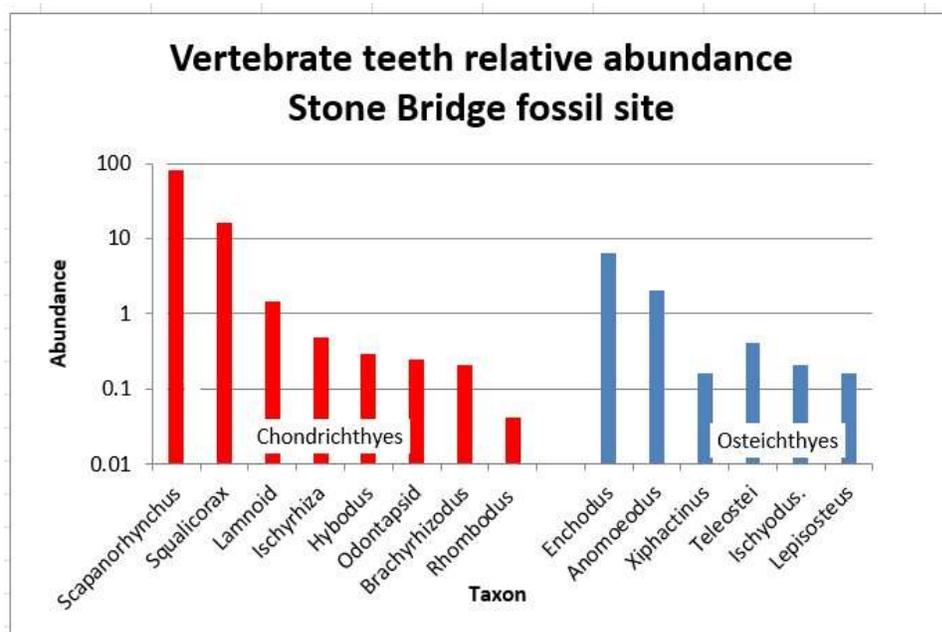
Figure 11. Relative abundance of fish fossil teeth at the Stone Bridge site.

Hadrosaurus sp.

Two specimens of *Hadrosaurus* sp. teeth were recovered from the Woodbury Formation at the Stone Bridge site with a possible third, a pathological tooth **Figure 12**.

Figure 12. Hadrosaurus sp. teeth, Stone Bridge site. Left, juvenile. Center, adult. Right. Pathological?

cf. *Serratolamna (Lamna) serrata* Agassiz (1843)

A single specimen of cf. *Serratolamna serrata* was found at Stone Bridge, this report, very worn obscuring its identity, **Figure 13**. One other specimen from the Stone Bridge site resides in the New Jersey State Museum as GP21929 (Kuehne, W. and Kuehne, A., 2018). This taxon is more common in the Maastrichtian Stage in New Jersey The only other reported occurrence is tentative from the Upper Cretaceous (Campanian) Merchantville Formation (Robb, 2004)

Figure 13. cf. Serratolamna serrata. Left, specimen from Stone Bridge, this report. Center, specimen from NJSM Stone Bridge collection, GP21929. Right, upper posterior tooth, photo from online resource for comparison.

Invertebrates

Cyprimeria depressa

C. depressa is the dominant bivalve at the Stone Bridge site at 61% of the total bivalve population, determined as outlined in species-abundance from G8, Ecology section of this report. Although disarticulated, the valves are complete in formation, unworn, without encrustation, show little sign of compressive deformation, slightly cracked and rarely bored. Only a single articulated *C. depressa* specimen was recovered **Figure 14**. Index fossils of North America shows *C. depressa* as an index fossil of the Upper Cretaceous (Shimer and Shrock, 1944). Richards et al. however, only reports *C. depressa* from the Woodbury Formation in New Jersey (Richards et al., 1958). Kuehne, D. (1993) also reports *C. depressa* from the Stone Bridge site. From these references for New Jersey, *C. depressa* is not reported outside of the Woodbury and Englishtown Formations, but the *Cyprimeria* genus, possible *depressa,* is also found in the Merchantville Formation (Kuehne, D., 1999).
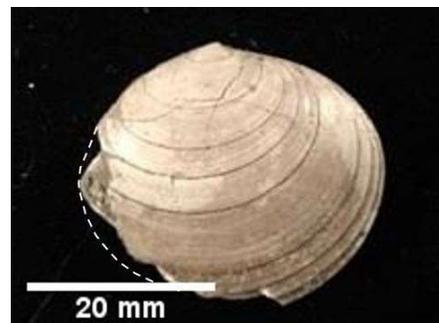
Figure 14. A nearly complete articulated Cyprimeria depressa bivalve, dominant at the Stone Bridge site, the only articulated specimen recovered. Specimen was complete in formation but the edge was broken when it was extracted from the matrix. Note fine detail, unworn nature and absence of deformation, encrustation or boring.

That the Stone Bridge site only contains mature valves of *C. depressa* is enigmatic, where are the intermediate growth stages? Other molluscan taxa at the site also show this trait, absence of juvenile growth stages. Modern molluscan colonies host a range of intermediate growth stages, for example (Atlantic surf clam, online). It is unlikely that juveniles have been winnowed away for the small (5 mm) bivalves Breviarca *haddonfieldensis* (**Plate 4**) and *Corbula crassaplica* (**Plate 3**) coexist with the larger

35-millimeter *C. depressa*. This phenomenon may relate to taphonomy or to the history of the community from which the fossils were displaced, however research did not provide a definitive explanation.

Exogyra sp.

Stephenson asserts that the two species of *Exogyra, E. ponderosa* and *E. costata*, do not overlap in their ranges (Stephenson, 1914),

"In the New Jersey Cretaceous the species *E. ponderosa* and *E. costata* do not overlap in their ranges, the former being known only from the Marshalltown Formation of the Matawan group and the latter being restricted to the Monmouth group."

which seems to be a generally recognized stratigraphic principle of New Jersey paleontology although it has faced challenges from recent work in the Woodbury and Englishtown Formations (Stephenson, 1914). According to Bernstein (1986),

Owens et al. (1970) did not challenge Stephenson's stratigraphic assignment. Later, however, Stephenson himself acknowledged that his stratigraphic distinction might not be as sharp as originally believed (Stephenson et al., 1942).

In this investigation, only a single *Exogyra* specimen was recovered, and this from a concretion in G8, **Figure 15**. The specimen has the structure and anatomical features of a species, but a larger sample would be necessary for confirmation. Richards et al. (1958) reports *E. costata* from the Woodbury Formation. Kuehne, D. (1993) recovered ten diminutive *Exogyra* sp. specimens, all looking very similar, which may be *E costata,* but their features were too worn for definitive identification. Oman et al. (2016) reports only *E. ponderosa* from the Stone Bridge site, an exception to Stephenson's principle which postulates that *E. ponderosa* is confined to the Marshalltown Formation.

| External mold | Internal mold |
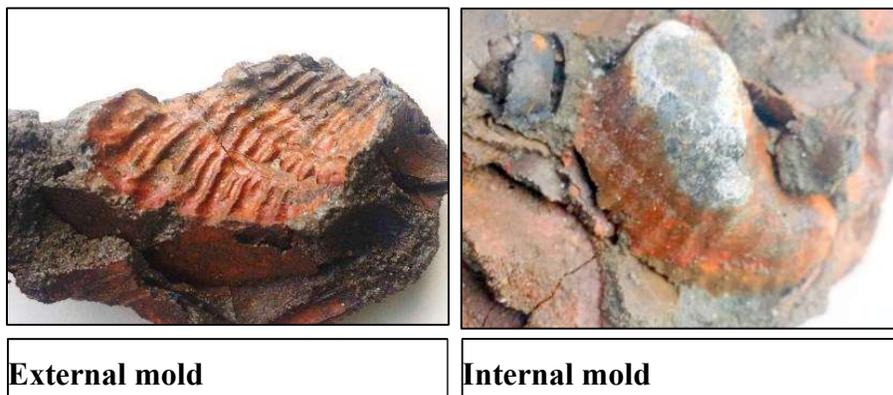
Figure 15. Exogyra sp. internal and external molds of the same individual from the leached biostrome on G8. Specimen is about four centimeters in length. Note residual calcitic residue on the internal mold.

Cucullaea-Lucina assemblages

Weller (1907) designates shallow water as dominated by *Lucina* assemblages and deeper water as dominated by *Cucullaea* assemblages. This distinction is not so apparent at the Stone Bridge site, both assemblages being found by Kuehne, W. and Kuehne, A. (2018) and in this report but not by Oman et al.

(2016). The following table summarizes the *Cucullaea* and *Lucina* assemblages in these three major investigations of the Stone Bridge site **Table 2**. A mitigating factor, evident from **Table 2**, is that *Lucina* seems to be more strongly expressed than *Cucullaea* but not clearly dominant*. Cucullaea* and *Lucina* bivalves are compared in **Figure 16**.

Taxon	Quantity	Description
This report		
Cucullaea woodburyensis	1	External mold, G8
Cucullaea antrosa	1	Internal cast, **Plate 4**, fig. 18
cf. *Cucullaea vulgaris*	1	Valve, external, **Plate 4**, fig. 11
cf. *Cucullaea gigantica*	1	Valve, external, **Plate 4**, fig. 12
Lucina glebula	7	3 calcareous, 4 molds
Lucina parva	3	3 molds
(Kuehne, W. and Kuehne, A., 2018)		
Cucullaea woodburyensis	4	p. 63
Lucina glebula	1	p. 70
(Oman et al., 2016)		
Cucullaea	None	
Lucina glebula	Common	p. 110
Lucina sp.	Uncommon	p. 111

Table 2**. Comprison of Cucullaea and Lucina assemblages at the Stone Bridge site.**
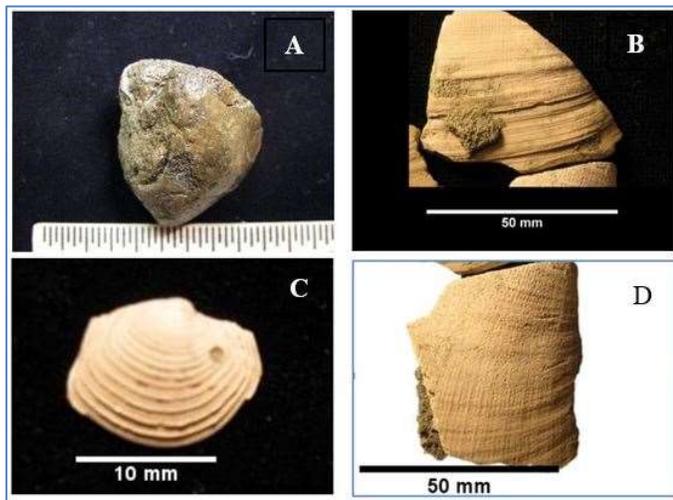
Figure 16. Cucullaea and Lucina bivalves from the Stone Bridge fossil site extracted from G11. A. Cucullaea antrosa, B. cf. Cucullaea vulgaris, C. Lucina glebula, D. cf. Cucullaea gigantica.

ECOLOGY

Habitat

In an effort to deduce the original habitat of life forms at the Stone Bridge fossil site, the trophic mode of benthic bivalves can reveal something of their original undisturbed substrate, infaunal (I)- muddy, epifaunal I- sandy. Trophic modes of bivalves from the three major investigation of Stone Bridge paleontology are compared in **Table 3.** From **Table 3**, infaunal bivalve taxa dominate indicating an original habitat dominantly soft matrix.

Reference	Exposure where collected (Figure 1)	I/E ratio bivalves	Bivalvia	Gastropoda	All taxa from Table 7.
This report	3, 5, 6 and 7	1.94	59	23	129
(Oman et al., 2016)	2	1.7	32	14	
(Kuehne W. and Kuehne A., 2018)	4	4.1	35		128
(Kuehne, D., 1993)	1				24
(Kuehne, D., 1999)	All Woodbury Formation of the northern ACP	1.79	106		
Actual, combined site	1-7		74		171
Expected, (Symbolab, online), calculated			129		

Table 3. Distribution of molluscan taxa by tropic mode across the calcareous and leached biostromes of Stone Bridge (The Paleobiology database, online). Includes only taxa from G11 as no new taxa were recovered from G10 or G8.

The wide variability of the I/E ratio, ranging from 1.7 to 4.1, is unexplained but may result from a heterogenous distribution of bivalves across G11, as the collector worked a different position on G11, Position 4 of Figure 1. and noted that the matrix was dark clay (Table 1). Actual combined site taxa 171 consists of taxa recovered from this report 129 plus 42 new taxa from Kuehne, W. and Kuehne A. (2018).

Species abundance

Due to the fragile nature of molluscan taxa at the Stone Bridge site, it was not possible to obtain an accurate species-abundance count as was done in (Kuehne, W. and Kuehne, A., 2018) . In the concretion layer, G8, however, a limited abundance count was obtained from the molds on 19 representative concretions extracted from G8, **Figure 24** and **Table 9** in **Appendix 4.** Results are graphed in **Figure 17.** From all appearances this relationship is also valid for the calcareous layers on G11 and G10.

Relative abundance of molluscan species concretion layer, Stone Bridge site
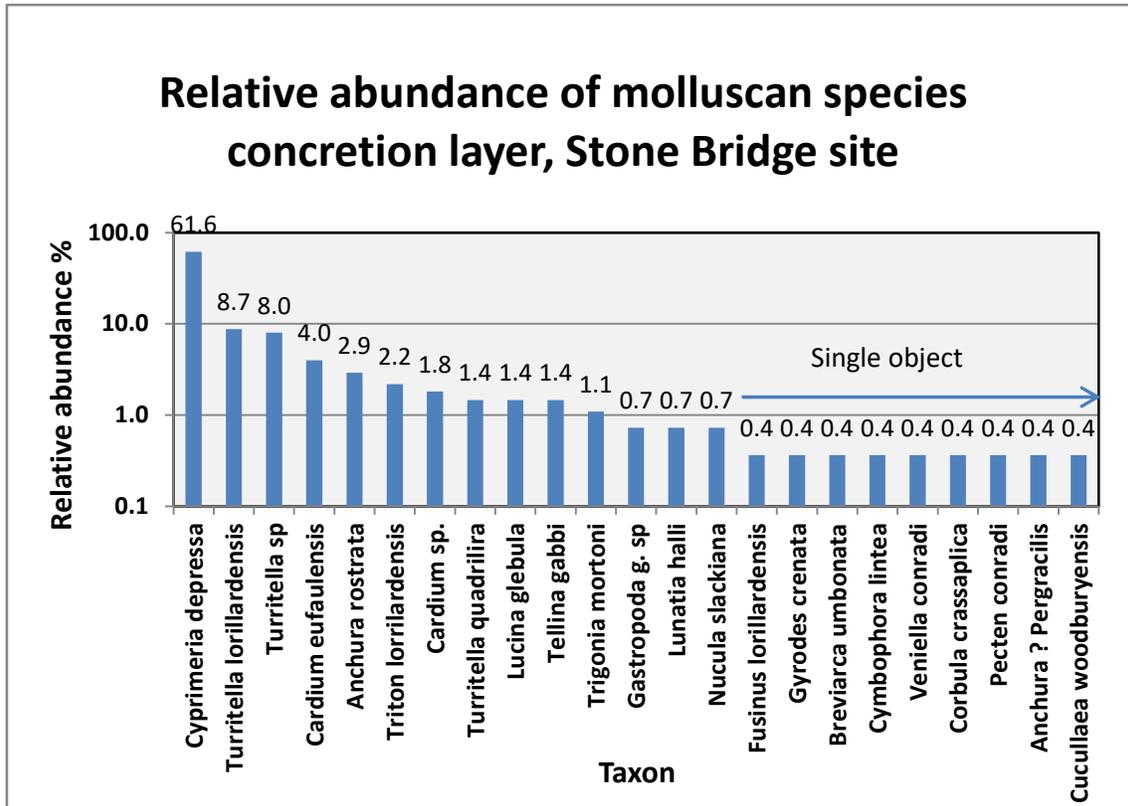
Figure 17. Relative abundance of molluscan taxa (Bivalvia plus Gastropoda) from concretion layer G8.

The species-abundance relationship in a community follows a log-normal distribution (Ludwig and Reynolds, 1988). Species abundance data acquired as shown in **Figure 17** from the concretion bed G8, is plotted in **Figure 18** by octaves of species abundance according to the method described by Ludwig and Reynolds (1988). When species abundance is plotted in this way, the resulting figure approximates lognormality, indicative of an ecological community at least for the mollusks expressed as molds on the set of concretions in **Appendix 4**.
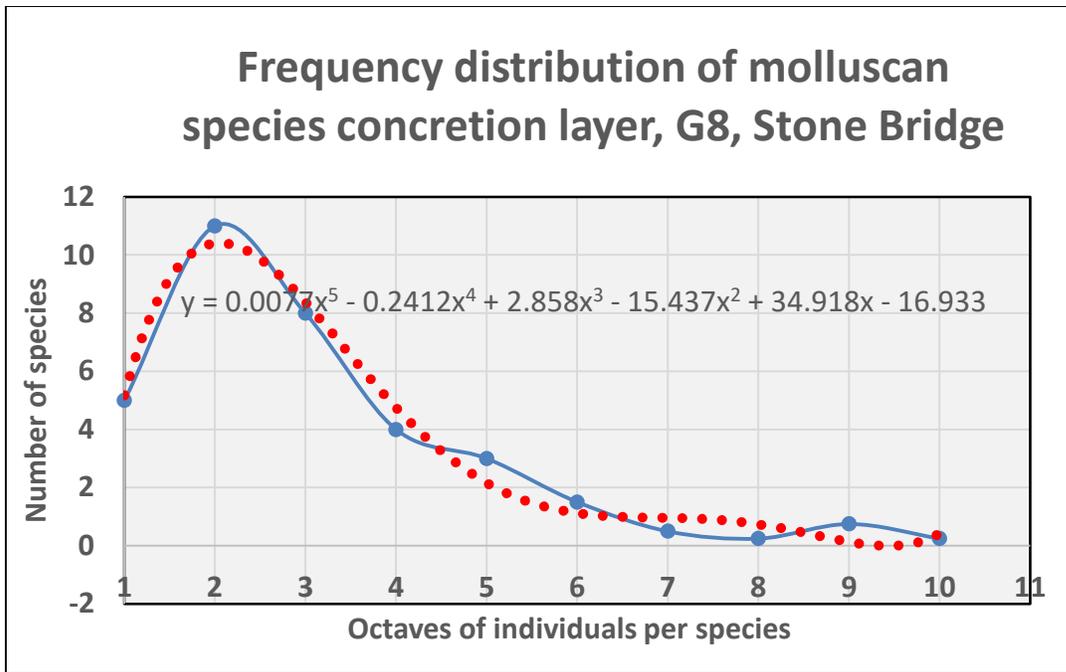
Figure 18. Molluscan species – abundance frequency distribution in the concretion bed, G8.

Fortunately, Kuehne, D. did track bivalve species abundance on the calcareous bed G11, reproduced as **Figure 19** from (Kuehne W and Kuehne A., 2018).
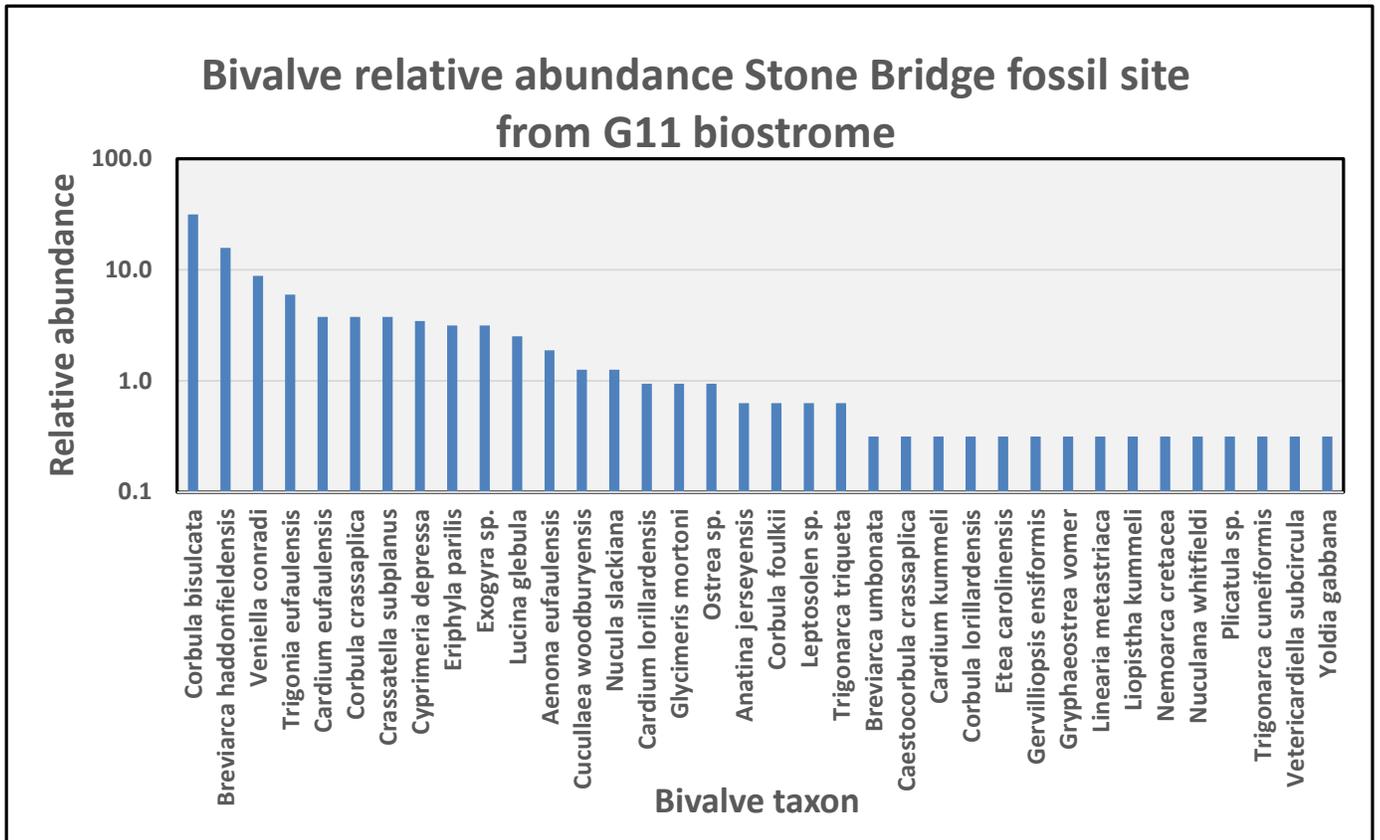
Figure 19. Bivalve relative abundance, Stone Bridge fossil site, from (Kuehne, W. and Kuehne A., 2018),

Plotting abundance by octaves according to Ludwig and Reynolds (1988) method for the abundances shown in **Figure 19**, yielded the trend line shown in red in **Figure 20**. The close fit of this trend line to log-normality suggests a community relationship. The area under this curve represents the total expected number of species (Ludwig and Reynolds, 1988). The area under the trend line as calculated equals 129 (Symbolab, online). The actual number of bivalves recovered was 59 plus 15 new from Kuehne, W. and Kuehne, A. (2018), see Assemblage in **Appendix 1** for the list, for a total of 74 bivalves taxa recovered from the Stone Bridge site. This means that 129 – 74 or 55 additional bivalve taxa are expected at the Stone Bridge site. A larger sample may recover the missing bivalves, expected at low abundances. All graphing by authors in Microsoft Excel.

Frequency distribution of bivalve species abundance from the G11 biostrome plotted by octaves

$$y = 0.1383x^3 - 2.5839x^2 + 11.325x + 7.8512$$

Number of species (y-axis)

Octaves of individuals per species (x-axis)
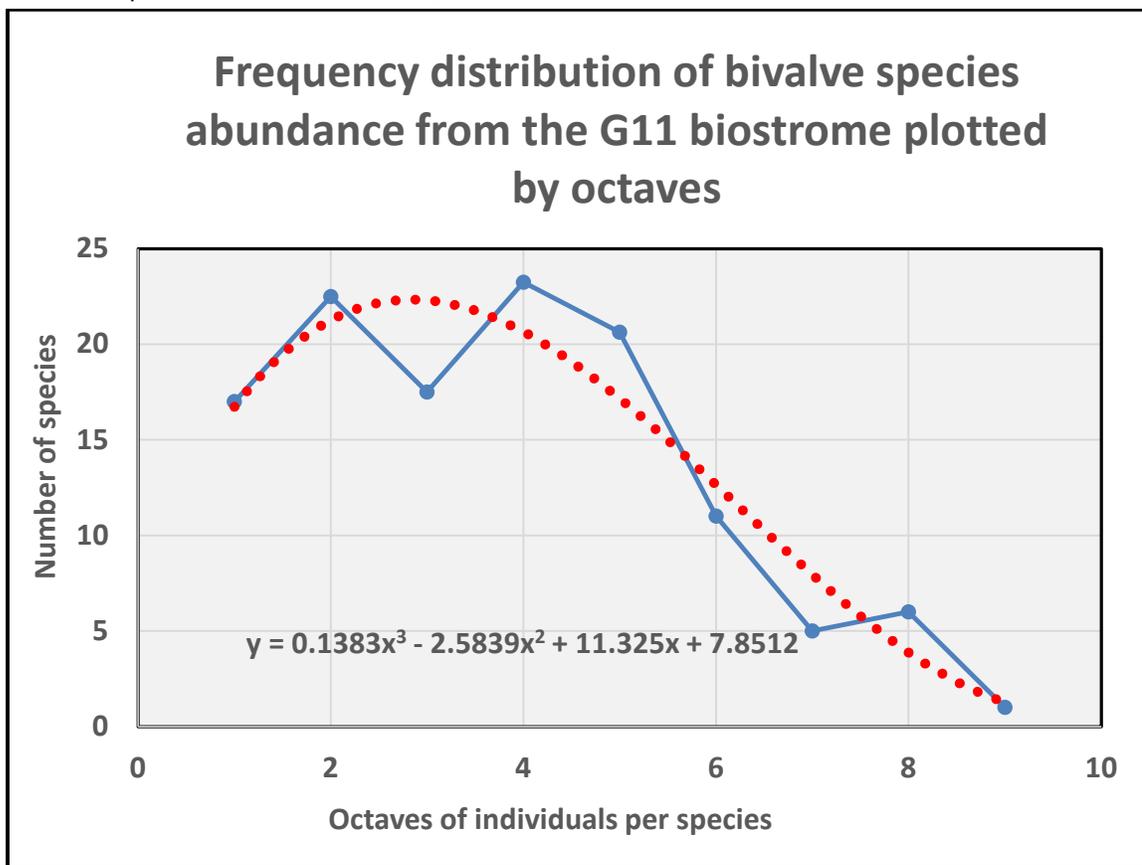
Figure 20. Frequency distribution of bivalve abundance, abundance plotted by octaves. Closest fit trend line is the third order polynomial shown in red.

Trophic mode, community

Comparison with modern analogues indicates that most trophic niches are present in the bivalve suite: infaunal, epifaunal, mobile, deposit and suspension feeders, suggesting that the bivalves at the Stone Bridge site originated in an ecological community. **Table 4** is an excerpt from the full list of the bivalve trophic modes located in **Appendix 3**.

Taxon	Trophic mode
Anatina jerseyensis Weller	facultatively mobile infaunal deposit feeder
Aphrodinia tippana jerseyensis Richards	not available
Breviarca cuneata (Gabb)	facultatively mobile epifaunal suspension feeder
Breviarca haddonfieldensis Stephenson	facultatively mobile epifaunal suspension feeder
Breviarca umbonata (Conrad)	facultatively mobile epifaunal suspension feeder
Cardium dumosum Conrad	facultatively mobile infaunal suspension feeder
Cardium eufaulensis Conrad	facultatively mobile infaunal suspension feeder
Cardium tenustriatum Whitfield	facultatively mobile infaunal suspension feeder
Cardium uniformis Weller	facultatively mobile infaunal suspension feeder
Corbula crassaplica Gabb	stationary infaunal suspension feeder

Table 4. Trophic modes of Stone Bridge bivalves, first ten records (The Paleobiology Database, online). Complete list for bivalves is in Appendix 3 of this report

TAPHONOMY

Introduction

The source of the fossils at the Stone Bridge site is uncertain, but, as none of the mollusks appear in life position, disruption and relocation is evident. Considering their intact nature, however, they were not transported far or energetically from their life position. This type of distribution has been recognized by Martin (1999) as 'parautochthonous,' consisting of organisms that lived in a community and were "moved, disarticulated, reoriented and concentrated from their original position." The state of the *Cyprimeria depressa* and large bivalves at the Stone Bridge matches this description, disarticulated, reoriented and concentrated **Figure 7**. Circumstances which could produce a fossiliferous bed like this include storm deposit (singular event), fluvial channel bed (continuous, unidirectional) and tidal channel bed (continuous, oscillating).

Storm deposit

Shennen et al. (2015) assert:

Storm deposits contain imbricated or nested shells with moderate fragmentation and minor articulation,

The state of Stone Bridge bivalves is largely consistent with this description except that no fragmentation was observed. Also, Benchley and Harper (1998) attributes thick accumulations of shells, as observed at Stone Bridge, G11, G8, **Figure 7** and **Figure 8**, to an event concentration, such as a storm.

Shells in such deposits may be imbricated. As a general rule, thick nearshore shelf concentrations are more common amongst the bivalve dominated assemblages of the Mesozoic and Cenozoic. Most shell concentrations in shelf facies are the product of storms. Because sedimentations is rapid, shells tend to be unfragmented.

Transport distance and current velocity

Chattopadhyay et al. (2013) demonstrated that right/left valves of bivalves are deflected by differing degrees dependent upon valve size, configuration and current velocity thus providing information on transport distance and flow velocity. Applying this

procedure to the dominant bivalve, *Cyprimeria. depressa*, showed no significant difference between numbers of right and left valves in a sample of 52 original shells from G11 and 8 concretion external molds from G8, implying either minimal transport distance, low current velocity or similarity of valve convexity. The disarticulated bivalves on G11 and G8 are convex down, an equilibrium arrangement consistent with a storm generated deposit. R/L valve hinge internal details show in **Figure 21** and research data in **Table 5**. The presence of smaller taxa *Breviarca haddonfieldensis* and *Corbula crassaplica* with *Cyprimeria depressa* in the biostrome on G11 is further evidence of low current velocity.
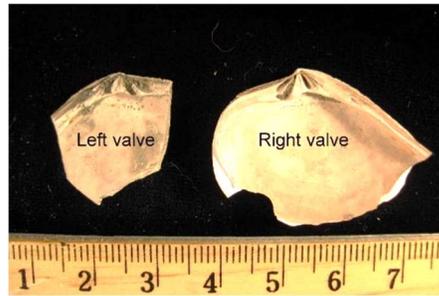
Figure 21. R/L valve hinge details of Cyprimeria depressa.

Valve	Original shell G11	External mold G8
Left	27	4
Right	25	4

Table 5. Counts of left and right valves of Cyprimeria depressa from the Stone Bridge fossil site.

Fluvial channel bed

To evaluate the possibility that the shell bed on G11 is a fluvial channel bed rather than a storm generated deposit, the characteristics of fluvial channel beds are compared to the shell bed on G11:

• Channel beds are often well defined lithologically in a host formation. Stone Bridge: Discrete channels are not observed in the lithology of the Stone Bridge site.

• Channel beds accumulate with higher energy resulting in breakage of fragile materials such as molluscan shells. Stone Bridge: No breakage is observed in any of the three shell beds G11, G10 or G8, of the Stone Bridge site.

• Channel beds contain a mix of materials including coarse detrital material. Stone Bridge: No detrital material was observed within the matrix of any of the shell beds at the Stone Bridge site.

Tidal channel bed

Study of Holocene cores in a Florida nearshore environment, concluded that thick, densely packed, imbricated shell beds 5-10 cm thick are the result of current deposition in tidal channels laterally extensive for a few meters (Cuffe et al., 1991). Stone Bridge: This description is consistent with the densely packed shell bed on G11 but is an unlikely explanation for the beds at Stone Bridge as the Florida shell deposits were highly fragmented.

From this analysis, it appears unlikely that a fluvial channel or a tidal channel dispersed the molluscan fossils as observed at Stone Bridge.

Leached concretionary bed

Explaining the difference in preservation of the two types of shell beds, i.e., upper beds G11 and G10 of calcareous mollusks, and a lower bed G8, leached of calcareous material, there are several possibilities.

1. Using the Aragonitic Saturation Depth (ASD) explanation, the lower bed of molds leached of calcareous content, G8, would need to be below 200 ft. of water depth.

2. The calcareous molluscan beds G11 and G10 are only 0.5 meters vertically above the leached bed G8. This could mean an intervening unconformity or a diastem, however, there is no other supportive physical evidence of either except the evidence of a hardground on G9.

3. Loss of aragonitic material has occasionally been observed at much shallower depths than the ASD by upwelling corrosive water reaching to the surface in the inshore waters near the coast (Feely, 2013).

4. Pyritized steinkerns of turritellids, example on **Plate 5**, fig. 13, and pyrite nodules are found in some deposits at Stone Bridge indicating an anoxic diagenesis which can lead to carbonate undersaturation and aragonite dissolution (Martin, 1999).

This would be the most plausible explanation for the leached concretion bed at Stone Bridge.

DISCUSSION

This work is the third major investigation of the paleontology and ecology of the Stone Bridge fossil site in Cherry Hill Township, Camden County, New Jersey, extending the work of Kuehne, D. (1993), Oman et al., 2016) and ourselves, Kuehne, W. and Kuehne, A. (2018). A significant feature of this report is the discovery of two new biostromes below the historic bed where earlier collectors focused their attention. A combined bivalve suite of 74 is less than the total bivalve count for the Woodbury Formation of the northern Atlantic Coastal Plain of 106 (Kuehne, D., 1999). however, from the species-abundance ecological analysis, 129 bivalve taxa were expected suggesting that addition collection efforts could reveal an additional 55 taxa. The filling of most trophic modes and species abundance of the bivalves suggest origin from a paleoecological community and, from the intact nature and dense packing of the mollusks, a community not far removed from its original life position, probably by a storm event, a conclusion differing from Oman et al.'s (2016) transgressive bed and submarine slide explanations which produce breakage and random dispersion. The overall taphonomy of the site is unusual with a leached shell layer below rather than above calcareous layers. Weller's *Cucullaea - Lucina* assemblages not coexisting is challenged, both taxa found together at the Stone Bridge site.

DEDICATION

This report on the Stone Bridge fossil site in Cherry Hill, NJ, is dedicated to our son, Daniel, who, while only in his teen years, was a dedicated student of paleontology especially adept at prospecting and field work. He spent many days at the site collecting, then identifying and preparing the fossils. The cover page of Volume VII of *The Mosasaur* publication of The Delaware Valley Paleontological Society was dedicated to his memory as an outstanding paleontologist and a frequent contributor to their newsletter.

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APPENDIX 1. ASSEMBLAGE.

Faunal assemblage of fossils by class recovered from the Stone Bridge fossil site. Good quality specimens were photographed. Not all specimens in the assemblage have photographs. Data flow is down Column 1 across up and down Column 2. Total taxa from the site: 129 recovered plus 42 new from Kuehne, W. and Kuehne, A. (2018).

Taxonomic class	This report	Kuehne, W. and Kuehne, A., 2018)	Stone Bridge new to this report
Bivalvia	59	36	15
Gastropoda	23	29	6
Chondrichthyes	14	25	11
Osteichthyes	9	14	5
Dinosauria	1	0	
Reptilia	3	8	5
Cnidaria	3	3	
Cephalopoda	4	2	
Chelonia	1	0	
Crustacea	3	2	
Annelida	5	4	
Scaphopoda	1	0	
Plantae	2	3	
Porifera	1	1	
Echinoidea	0	1	
Total taxa	**129**	**128**	**42**

Table 6. Assemblage summary table.

A * incdicates a new occurrence

PORIFERA 1

cf. *Coeloptychium*? *jerseyensis* Shimer & Powers

CNIDARIA 3

Microbacia cribaria Stephenson

Trochocyathus woolmani Vaughan

Astrangea cretacea Bolshe

ANNELIDA 5

Hamulus falcatus (Conrad)

Longitubus lineatus (Weller)

Serpula sp. A

Serpula sp. B

Serpula sp. C

BRACHIOPODA 1

Lingula subspatulata Scott

BIVALVIA 59

*Anatina jerseyensis Weller

*Aphrodinia tippana jerseyensis Richards

*Breviarca cuneata (Gabb)

Breviarca haddonfieldensis Stephenson

Breviarca umbonata (Conrad)

*Cardium dumosum Conrad

Cardium eufaulensis Conrad

*Cardium tenustriatum Whitfield

*Cardium uniformis Weller

Corbula crassaplica Gabb

Corbula foulkii Lea

Corymya tenuis Whitfield

Cucullaea antrosa Morton

cf. *Cucullaea vulgaris* Morton

cf. *Cucullaea gigantica* Conrad

*Cymella bella texana Stephenson

Cyprimeria densata (Conrad)

Cyprimeria depressa Conrad

*Etea carolinensis Stephenson

*Etea delawarensis (Gabb)

Exogyra costata Say

Gastrochaena cuneiformis Spengler

Gervilliopsis ensiformis (Conrad)

Glycimeris mortoni (Conrad)

Inoceramus proximus Tuomey

Legumen concentricum Stephenson

Lima lorillardensis Weller

Linearia metastriata Conrad

Lucina glebula Conrad

Lucina parva Stephenson

*Nemodon brevifrons Conrad

Nucula percrassa Conrad

Nucula slackiana (Gabb)

*Nuculana compressifrons Whitfield

Nuculana longifrons (Conrad)

*Pecten bellisculptus (Conrad)

*Pecten burlingtonensis Gabb

*Pecten conradi (Whitfield)

*Pecten craticulus Morton

*Pecten quinquecostata Sowerby

Pecten simplicius Conrad

Pinna laqueata Conrad

Pteria petrosa (Conrad)

*Solmya lineolatus Conrad

*Striarca congesta (Conrad)

*Tellina gabbi Gardner

*Tenea parilis (Conrad)

*Tenea pingus (Conrad)

Teredolites

Trigonarca cuniformis Conrad

*Trigonarca triqueta Conrad

Trigonia eufaulensis Gabb

Trigonia mortoni Whitfield

Veniella conradi Morton

Veniella etea carolinensis Stephenson

*Veniella subovatus Whitfield

Vetericardia crenalirata (Conrad)

*Volsella julia (Lea)

GASTROPODA 23

Anchura? pergracilis Johnson

Anchura johnsoni Stephenson

Anchura rostrata (Gabb)

Avellana cretacea (Johnson)

Caveola subalta (Conrad)

Fusinus lorillardensis Weller

Gastropoda g. sp.

Gyrodes crenata Conrad

Liostriaca cretacea Wade

Lunatia halli Gabb

Margarites abyssinia (Gabb)

Triton lorrilardensis Weller

Triton sp.

Turritella lenolensis Weller

Turritella lorillardensis Weller

Turritella quadrilira Johnson

Turritella tippana Conrad

Turritella vertebroides Morton

Turritella sp. A

Turritella sp. B

Turritella sp. C

Turritella sp. D

Pyritized turritella steinkern

Volutoderma conradi Gabb

SCAPHOPODA 1

*Dentalium sp.

CEPHALOPODA 4

Placenticeras placenta DeKay

Ammonoidea g. sp.

Baculites ovatus Say

Menabites delawarensis (Morton)

CRUSTACEA 3

Hoploparia sp.

Ophiomorpha nodosa Lundgrun

CHONDRICHTHYES 14

Archaeolamna kopingensis (Davis)

Brachyrhizodus wichitaensis Romer

Carcharias holmdelensis Cappetta & Case

Cretolamna appendiculata (Agassiz)

Hybodus sp.

Ischyrhiza mira Leidy

Pachyrhizodus sp.

Odontapsis aculeatus Cappetta & Case

Rhombodus laevis Cappetta & Case

Scapanorhynchus texanus (Roemer)

Serratolamna serrata Agassiz

Squalicorax yangaensis (Dartevelle)

Squalicorax kaupi (Agassiz)

Squatina hassei Leriche

Myliobatid vertebrae

Myliobatid dermal denticle

Shark coprolite

Shark vertebrae

Hybodont cephalic hook

S. texanus, adult teeth

S. texanus, juvenile lateral teeth

S. texanus, posterior teeth

S. texanus, far posterior tooth

S. texanus, symphyseal teeth

Ischyrhiza mira Leidy, rostral spine

Ischyrhiza mira Leidy, oral tooth

Ossified shark cartilage

OSTEICHTHYES 9

Anomoeodus phaseolus Hay

Enchodus petrosus Cope

Hadrodus priscus Leidy

Ischyodus bifurcates Case

Lepisosteus sp. scale

Osteichthyes sp.

Scomberomorus sp.

Lepisosteus sp.

Osteichthyian vertebrae

Otolith? in concretion from G8

Otoliths

H. priscus, branchial pharyngeal tooth

H. priscus, oral tooth

E. ferox, jaw

E. ferox, lateral tooth

E. ferox, palatine fang

REPTILIA 3

Clidastes propython Cope

Crocodile scutes

Crocodile teeth

Mosasaurus sp.

Mosasaur coprolite A

Mosasaur coprolite B

CHELONIA 1

Carapace

Bones

DINOSAURIA 1

Hadrosaurus sp.

PLANTAE 2

Lignite A

Amber

Lignite B

Lignite C

Lignitized wood in pyrite

Petrified wood

Pine branchlets

Plantae growth rings

Table 7. Assemblage

APPENDIX 2 - PLATES

PLATE 1 – VERTEBRATA

Scapanorhynchus texanus	*Scapanorhynchus texanus*	*Scapanorhynchus texanus*
	Archaeolamna kopingensis	*Squalicorax* (kuupi, yangaensis)
Ischyrizma mira mira	*Ischyrizma mira mira*	*Hybodus* sp. — *Hybodus* sp.
Cretolamna appendiculata	*Serratolamna serrata*	*Sqatina hassei* — *Carcharias holmdelensis*
Chondrichthyian vertebrae	Chondrichthyian coprolite	Ossified shark cartilage — *Scapanorhynchus texanus*
Brachyrhizodus wichitaensis	*Brachyrhizodus wichitaensis*	*Rhombodus laevis* — Myliobatid vertebra.

Plate 1 key Vertebrata.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

Chondrichthyes

1. *Scapanorhynchus texanus,* adult anterior teeth, 48 mm

2. *Scapanorhynchus texanus,* juvenile anterior and lateral teeth

3. *Scapanorhynchus texanus*, posterior teeth

4. *Scapanorhynchus texanus*. far posterior tooth, 7 mm. identified by Earl Manning

5. *Scapanorhynchus texanus*, adult lateral teeth, 30 mm

6. *Scapanorhynchus texanus,* symphyseal teeth, 2 views, 7 mm

7. *Archaeolamna kopingensis*, 15 mm

8. *Squalicorax. L. kaupi R. yanganensis* with juveniles

9. *Ischyrhiza mira,* rostral denticle

10. *Ischyrhiza mira*, oral tooth

11. *Hybodus* sp., 4 mm

12. *Hybodus* sp., cephalic hook, 7 mm

13. *Cretolamna appendiculata*

14. *Serratolamna serrata*

15. *Squatina hassei*

16. *Carcharias holmdelensis*. identified by Earl Manning (pers. comm.)

17. Chondrichthyan, centra vertebrae

18. Chondrichthyan, coprolite

19. Ossified shark cartilage

20. *Scapanorhynchus texanus*, lateral tooth in concretion from G8

Myliobatiformes

21. *Brachyrhizodus wichitaensis*, teeth

22. *Brachyrhizodus wichitaensis,* dermal denticle, 2 views

23. *Rhombodus laevis*

24. Myliobatid vertebra

PLATE 2 - VERTEBRATA

Hadrosaurus sp.	*Hadrosaurus* sp.	*Hadrosaurus* sp.	Mosasaurid teeth
Marine reptilian teeth	*Clidastes propython*	*Pachyrhizodus* sp.	*Pachyrhizodus* sp.
Odontaspis aculeatus	Crocodilian scutes	Teleost otolith	*Anomoeodus phaseolus*
Osteichthyian vertebrae	*Xiphactinus audax veda*	*Hadrodus priscus*	*Hadrodus priscus*
Enchodus ferox	*Enchodus ferox*	*Ischyodus bifurcatus*	*Scomberomorus* sp
B. wichitoensis	*B. wichitoensis*	*Rhombodus laevis*	Myliobatid vertebra
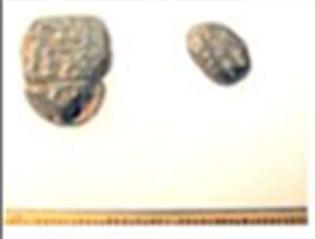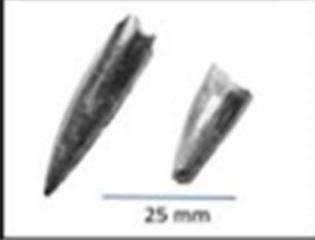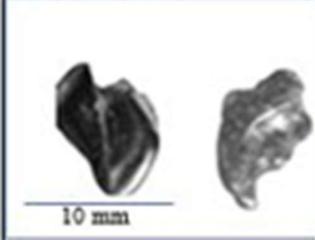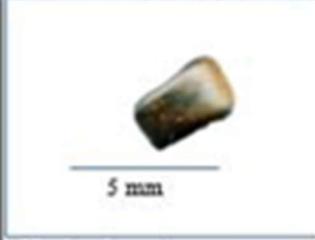
Plate 2 Key Vertebrata

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

1. *Hadrosaurus* sp.   juvenile tooth
2. *Hadrosaurus* sp.   adult tooth
3. *Hadrosaurus* sp.   pathological tooth?
4. Mosasaurid teeth
5. Marine reptilian teeth (cf. crocodilian)
6. *Clidastes propython*

7. *Pachyrhizodus* sp.
8. Unidentified

9. *Odontapsis arculeatus*
10. Crocodilian scute**s**
11. Teleost otolith
12. *Anomoeodus phaseolus*
13. Osteichthyian vertebrae

14. *Xiphactinus audax veda*
15. *Hadrodus priscus* branchial pharyngeal teeth
16. *Hadrodus priscus* oral tooth
17. *Enchodus ferox* jaw and palatine fangs
18. *Enchodus ferox* lateral
19. *Ischyodus bifurcatus*
20. *Scomberomorus* sp*.*
21. Chelonian carapace fragments recovered together, presumably the same individual
22. Chelonian bones
23. *Lepisosteus* sp. scale.
24. Mosasaur coprolite

PLATE 3 BIVALVIA

Cyprimeria depressa	*C. depressa*	*C. depressa*	*Tensa pinguis*
Lucina glebula	*L. glebula*	*Venisella conradi*	*Corbula foulkei*
Nuculana percrassa	*N. percrassa*	*Corymya tenuis*	*C. tenuis*
Vetericardia crenalirata	*V. crenalirata*	*Venisella etea carolinensis*	*V. etea carolinensis*
Trigonarca triqueta	*T. triqueta*	*Breviarca umbonata*	*B. umbonata*
Striarca congesta	*S. congesta*	*Glycimeris mortoni*	*G. mortoni*

Plate 3 Key Bivalvia

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

1. *Cyprimeria depressa* exterior, right valve, 35 mm
2. *Cyprimeria depressa* interior, right and left valves
3. *Cyprimeria depressa* internal mold, right valve
4. *Tenea pingus* exterior, 10 mm
5. *Lucina glebula* exterior, note boring, 12 mm
6. *Lucina glebula* interior
7. *Veniella conradi*, right, left valve, interior and exterior, 18 mm
8. *Corbula foulkii* right, left valve interior and exterior, 4 mm, note borings
9. *Nuculana percrassa* exterior, 30 mm
10. *Nuculana percrassa* interior
11. *Corimya tenuis* exterior
12. *Corimya tenuis* interior
13. *Vetericardia crenalirata* exterior
14. *Vetericardia crenalirata* interior
15. *Veniella etea carolinensis* exterior
16. *Veniella etea carolinensis* interior
17. *Trigonarca triqueta* exterior
18. *Trigonarca triqueta* interior
19. *Breviarca umbonata* exterior
20. *Breviarca umbonata* interior
21. *Striarca congesta* exterior
22. *Striarca congesta* interior
23. *Glycimeris mortoni* exterior
24. *Glycimeris mortoni* interior

PLATE 3 - BIVALVIA PLUS MISCELLANEOUS

Breviarca haddonfieldensis	*Cardium dumosum*	*C. dumosum*	*Volsella julia*
Cymella bella	*Tellina gabbi*	*Trigonia mortoni*	*Pecten quinquecostata*
Cardium eufaulensis	*C. eufaulensis*	cf. *Cucullaea vulgaris*	cf. *Cucullaea gigantica*
Exogyra sp.	*E. sp.*	*Cardium sp.*	*Cardium sp.*
Inoceramus proximus	*Cucullaea antrosa*	Block from shell bed G11	Block from shell bed G8
Teredolites on lignite	*Ophiomorpha nodosa*	Plantae	Hoploparia

Plate 4 key Bivalvia plus miscellaneous.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

1. *Breviarca haddonfieldensis*   13 mm

2. *Cardium dumosum*   exterior 11 mm
3. *Cardium dumosum*   interior
4. *Volsella julia* 30 mm

5. *Cymella bella* 20 mm
6. *Tellina gabbi* 20 mm

7. *Trigonia mortoni* 25 mm

8. *Pecten quinquecostata*
9. *Cardium eufaulensis* external 13 mm

10. *Cardium eufaulensis* internal

11. cf. *Cucullaea vulgaris*

12. cf. *Cucullaea gigantica*

13. *Exogyra* sp. internal mold, calcitic traces

14. *Exogyra* sp. external mold
15. *Cardium* sp. external

16. *Cardium* sp. internal

17. *Inoceramus* external mold **>** 70 mm

18. *Cucullaea antrosa*

19. Block from G11, calcareous biostrome

20. Block from G8, leached biostrome

21. Teredolites on pyritized lignite

22. *Ophiomorpha nodosa*

23. Plantae, growth rings on siderite replacement, 4 cm diameter

24. *Hoploparia*

PLATE 4 – GASTROPODA, CEPHALPODA, ANNELIDA

Lunatia halli	*Turritella tippana*	*Turritella vertebroides*	*Triton lorrilardensis*
Gyrodes crenata	cf. *Liostraca cretacea*	*Turritella quadrilira*	*Volutoderma conradi*
Turritella lenolensis	*Caveola subalta*	*Caveola subalta*	*Avellana cretacea* m
Turritella sp.	*Lingula subspatulata*	*Longitubis lineatus*	*Longitubis lineatus*
Trochocyathus woolmani	*Astrangea cretacea*	*Hamulus falcatus*	*Hamulus falcatus*
Coeloptychium jerseyensi	*Placentaceras placenta*	Ammonite	*Baculites ovatus*

Plate 5. key Gastropod, Cephalopoda Annelida.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

1. *Lunatia halli* 12 mm

2. *Turritella tippana* ca. 5 cm

3. *Turritella vertebroides* ca. 4 cm

4. *Triton lorillardensis*   3 mm

5. *Gyrodes crenata* 6 mm   cast

6. *Leiostriaca cretacea*, 6 mm

7. *Turritella quadrilira* ca. 4 cm

8. *Volutoderma conradi* ca. 5 cm

9. *Turritella lenolensis* 15 mm

10, *Caveola subalta*   3 mm

11. *Caveola subalta*

12, *Avellana cretacea* 5 mm

13. *Turritella* sp. pyritized steinkern ca. 5 cm

14. *Lingula subspatulata*

15. *Longitubus lineatus*

16. *Longitubus lineatus*

17. *Trochocyathus woolmani*

18. *Astrangea cretacea*

19. *Hamulus falcatus*

20. *Hamulus falcatus* operculae

21. cf. *Coeloptychium jerseyensis* Poriferid, see (Richards et al., 1958)

22. *Placenticeras placenta*

23. Ammonite

24. *Baculites ovatus*

PLATE 6 – PALEOZOIC

Crinoid calyx

Crinoid stem

Billingsastraea vandelli

Discotrochus californicus

Brachiopod

Brachiopod

Bryozoan w/ brachiopod

cf. *Lyella americana*

Bryozoan

Dalmanella sp.

Brachiopods (2)

Rugose coral

Rugose coral

Emmonsia emmonsii

Tabulate coral, favositid

Unidentified

Rugose coral

Stromatolite

Stromatolite

Lichenalia concentrica

Coenites sp.

Petrified wood

Rugose coral

Rugose coral

Plate 6 key Paleozoic

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

1. Crinoid calyx
2. Crinoid stem
3. Rugosa, colonial. cf. *Billingsastraea yandelli* Devonian, (Louisville Fossils, online)
4. cf. *Discotrochus califoricus* (Shimer and Shrock, 1944):pl 44 fig 5 p. 117
5. Brachiopod
6. Brachiopod
7. Bryozoan with brachiopod cf. *Rafesquina* sp.
8. Bryozoan f. *Lyella americana* (Shimer and Shrock, 1944) pl 35 fig 11
9. Bryozoan
10. Brachiopod cf. *Dalmanella* sp.
11. cf. *Calapoecia. Canadensis antocostiensis* (Shimer and Shrock, 1944) fig 15 p. 38.
12. Rugose coral cf. *Aulacophyllum sulcatum* (Shimer and Shrock, 1944) pl 3 fig 7, 8
13. Rugose coral
14. Tabulate coral cf. *Emmonsia emmonsii,* from the Devonian Onondaga Limestone of Genesee County, New York. (Digital Atlas – Tabulata, online)
15. Rugosa *Heliophyllum* sp.
16. Unidentified
17. Rugose coral
18. Stromatolite
19. Stromatolite
20. Bryozoan cf. *Lichenalia concentrica* Shimer and Shrock, 1944):pl 103, fig 4
21. *Coenites*
22. Petrified wood   Kirkwood Formation?
23. Rugose coral
24. Rugose coral

APPENDIX 3. Trophic mode of Bivalves (Paleobiology database, online).

Bivalve taxon	Trophic mode
Anatina jerseyensis Weller	facultatively mobile infaunal deposit feeder
Aphrodinia tippana jerseyensis Richards	No record
Breviarca cuneata (Gabb)	facultatively mobile epifaunal suspension feeder
Breviarca haddonfieldensis Stephenson	facultatively mobile epifaunal suspension feeder
Breviarca umbonata (Conrad)	facultatively mobile epifaunal suspension feeder
Cardium dumosum Conrad	facultatively mobile infaunal suspension feeder
Cardium eufaulensis Conrad	facultatively mobile infaunal suspension feeder
Cardium tenustriatum Whitfield	facultatively mobile infaunal suspension feeder
Cardium uniformis Weller	facultatively mobile infaunal suspension feeder
Corbula crassaplica Gabb	stationary infaunal suspension feeder
Corymya tenuis Whitfield	facultatively mobile infaunal suspension feeder
Cucullaea antrosa Morton	facultatively mobile infaunal suspension feeder
Cymella bella texana Stephenson	facultatively mobile infaunal carnivore
Cyprimeria densata (Conrad)	facultatively mobile infaunal suspension feeder
Cyprimeria depressa Conrad	facultatively mobile infaunal suspension feeder
Etea carolinensis Stephenson	facultatively mobile infaunal suspension feeder
Etea delawarensis (Gabb)	facultatively mobile infaunal suspension feeder
Exogyra costata Say	stationary epifaunal suspension feeder
Gastrochaena linguiformis	stationary boring suspension feeder
Gervilliopsis ensiformis (Conrad)	stationary epifaunal suspension feeder
Glycimeris mortoni (Conrad)	facultatively mobile infaunal suspension feeder
Inoceramus Proximus Tuomes	facultatively mobile epifaunal suspension feeder
Legumen concentricum Stephenson	facultatively mobile infaunal suspension feeder
Lima lorillardensis Weller	facultatively mobile epifaunal suspension feeder
Linearia metastriata Conrad	facultatively mobile infaunal deposit feeder
Lucina glebula Conrad	facultatively mobile infaunal chemosymbiotic
Lucina parva Stephenson	facultatively mobile infaunal chemosymbiotic
Nemodon brevifrons Conrad	facultatively mobile low-level epifaunal suspension feeder
Nucula percrassa Conrad	facultatively mobile infaunal deposit feeder-suspension feeder
Nucula slackiana (Gabb)	facultatively mobile infaunal deposit feeder-suspension feeder
Nuculana compressifrons Whitfield	facultatively mobile infaunal deposit feeder-suspension feeder
Nuculana longifrons (Conrad)	facultatively mobile infaunal deposit feeder-suspension feeder
Pecten bellisculptus (Conrad)	facultatively mobile epifaunal suspension feeder
Pecten burlingtonensis Gabb	facultatively mobile epifaunal suspension feeder
Pecten conradi (Whitfield)	facultatively mobile epifaunal suspension feeder
Pecten craticulus Morton	facultatively mobile epifaunal suspension feeder
Pecten quinquecostata Sowerby	facultatively mobile epifaunal suspension feeder
Pecten simplicius Conrad	facultatively mobile epifaunal suspension feeder
Pinna laqueata Conrad	stationary semi-infaunal suspension feeder

Pteria petrosa (Conrad)	stationary epifaunal suspension feeder
Solmya lineolatus Conrad	facultatively mobile infaunal deposit feeder
Striarca congesta (Conrad)	facultatively mobile epifaunal suspension feeder
Tellina gabbi Gardner	facultatively mobile deep infaunal deposit feeder
Tenea parilis (Conrad)	facultatively mobile infaunal suspension feeder
Tenea pingus (Conrad)	facultatively mobile infaunal suspension feeder
Trigonarca cuniformis Conrad	facultatively mobile semi-infaunal suspension feeder
Trigonarca triqueta Conrad	facultatively mobile semi-infaunal suspension feeder
Trigonia eufaulensis Gabb	facultatively mobile infaunal suspension feeder
Trigonia mortoni Whitfield	facultatively mobile infaunal suspension feeder
Veniella Conradi Morton	facultatively mobile infaunal suspension feeder
Veniella subovatus Whitfield	facultatively mobile infaunal suspension feeder
Vetericardia crenalirata (Conrad)	facultatively mobile infaunal suspension feeder
Volsella julia (Lea)	stationary epifaunal suspension feeder
53	

Table 8. Trophic modes of Stone Bridge bivalve fossils

APPENDIX 4. Set of concretions from G8 used for species-abundance determination

Figure 23. Concretion set used in species-abundance determination for the concretion layer on G8. Scale bar is 10 cm

Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
Hamulus falcatus	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Gastropoda g. sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Anchura rostrata	0	1	1	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	5
Fusinus lorillardensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Gyrodes crenata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Lunatia halli	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Turritella quadrilira	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	4
Triton lorrilardensis	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	1	0	2	6
Turritella lorillardensis	0	1	0	5	3	2	0	0	0	0	3	1	0	0	5	3	0	0	0	23
Turritella sp	4	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	7	2	3	20
Breviarca umbonata	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cardium sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	5
Cardium eufaulensis	2	0	1	0	0	0	0	2	1	0	1	0	0	0	1	0	0	0	0	8
Cymbophora lintea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Cyprimeria depressa	13	4	16	8	7	9	11	11	7	20	1	4	2	6	4	10	20	7	4	164
Lucina glebula	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
Nucula slackiana	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
Tellina gabbi	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	4
Trigonia mortoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	3
Corbula crassaplica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Pecten conradi	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Anchura ? Pergracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Lignite	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	2	1	0	0	6
Menabites delawarensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Cucullaea wooburyensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Row total 25	22	8	23	14	12	12	12	17	12	23	6	6	3	8	12	17	39	10	12	268

Table 9. Concretion matrix. Top row is the concretion Number