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THE PENNSYLVANIAN

A LOVE OF FOSSILS BRINGS US TOGETHER

M.A.P.S. Digest--EXPO XXXIV Edition

M.A.P.S. Board Members

Preface

The editors wish to thank the contributors for responding to the Call for Papers in such a timely manner. The papers represent a wide range of Pennsylvanian related topics contributed by our members and others. We would also like to thank Scott D. Elrick for delivering the keynote address.

About the Cover

The cover image illustrates the Mazon Creek Biota from the Mazon Creek Coal Forest diorama exhibit that debuted at the Field Museum, Chicago, in 1931. See Figure 5 of Shabica and Baird this volume for a complete description. (© The Field Museum, #GEO85637c)

Western Illinois University
Western Hall
Macomb, Illinois
March 30, 31 and April 1, 2012

John Catalani and Chris Cozart, Editors

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Introduction to the Pennsylvanian of North America

Chris Cozart

History of Time Unit

The Pennsylvanian is a unit of geologic time dating roughly from 318 to 299 million years ago. It is presently considered to be a sub unit or subsystem within the Carboniferous System.

The Carboniferous, 354 to 299 million years ago, was originally described in 1832 from coal bearing rock units lying above the Devonian Old Red sandstone and unfossliferous red sandstones and dolostones (Permian) in the United Kingdom. These rocks units, also known as the coal measures, included strata of lower and Upper Carboniferous age and are largely a sequence of lowland continental deposits. In North America, a significant unconformity and difference in lithology (type of rock) between the rocks of the upper and lower Carboniferous led to the division of the Carboniferous in the United State into two separate systems, the upper being named the Pennsylvanian after rock exposed in the state of Pennsylvania, and the lower system named the Mississippian after rocks exposed in the valley of the Mississippi River. The Mississippian rocks in the United State are largely marine limestones, except for a transitional stage in the upper Mississippian, unlike the lowland continental deposits of the Pennsylvanian. Recently, the US has adopted the international used timescale of the ICS and the Pennsylvanian is now considered a subsystem of the Carboniferous.

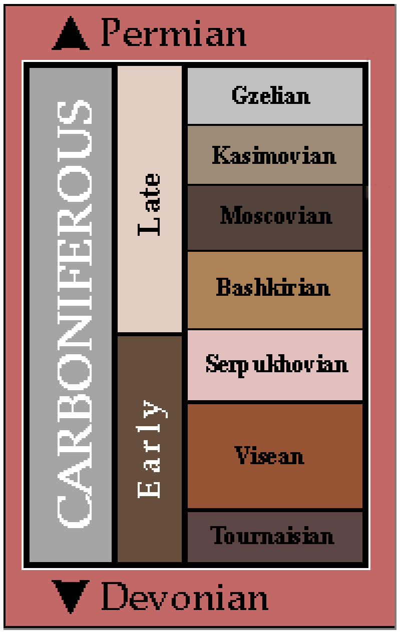

Figure 1. Basic subdivisions of the Carboniferous System. Late Carboniferous is equivalent to the Mississippian Subsystem and the Late Carboniferous is equivalent to the Pennsylvanian Subsystem.

Geological Events During the Pennsylvanian Period

The main global geological event occurring during the Pennsylvanian was the slow collision of the Laurasian (North America, Greenland, Europe, Siberia Kazakhstan and Northern China today.) and Gondwanaland (Antarctica, Africa, India, Australia and South America, of today.) landmasses to form the supercontinent named Pangaea in the early Permian. This collision formed the Appalachian Mountains in North America. In the East of North America, erosional sediments from the rising Appalachian Mountains filled the Appalachian geosyncline on the western margin of the mountains. In the early Pennsylvanian the Arbuckle Mountains, the Criner Hills, The Wichita Mountains, and the Amarillo mountains formed in Oklahoma and north Texas. The mountains exist as remnant stumps or are buried today.

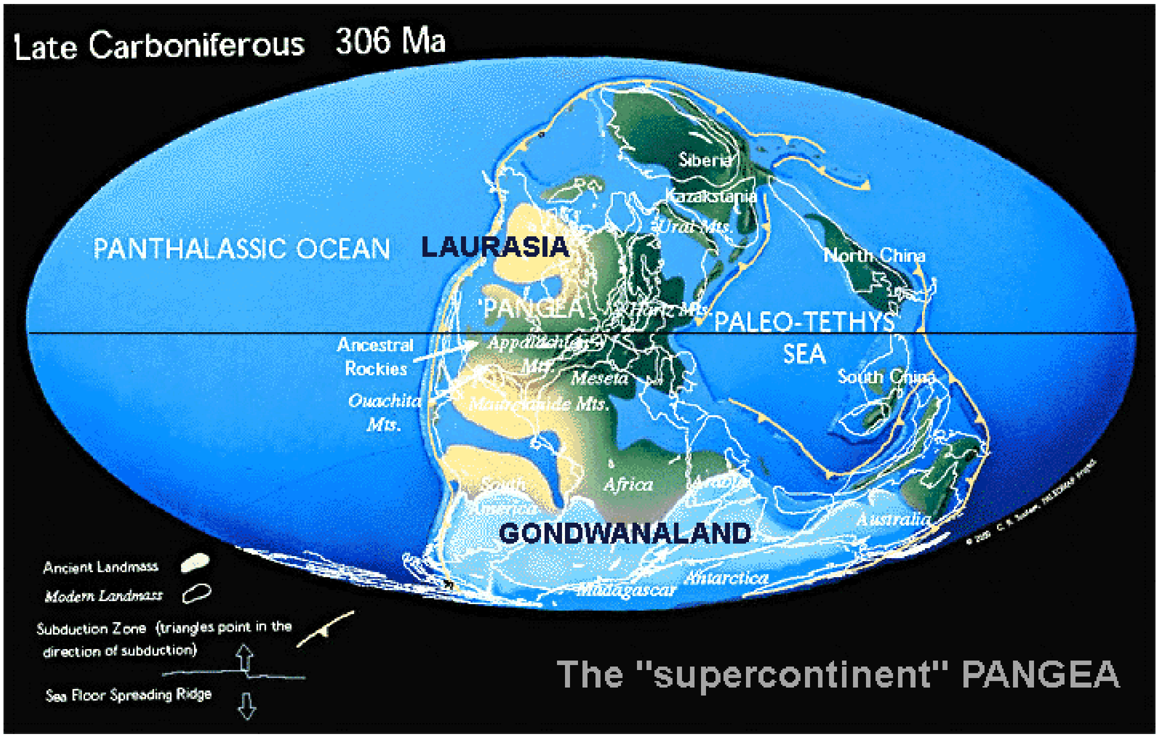

Figure 2. The Late Pennsylvanian world showing major land masses and oceans.

The seas over what is now the United States were restricted to the southern portion of the US geography during the early Pennsylvanian. As the period continued, the seas spread to the north, and covered most of the continental US by the mid Pennsylvanian. Large areas of mountainous high islands had formed by this time in Oklahoma and Colorado. Canada was largely land to the north. South of the Oklahoma highlands sediments are mainly marine. South and west of the Colorado highlands, deposited sediments are both marine and non-marine depending on proximity of the highlands. The basins roughly encircled by the Appalachians to the east, and the mountains of Oklahoma and Colorado to the south and west alternately filled with sediments and sank with the accumulated with of the sediments, depending on the relative rates of deposition and subsidence. Sea levels also rose and fell in response to glaciers that periodically grew and retreated during the period. This resulted in the deposition of numerous alternating thin beds of limestone, sandstone, shale and coal.

These beds were deposited in a cyclical fashion driven by the cycles of rising or receding seas. Each cycle of deposition by one of these cycles resulted in a fairly uniform sequence of deposition. These depositional cycles are known as cyclothems, and are well developed in the central US. There are about 100 individual cyclothems known in Illinois.

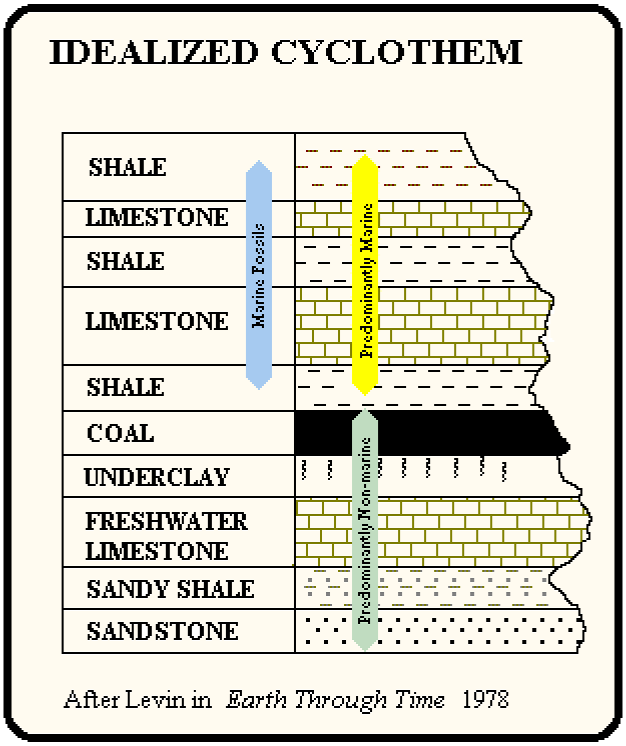

Figure 3. Idealized cyclothem illustrating the succession of marine and non-marine units.

The extensive lowlands around the margin of the central basins created by the interplay of deposition and subsidence are the source of many of the terrestrial and estuarial fossil deposits prized today.

Climate of the Pennsylvanian Period

The Pennsylvanian period began hot and humid. A gradual cooling took place during the period so that average global temperatures are believed to have declined by 10 – 12 degrees C by the end of the period. Much of the climate became dryer at the end of the Pennsylvanian due to the formation of the super continent Pangaea and the resulting development of a vast continental interior.

North America was located along the equator and despite the formation of glaciers at the poles, especially the in the south hemisphere, extensive lowland equatorial coastal swamps extended across the middle of what is now the continental US.

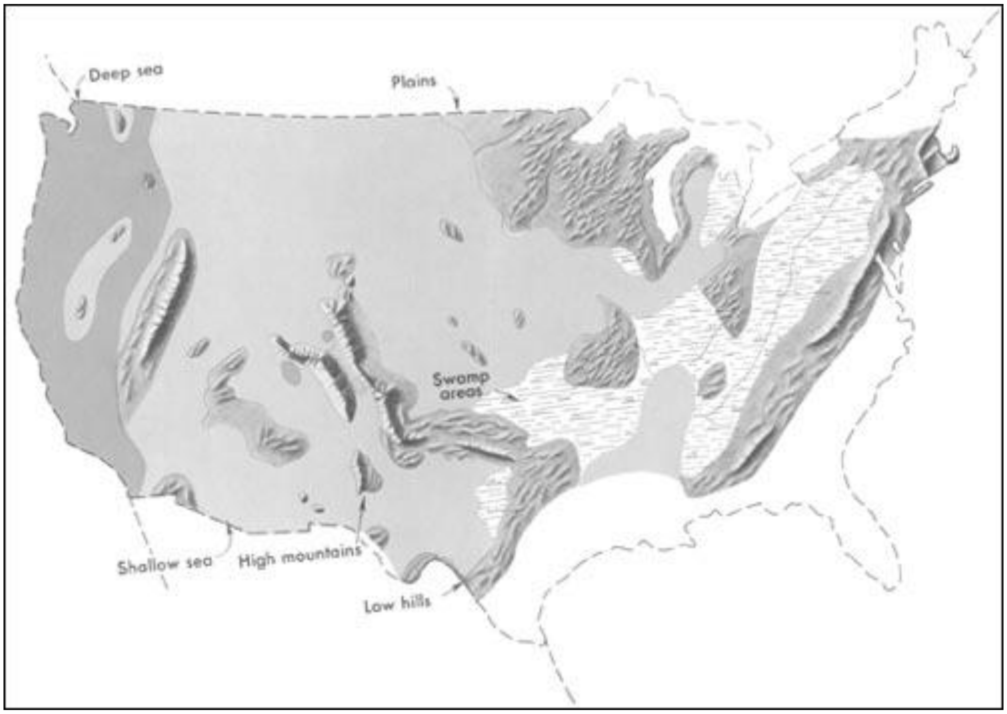

Figure 4. Paleogeography of the United States showing the coastal-swamp environment that was responsible for the many Midcontinent cyclothems.

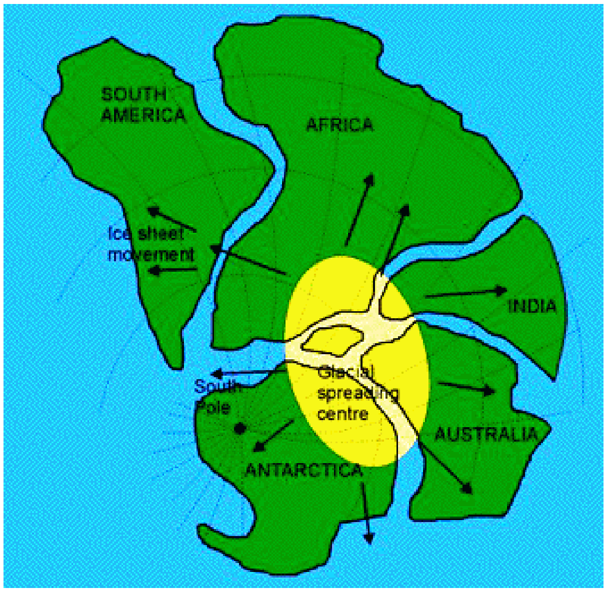

Figure 5. Extent of the Late Carboniferous glaciation event.

Interestingly, present day global carbon dioxide levels are at a geohistorical minimum only previously occurring during the late Ordovician and Late Pennsylvanian - early Permian periods. These, including the present, are all times of ice ages. Today's average global temperature is also at a geohistorical minimum, the same as during the late Ordovician and late Pennsylvanian - early Permian. Unlike much of Earth's history, which was much warmer, climate in the Pennsylvanian was much like today.

Life during the Pennsylvania

The Pennsylvanian is known for the abundant plant and animal life preserved in the coal measure deposits left behind from the sediments deposited in and along the equatorial lowlands as sea level fluctuated up and down due to erosional deposition, tectonic subsidence and sea levels rising and falling in response to the advance and retreat of glaciers. Famous are the Lagerstätten at Mazon Creek and Astoria in northern Illinois; Pontiac and Danville in central Illinois; Carterville, Murphysboro and other places in southern Illinois; Terre Haute, Mecca and Dugger in southern Indiana; Knob Knoster in Missouri; Linton in Ohio; and also the coal measures in Britain and France. There are numerous other localities in the US and around the world.

The lowland swamps of the Pennsylvanian were vast forests of lycopod trees (present day descendants club mosses), articulates (horse tails), true ferns, seed ferns and Cordaites. Cordaites are rare in the lowland flora, but common in upland deposits. The earliest relatives of the conifers also appeared.

Also present in the swamps were numerous arthropods, dominated by hundreds of known species of insects. Some insects reached gigantic size, with a wingspan of two feet. It is hypothesized that these insects were able to achieve this size due to the very high level of oxygen in the atmosphere at the time. This high level of oxygen may also have enabled large forest fires even in the wet conditions of a swamp. Other arthropods were millipedes, centipedes, scorpions and spiders. Giant millipedes could reach lengths of a yard. Vertebrates of the coal forest were amphibians and early reptiles.

Some major evolutionary developments during this period were the development of the amniotic egg and herbivory. An amniotic egg is an egg with a semi permeable outer membrane that can survive on land. This permitted the evolution of early reptiles called cotylosaurs in the Pennsylvanian, and later all other land dwelling vertebrates. The development of herbivory, the eating of plants, by early reptiles facilitated the evolution of new reptile groups. Other evolutionary developments were the first land snails and insects with unfoldable wings, such as dragonflies.

Shallow water marine invertebrate communities continued on the Paleozoic model with abundant brachiopods, bryozoans and foraminifers. Also common were pelecypods, gastropods and sponges. While crinoids were abundant, blastoid diversity and abundance declined drastically. Trilobites continued their decline. Nautiloids were also declining. Vertebrate communities included diverse groups of bony fishes and sharks.

Paleontology of a Late Pennsylvanian Quarry: Part 1 – Stratigraphy

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Many fossil collectors from northern Illinois have visited the Lone Star (now Buzzi Unicem) quarry near Oglesby, Illinois. The operation mines the La Salle Limestone member of the Bond Formation (Missourian, Pennsylvanian) for the production of cement. Also exposed at the quarry are red and gray shales above the limestone, and gray and black shale layers below it. Figure 1 is a picture of the quarry wall showing the upper three layers.

Figure 1. Picture of the quarry wall. (Photo by J. Catalani)

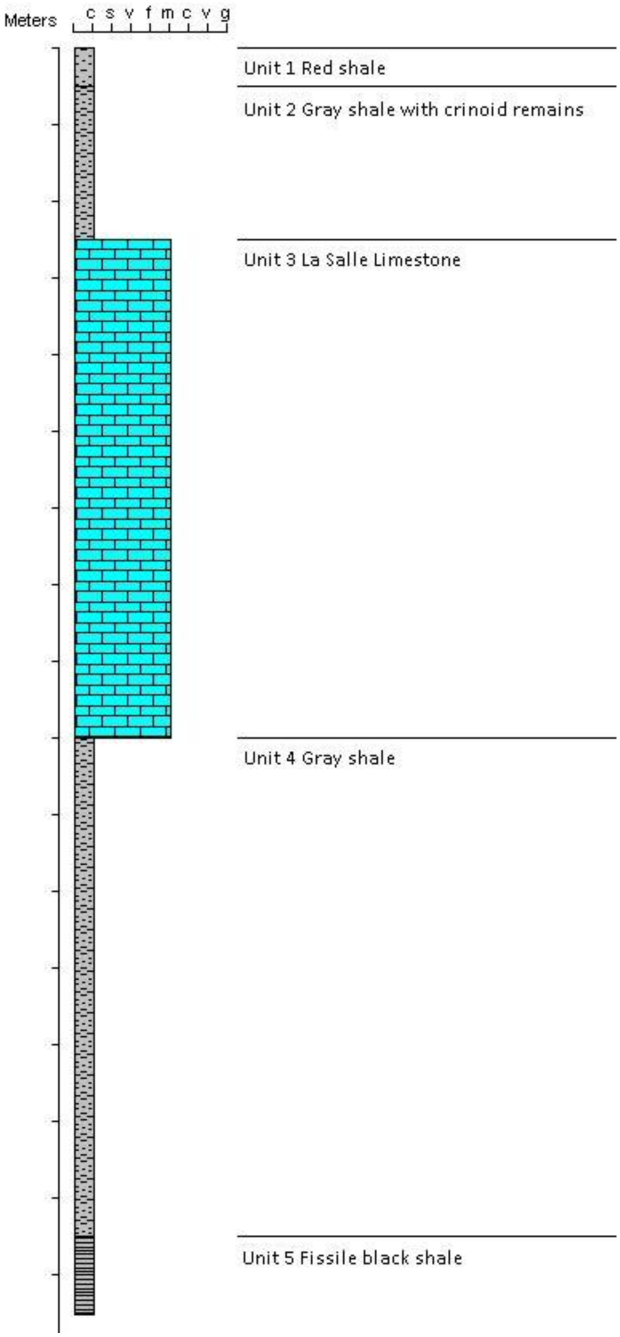

Figure 2. Generalized stratigraphic column of the layers in the quarry.

The topmost rock layer is reddish shale (Unit 1). This layer is removed as overburden and generally is not available for collecting. Beneath this is gray shale with abundant crinoid remains and often shark's teeth (Unit 2). The La Salle Limestone (Unit 3) is the only named unit in the section. Jacobson (1983) places the La Salle Limestone as the upper-most layer in the Bond Formation. Fraser (1991) considers the upper shales to exist in "depressions" in the limestone. These shales are widespread at Lone Star and have a lithology and fauna distinct from that in the underlying limestone. As such, they may belong to the overlying Mattoon Formation. Petrographic analysis by Fraser (1991) indicates the La Salle Limestone was deposited in an "algal bank". Such deposits are composed of phylloid algal plates from 2 to 10 cm in length surrounded by micritic sediment (Scholle and Ulmer-Scholle, 2003). Below the limestone is a thick, fossiliferous gray shale layer (Unit 4). Well-preserved brachiopods, gastropods and rugose corals are common in this layer. Crinoids are occasionally found, and shark's teeth are rare. Beneath this is a layer of black, fissile shale (Unit 5). This shale is below the normal working floor of the quarry, and is only exposed in drainage ditches. Conodonts are common in this layer along with orbiculoid brachiopods. Fish, stomach ejecta and shark's teeth have also been found.

This stratigraphic description will be used for the article that follows describing the fossil gastropod fauna from the Oglesby Illinois Lone Star Quarry.

Relationship to the Francis Creek Shale (Mazon Creek)

Both the Lone Star Quarry and Mazon Creek lie on the northern edge of the Illinois Basin. The Illinois Basin was the site of many cycles of sediment deposition (cyclothems) during the Pennsylvanian (Jacobson, 2000). Each cyclothem represents a cycle of marine transgression and regression spanning 200 to 400 thousand years (Heckel, 1986). In the area of Mazon Creek, the Francis Creek Shale member of the Carbondale Formation produces siderite nodules containing a huge variety of animal and plant fossils many with soft tissue preserved. The Carbondale Formation (Desmoinesian) includes several cyclothems and underlies the Modesto Formation. The Modesto Formation, in turn, contains several more cyclothems, and underlies the Bond Formation. The layers at Lone Star belong to the uppermost Bond Formation and possibly the lower Mattoon Formation. While both are Pennsylvanian in age, the strata exposed at the Lone Star Quarry are notably younger than those at Mazon Creek.

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Paleontology of a Late Pennsylvanian Quarry: Part 2 – Gastropods

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Abstract

A diverse gastropod fauna from the Bond formation (Pennsylvanian, Missourian) of northern Illinois is described. Some specimens of *Euconospira turbiniformis*, *Naticopsis* and *Anomphalus* retain color patterns. The shapes of the patterns are described and their expression across specimens of different sizes is discussed.

Introduction

Gastropods are a common and recognizable element of Midwest Pennsylvanian marine faunas. In the 19th century, Meek and Worthen (1866, 1873) and Worthen et al. (1890) described many specimens including gastropods from the "Coal Measures" of Illinois, but they lack complete stratigraphic and locality data. More recently Knight (1930, 1933, and others) published a series of detailed accounts of the gastropod fauna from a Pennsylvanian outlier in St. Louis. Wanless (1958) published a comprehensive list of Pennsylvanian faunas from western Illinois including gastropods. This report will describe the gastropod fauna of the Bond formation (Pennsylvanian, Missourian) from the Lone Star (now Buzzi-Unicem) quarry near Oglesby in north-central Illinois.

Some of the specimens described retain a portion of the original shell color pattern. Retention of color and/or pattern in Carboniferous gastropods has been documented by Greger (1917), Foerste (1930), Squires (1976), Hoare and Sturgeon (1978a and 1978b) and Chestnut and Slucher (1990) among others. For the specimens included here, the pattern will be described and its variability between specimens will be discussed.

Locality and Stratigraphy

All specimens were collected at the location described by the author in Part 1 of this series (this volume). Specific strata in which each specimen was found will be listed in this report in the section on "Specimen Descriptions" using the terminology found in Part 1.

Identification

The condition of specimens available for study varies greatly. Some lack definitive characters which make their identification difficult. Publications by Meek and Worthen (1866, 1873), Worthen et al. (1890), Knight et al. (1960), Hoare (1961) and Kues and Batten (2001) were used as a source of reference data and pictures.

Classification

Taxonomy and classification within the Gastropoda are under constant revision. This report makes no attempt to address any issues of classification. Except for bellerophontoids, no taxa above the family level are specified.

Faunal List

Family Platyceritidae
  Platyceras sp. (Unit 4)
Family Anomphalidae
  Anomphalus? sp. (Unit 4)
Family Neritopsidae
  Naticopsis sp. A (Units 3 and 4)
  Naticopsis cf. N. ventrica Norwood and Pratten, 1855 (Unit 4)
  Trachydomia nodosa Meek and Worthen, 1861 (Unit 4)
Family Eotomariidae
  Euconospira turbiniformis Meek and Worthen, 1860 (Unit 4)
Family Raphistomatidae
  Trepospira sp. (Unit 4)
Family Lophospiriidae
  Worthenia? sp. (Unit 4)
Family Subulitidae
  Strobeus? sp. (Units 3 and 4)
  Strobeus cf. S. primigenius Conrad, 1935 (Unit 3)
Family Meekospiridae
  Meekospira? sp. (Unit 4)
Family Pseudozygopleuridae
  Hemizyga? sp. (Unit 4)
Superfamily Bellerophontoidea
  Unidentified specimens (Unit 4)
Indeterminate genus (Unit 4)

Specimen Descriptions

Family Platyceritidae Hall, 1879
Genus *Platyceras* Conrad, 1840
Platyceras sp.
25 specimens
Figure 1, a.

Description –
Common, small, with disjunct shell. All specimens are brown, and most show distinct folds developed as the shape of the shell conformed to that of the crinoid calyx to which it was attached (Knight et al., 1960). Shell thickness on the order of 1 mm, but durable. All but 2

specimens show growth lines, the others being completely smooth. The latter also has no folds in the shell, and the aperture appears more flared. Largest specimen (LS1039) is 27 mm in length and 12.7 mm in height.

Family Anomphalidae Wenz, 1938

Genus *Anomphalus* Meek and Worthen, 1867
Anomphalus? sp.
1 specimen
Figure 1, b.

Description –
Rare, medium-sized, rotelliform shell. Brown, with dark growth lines. Single specimen is slightly crushed vertically. It is 23 mm wide and 7.7 mm in height.

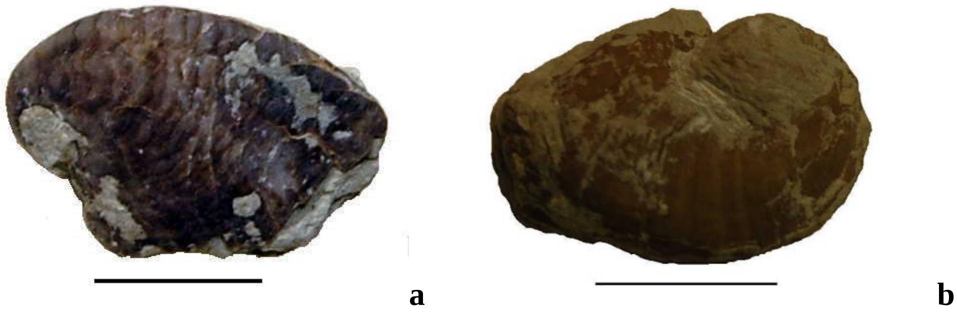

Figure 1. a) LS1039, *Platyceras sp*., **b)** LS1062, *Anomphalus? sp*. Scale bar = 1 cm.

Family Neritopsidae Gray, 1847

Subfamily Naticopsinae Waagen, 1880
Genus *Naticopsis* McCoy, 1844
Naticopsis sp. A
4 specimens
Figure 2, a and b.

Description –
Small to medium, globular, low spire. Final whorl more rounded than in *Naticopsis sp. B*. Specimens are all steinkerns.

Naticopsis cf. N. ventrica Norwood and Pratten, 1855
40 specimens
Figure 2, c and d.

Description –
Common, medium-sized neritopsid with moderately-high spire. Specimens are brown and often show fine brown growth lines, similar to that described by Kemp (1957). However, the final whorl is slightly less globose than *Naticopsis sp. A* and the spire is taller. Shell is thin, < 1 mm. Largest specimen is 32 mm high and 31 mm wide.

Subfamily Neritopsinae
Genus *Trachydomia* Meek and Worthen, 1866
Trachydomia nodosa Meek and Worthen, 1861
5 specimens
Figure2, e.

Description –
Small to medium, globular with distinct growth lines and nodules. Nodules are weakly organized or in radial rows, inconsistent in size and darker than surrounding shell. Growth lines of inconsistent width. Shells are a light gray or tan, growth lines often darker, and nodules dark. Specimens did not fluoresce under UV. Three specimens are fairly complete though the apices are somewhat flattened. Measured widths for these are 12 mm, 19 mm and 28 mm.

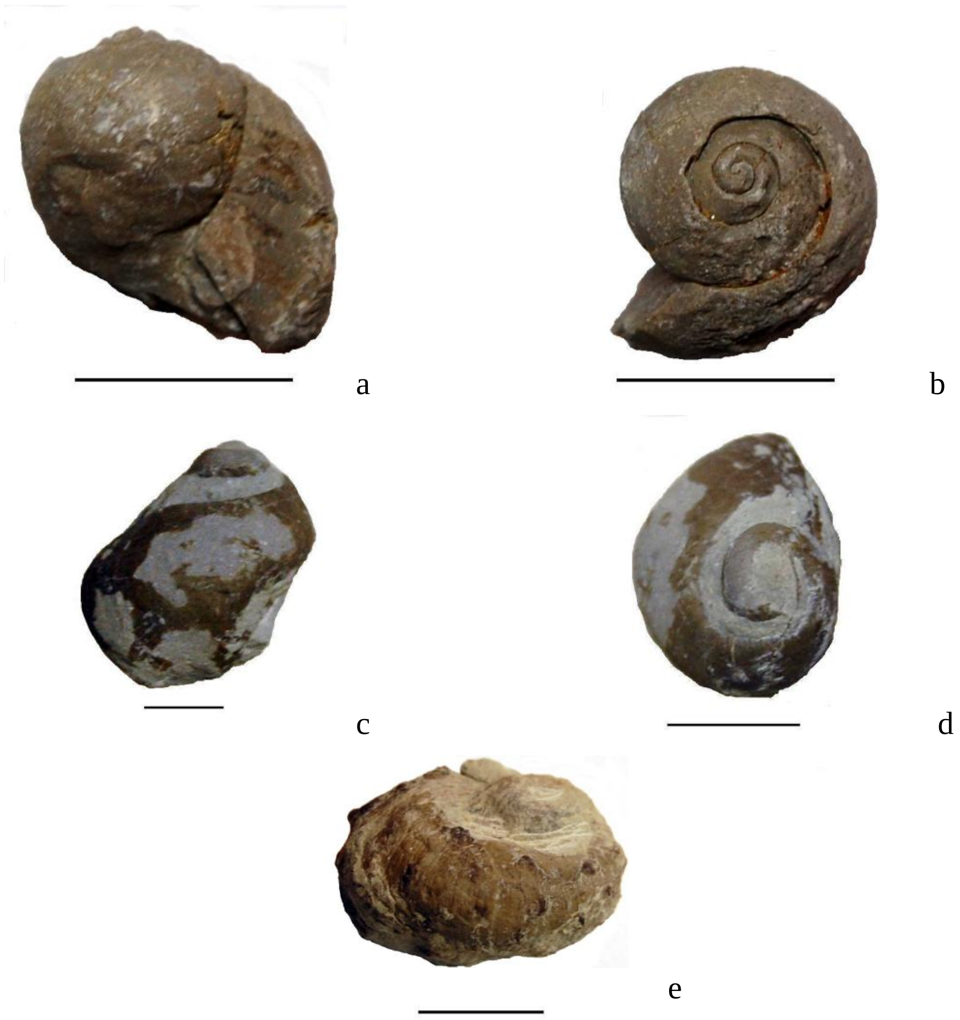

Figure 2. a) LS1018, *Naticopsis sp. A*, lateral view, **b)** LS1018, top view, **c)** LS1032, *Naticopsis cf. N ventrica*, lateral view, **d)** LS1032, top view, **e)** LS1049, *Trachydomia nodosa*. Scale bar = 1 cm.

Family Subulitidae Lindström, 1884

Subfamily Soleniscinae Wenz, 1938
Genus *Strobeus* de Koninck, 1881

Strobeus? sp.
7 specimens
Figure 3, a and b.

Description –
Medium to large, preserved as a steinkern only. Most specimens have 3 or 4 whorls and are missing the apex. Shape is fusiform and the sutures are shallow. The final whorl makes up more than ¾ of the total height. The largest specimen is 35 mm in width and 52 mm in height.

Strobeus cf. S. primigenius Conrad, 1935
4 specimens
Figure3, c and d.

Description –
Uncommon, small to medium, globose with a moderately-high spire. Two specimens retain the thin, smooth shell, though it is replaced. Largest specimen is 27 mm wide and 34 mm in height.

Family Eotomariidae Wenz, 1938

Subfamily Liospirinae Knight, 1956
Genus *Trepospira* Ulrich and Scofield, 1897
Trepospira sp.
20 specimens
Figures 3, e.

Description –
Small, cryptomphalous, discoidal, outer surface of last whorl presents a sharp angle. Has a row of nodes below the suture. Shell is thin and brown. Largest specimen is 18 mm wide and 6 mm high. Condition of specimens does not allow identification to species level.

Subfamily Eotomariinae Wenz, 1938
Genus *Euconospira* Ulrich and Scofield, 1897
Euconospira turbiniformis Meek and Worthen, 1860
32 specimens
Figure 3, f and g.

Description –
Medium-sized, conical, trochiform with a flattened base. None of the specimens examined are completely undamaged. Most are compressed vertically especially at the apex, making height measurement difficult. Width ranges from 10 mm to 33 mm. Shell is thin, < 1 mm. Shell surface often shows fine cross-hatched lines which “lean” towards the aperture

(prosocline) from top to bottom. Specimens are tan to light brown. Commonly retains color pattern on shell (see later section in this paper).

Figure 3. a) LS1021, *Strobeus? sp*. lateral view, **b)** LS1021 top view, **c)** LS1020, *Strobeus cf. S. primigenius*, lateral view, **d)** LS1020, top view, **e)** LS1011, *Trepospira sp*., **f)** LS1070, *Euconospira turbiniformis*, lateral view, **g)** LS1070, top view, **h)** LS1037, *Worthenia? sp*., lateral view, **i)** LS1037, top view. Scale bar = 1 cm.

Family Lophospiriidae Wenz, 1938

Genus *Worthenia* de Koninck, 1881
Worthenia? sp.
1 specimen
Figure 3, h and i.

Description –
Rare, large, trochiform with high spire. Final whorl has a flattened lateral surface. The single specimen is a steinkern and slightly deformed (flattened) on one side. Important shell characters are missing and the size is large, though the shape is consistent with *Worthenia* (Kues pers. comm., 2012). It measures 47 mm wide and 37 mm high and has 4 whorls.

Family Meekospiridae Knight, 1956

Genus *Meekospira* Ulrich, 1897
Meekospira? sp.
1 specimen
Figure 4d.

Description –
Small, slender with no ornamentation or growth lines. There are 7 whorls preserved. Sutures are shallow and outer walls are straight. The single specimen is 17 mm high and 7 mm wide at the base.

Family Pseudozygopleuridae Knight, 1930

Genus *Hemizyga* Girty, 1915
Hemizyga? sp.
1 specimen
Figure 4c.

Description –
Small, somewhat globose at base. The single specimen is a steinkern and is missing the apex. It measures 17mm in height and 12 mm in width, and 3 whorls are preserved. Identification as *Hemizyga* is tentative due to the lack of characters preserved.

Indeterminate genus

1 specimen
Figure 4, a and b.

Description –
Rarely found, large, turbiniform, with a shallow suture. Spire is moderately high. With no other characters preserved, a determination to genus cannot be made. The single specimen is a steinkern with 4 whorls, and measures 34 mm in width and 23 mm high.

Superfamily Bellerophontoidea

Unidentified Bellerophontoids
3 specimens
Figure 4, e through h.

Description –
Specimen LS1039 is a steinkern with no ornamentation or markings. LS1040 is more complete but distorted, and the shell appears to be replaced and missing most of its original details. Bellerophontoids are a significant part of Pennsylvanian marine faunas from New Mexico (Kues and Batten, 2001) and southwest Missouri (Hoare, 1961). While not common, the specimens figured here demonstrate that bellerophontoids are present in the Bond Formation fauna.

Figure 4. a) LS1007, indeterminate genus, lateral view, **b)** LS1007, top view, **c)** LS1042, *Hemizyga* sp. lateral view, **d)** LS1047, *Meekospira* sp. lateral view, **e)** LS1029, unidentified bellerophontoid “top” view, **f)** LS1029, “bottom” view, **g)** LS1028, unidentified bellerophontoid “top” view, **h)** LS1028, “bottom” view. Scale bar = 1 cm.

Color Pattern Retention in *Euconospira turbiniformis*

As a fraction of the total number of gastropod fossils, the number that retains at least a trace of the original color pattern must be very small, but is nonetheless well-documented. Foerste (1930) counted 293 fossil species known to retain coloration, and Kobluk and Mapes (1989) listed 43 genera with preserved color from the Carboniferous period alone. A few examples will serve to demonstrate the diversity of the patterns preserved. Revolving bands of dark and light color were reported on *Euconospira* from the Pennsylvanian of Missouri by Greger (1917). Kemp (1957) described "light brown to brownish black" shading on the outer whorls of *Euomphalus*, and sinuous bands following the growth lines in *Naticopsis*, both from the Permian of Texas. Squires (1976) found parallel revolving brown bands on *Naticopsis* from the Pennsylvanian of Oklahoma, while Chestnut and Slucher (1990) noted a dark stripe on specimens of *Straparollus* from the Pennsylvanian of Kentucky. When the number of specimens allowed, the variation in preserved color pattern in *Callistadia* was studied by Hoare and Sturgeon (1978a).

Gastropods have a shell usually composed of aragonite covered by a thin periostracum. It is in these layers that compounds (biochromes) are deposited which produce color and patterns (Knight et al., 1960). The degree to which these colors and patterns are preserved on fossils depends chiefly on the physical condition of the shell and the chemistry of the pigment. The most common pigments in modern gastropods are melanins and porphyrins (Comfort, 1951). Melanins are relatively stable, but are deposited in the periostracum and outermost shell layer which are more likely to be lost. Porphyrins, though soluble, are incorporated into the outer portion of the shell itself. These pigments also fluoresce red under ultraviolet light. The patterned specimens of *E. turbiniformis* from the Bond Formation were exposed to longwave and shortwave ultraviolet light from a Versalume PP-FLS lamp. No fluorescence was noted. Examination with a binocular light microscope revealed no superficial crystals or staining in the banded areas. Hollingsworth and Barker (1991) examined 8 species of color-banded gastropods, including recent and fossil, for their chemical composition. They reported that the atomic spectra did not differ greatly between fossil and recent shells, and that inordinate amounts of iron oxide were not found. Thus, the color bands in the fossil specimens were not due to diagenetic replacement of pigment with inorganic substances.

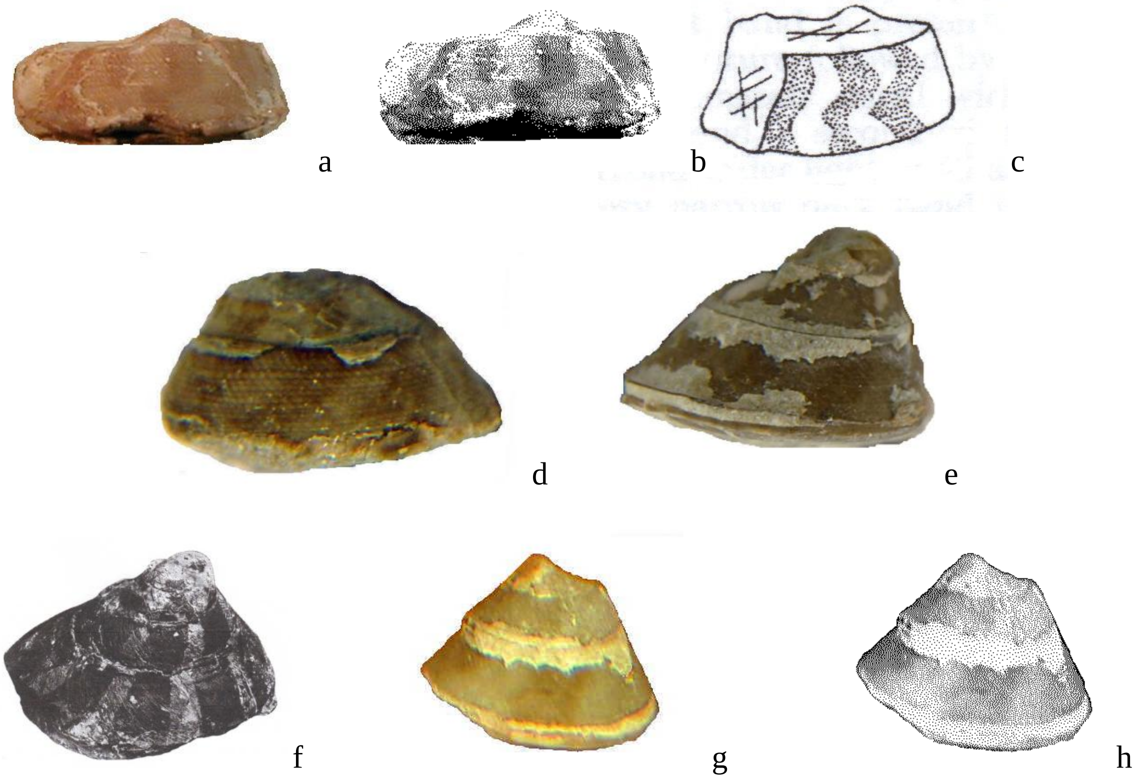

Figure 5. a) Specimen LS1073 *E. turbiniformis*, **b)** Computer-enhanced picture of LS1073, **c)** Illustration of *E. turbiniformis* from Hoare and Sturgeon (1978b), **d)** Picture of LS1057, **e)** Picture of LS1058, **f)** Picture of *E. nipponica* from Hayasaka (1954), **g)** Specimen LS1055. **h)** Computer-enhanced picture of LS1055.

Pattern retention in fossils of *Euconospira* has been noted by multiple authors. Hollingsworth and Barker (1991) performed geochemical tests on the markings on *E. conica*, a Lower Carboniferous species, but provided no picture. Hoare and Sturgeon (1978b) described nine species of gastropods from the Pennsylvanian of Ohio that retained color patterns. Among these was *E. turbiniformis*, shown in Figure 5c. The pattern on this specimen is very similar to that on LS1073, which is most visible in Figure 5b. Hayasaka (1954) described and figured a new species, *E. nipponica* from the Permian of Japan. Markings on this specimen consist of alternating dark and light vertical bands. Two specimens from the present study, LS1055 and LS1069, retain very faint vertical color bands, similar to *E. nipponica* (see Figure 5d). Both these specimens are small, measuring only 10 mm wide, while the single specimen of *E. nipponica* measured 110 mm in width. Hoare and Sturgeon (1978a) found considerable pattern variation in 120 specimens of the Pennsylvanian gastropod *Callistadia spirallis*. Variation in the coloration on *E. turbiniformis*, however, appears to follow a pattern. The smallest/youngest, LS1055, has vertical to slightly-diagonal bars with parallel sides. The intermediate specimens, LS1057 (20 mm wide) and LS1058 (19 mm wide) have simple vertical bars on the upper whorl, with a diagonal or slightly zigzagged pattern on the lower whorl. LS1073, the most mature specimen, has a width of 27 mm and displays a strong zigzag or dog-leg pattern. Though the sample size is small, pattern shape in *E. turbiniformis* appears to be linked to ontogeny.

Summary

The gastropods of the of the Bond formation are a diverse group representing at least 12 genera. Most are known from the gray shale (unit 4) though this may be due to preservational bias. Unit 2 is almost completely devoid of gastropod fossils. The density of crinoid and vertebrate remains in this unit suggests that it was well-oxygenated, while the worn condition of the crinoid columnals indicates a higher-energy environment or transport of sediments. Either gastropods of any appreciable size were absent from this environment, or their shells did not survive and fossilize. No gastropods were found in unit 5.

Some specimens of *Euconospira turbiniformis*, *Naticopsis*, and *Anomphalus* from unit 4 appear to retain original shell color patterns. The patterns found on fossils of *E. turbiniformis* support the conclusion that the pattern expressed is ontogenetically controlled. Porphyrins did not appear to be responsible for patterns in any specimens since no fluorescence was noted upon exposure to UV light.

Acknowledgements

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Pennsylvanian Nautiloids of the Midcontinent
John A. Catalani

The cephalopod faunas of the Pennsylvanian Subsystem of the Carboniferous System are remarkably consistent where exposed in the eastern two-thirds of the United States. Although a substantial number of ammonoids are present, they are generally not as morphologically diverse or abundant as the nautiloids. These faunas are mostly contained in rocks of the Desmoinesian, Missourian, and Virgilian Stages of the Middle and Upper Pennsylvanian Epochs.

The study of Midcontinent Pennsylvanian stratigraphy is intimately involved with the concept of cyclothems. Cyclothems represent a cyclical pattern of sedimentary deposition resulting from a sequence of repeating environment-altering processes. The term sequence stratigraphy has been used to describe such patterns of sedimentation within various temporal scales. In simplistic terms, cyclothems represent repeated transgressions and regressions of the epeiric seas that covered the North American craton in Paleozoic times resulting in cyclic sequences of marine and nonmarine facies. A more realistic approach involves a depositional continuum from tectonically (plate collisions) driven fluctuations in the east, termed Appalachian-type and dominated by nonmarine clastics, to eustatic changes in sea-levels in the west, termed Kansas-type and dominated by marine carbonates. Cyclothem sections intermediate between the two have been termed Illinois-type. The Midcontinent sea-level fluctuations have been attributed to glacioeustasy (Gondwana glaciations) driven by orbital-parameter forced periodicity (Milankovitch Cycles) that correspond to specific depositional sequence time scales. These cyclothemic processes resulted in the various coal beds present in the Midcontinent and the concretion-bearing shales (e.g. Francis Creek Shale) that directly overlie these coals. **Fig. 1** diagrams both idealized and field-observed cyclothem sequences. It is the marine limestone units of these sequences that contain the nautiloids under discussion.

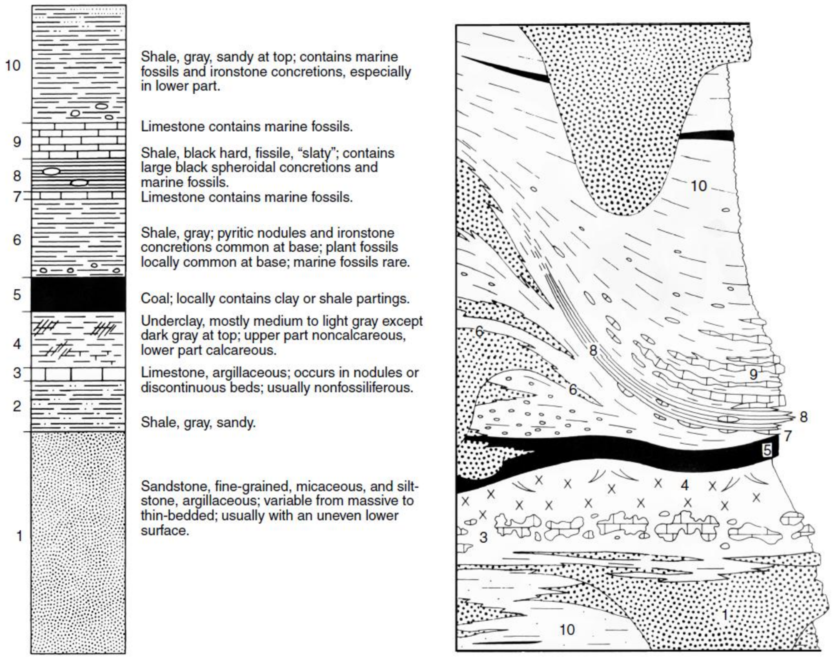

Fig. 1. Ideal (left) and field-observed (right) cyclothem sequences. (Modified from Illinois State Geological Survey, GeoNote 2.)

From a maximum of ten-or-so orders in the Ordovician, nautiloid diversity declined to only three orders by the Pennsylvanian. The two less common orders, the Orthocerida and the Pseudorthocerida, were composed mainly of straight-shelled nautiloids. The Orthocerida also contained one or two forms that truncated (shed) juvenile shells to trim weight as maturity was approached. The order Nautilida dominated the nautiloid faunas of the Pennsylvanian and was composed of nautiloids with a range of coiled shell types (see **Fig. 2**). (The Nautilida is the only order that survives today in the form of two genera, *Nautilus* and *Allonautilus*.) In this paper, I will briefly describe some of the more common nautiloids contained in Pennsylvanian rocks of the Midcontinent using one species to illustrate each genus.

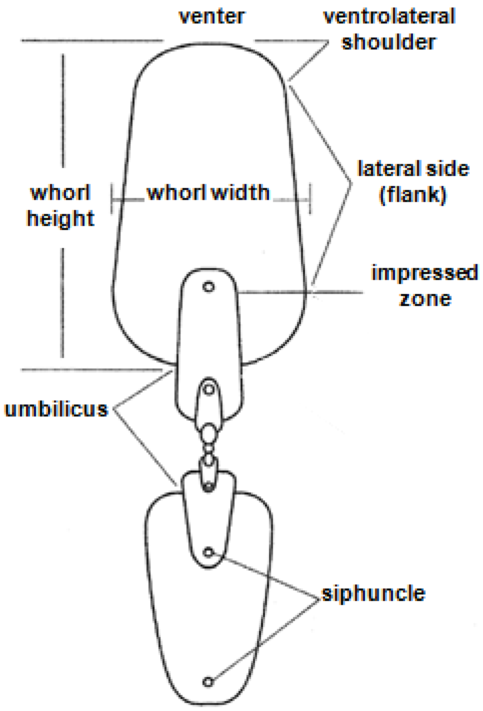

Fig. 2. Diagram illustrating morphologic terminology associated with coiled nautiloid shells. (Modified from Teichert *et al*. 1964, Fig. 8.)

The most abundant straight-shelled nautiloids are species of *Mooreoceras*, *Pseudorthoceras*, and *Euloxoceras*. By far the largest of these are certain species of *Mooreoceras*. The most common species is *M. normale* (**Fig. 3**). However, due to the large variability in the size of mature specimens that have been designated *M. normale*, it is certain that subsequent work will result in splitting into several new species. *Mooreoceras* is characterized by a smooth shell that gradually expands. Cross-sections can be circular or, more commonly, slightly depressed (wider than high with an oval profile), sutures are mostly straight, and the siphuncle is located between center and the venter.

Shells of *Pseudorthoceras knoxense* (the most widespread nautiloid species found in Pennsylvanian rocks) are small, slender, and gradually expanding with a circular cross-section and straight sutures. This species is characterized by closely spaced septa as well as extensive cameral deposits concentrated along the venter (**Figs. 4 & 6**).

Shells of *Euloxoceras greenei* are also small, slender, gradually expanding, with closely spaced septa but the cross-section is compressed (higher than wide with an oval profile) and the sutures form shallow lateral lobes (bends away from the living chamber). The relatively large siphuncle is located between the center and the venter (**Figs. 5 & 6**).

Another straight-shelled nautiloid, "*Michelinoceras*" *directum* (undescribed new genus) is restricted to the Buckhorn Asphalt Quarry (Oklahoma; see below) where it is relatively common. This species is easy to identify by the very gradually expanding shell with widely-spaced septa resulting in relatively large chamber volumes (**Fig. 15**).

Fig. 3. A large specimen of *Mooreoceras normale* from Pennsylvanian strata near Kansas City, Missouri. (All specimen photographs by the author.)

Fig. 4. *Pseudorthoceras knoxense* from the Ada Brick Pit, Oklahoma.

Fig. 5. *Euloxoceras greenei* from the Ada Brick Pit, Oklahoma.

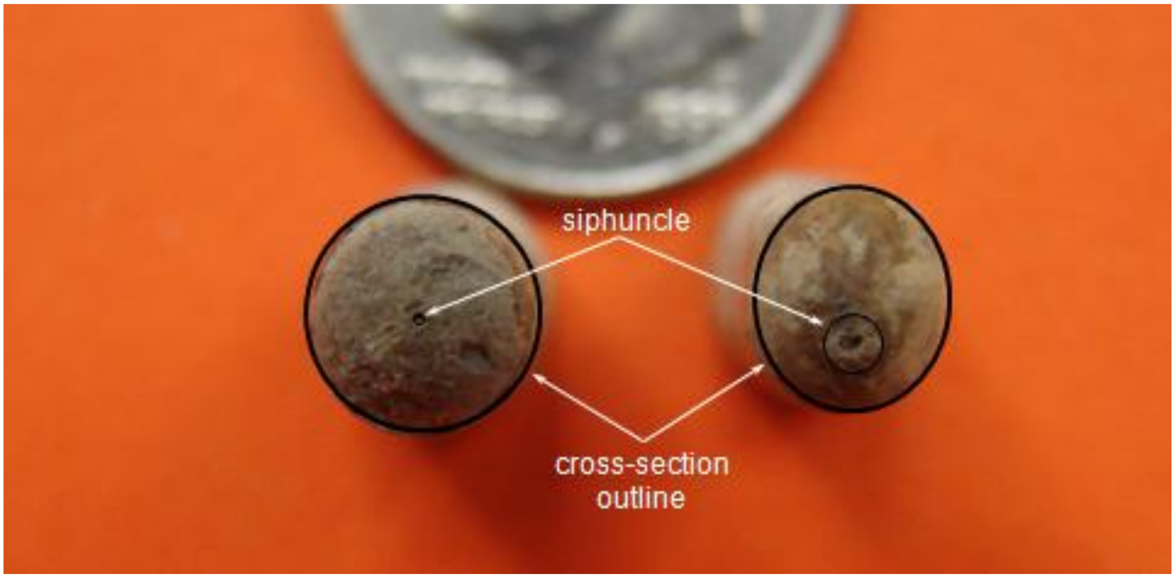

Fig. 6. Comparison of cross-sections of *Pseudorthoceras knoxense* (left) and *Euloxoceras greenei* (right). Heavy lines outline cross-section shapes as well as position and size of the siphuncles.

Fig. 7. Examples of the mature (top) and deciduous or juvenile (bottom) shells of *Brachycycloceras normale* from the Graham Formation near Jacksboro, Texas. Note differences in ornamentation and the blunt termination of the adult shell where truncation of the juvenile shell occurred.

One of the most unusual nautiloids of the Pennsylvanian is one that truncates a juvenile shell during ontogeny to lessen shell weight. Nautiloids are unusual in the invertebrate world in that they attain a mature size after which growth ceases. This normally occurs as sexual maturity is reached. Truncation is known to have occurred in several orders (Ascocerida, Oncocerida, Orthocerida). Most often truncation occurs only once and the resulting adult shell often bears very little resemblance to the juvenile shell. In the Pennsylvanian, the one nautiloid that is known to have truncated a juvenile shell is *Brachycycloceras normale*, tentatively placed in the Orthocerida. The juvenile (termed deciduous) shell was strongly annulated while the mature shell sported more subdued ornamentation and a blunt termination (**Fig. 7**).

By far the most diverse and abundant nautiloids in the Pennsylvanian are coiled forms of the order Nautilida. Recognition of the various species involves morphologic features such as shell cross-section (depressed or compressed), shape of the sutures, position of the siphuncle, ornamentation, and size of the umbilicus (see **Fig. 2**). The most common coiled genus is undoubtedly *Metacoceras*—more species are assigned to this genus than any other—followed closely by the morphologically similar genus *Tainoceras*. Confusion in identifying the two genera persists and at some collecting sites (e.g. quarries near LaSalle, Illinois) *Tainoceras* is actually much more abundant than *Metacoceras*. Both genera exhibit coiled shells with a wide and open umbilicus and subrectangular to subquadrate cross-sections (gently rounded to relatively flat venters). The difference is in the placement of nodal rows—a difference that facilitates identification to the generic level. *Metacoceras* (**Fig. 8**) had nodes only along the ventrolateral shoulders while *Tainoceras* (**Fig. 9**) had nodes not only along the ventrolateral shoulders but also weaker nodes in two rows along the venter.

Besides *Metacoceras* and *Tainoceras*, there are several other coiled nautiloids that are broadly represented and occasionally common in rocks of many Pennsylvanian sections. One of the easiest to identify is *Ephippioceras*. The sutures of this genus display a very pronounced V-shaped mid-ventral saddle (bend toward the living chamber) unlike any other nautiloid (**Fig. 10**). The shell of *Ephippioceras* is smooth, rapidly expanding, broadly rounded, almost globular in shape, with a very narrow, closed umbilicus and a centrally located siphuncle. The overall appearance of this species is reminiscent of a goniatite. Closely related but extremely rare is the genus *Megaglossoceras* with sutures displaying a U-shaped mid-ventral saddle (described as "tongue-like").

Solenochilus displays sutures with a peculiar, very narrow, notch-like mid-ventral lobe that identifies the position of the siphuncle, which is located at or near the ventral wall (**Fig. 11**). The shell is relatively large and smooth with a short living chamber that flares at the aperture, a somewhat flattened venter, and a small umbilicus.

Shells of *Liroceras* are small, rapidly expanding, slightly depressed in cross-section with a rounded profile, and a small but deep umbilicus (**Fig. 12**). The septa are relatively closely spaced and the siphuncle is more or less centrally placed but can vary from species to species.

A closely related genus to *Liroceras* is *Planetoceras* (**Fig. 13**). Septa of this genus are also closely spaced but the shell is more depressed than *Liroceras* with ventral sutures displaying shallow lobes. The umbilicus is wide and deep and the shoulders are angular.

Domatoceras is a very compressed form with flattened flanks and venter (**Fig. 14**). Sutures display ventral and lateral lobes and the umbilicus is small and closed.

Fig. 8. The common species *Metacoceras sangamonense* from Pennsylvanian strata near Kansas City, Missouri, displaying ventrolateral nodes.

Fig. 9. Specimen of *Tainoceras nebrascense* from the Bond Formation (Lone Star Quarry), Illinois, showing ventrolateral nodes and much weaker ventral nodes.

Fig. 10. A mature specimen of *Ephippioceras ferratum* from Pennsylvanian strata near Kansas City, Missouri, illustrating the pronounced mid-ventral saddle traced by the sutures.

Fig. 11. An example of *Solenochilus missouriensis* from the Bond Formation (Lone Star Quarry), Illinois, showing the notch-like lobes of the sutures characteristic of this genus.

Fig 12. Specimen of *Liroceras milleri* from Pennsylvanian strata near Kansas City, Missouri, with characteristically closely-spaced sutures and displaying a rounded profile.

Fig. 13. Example of *Planetoceras sp.* from the Bond Formation (Lone Star Quarry), Illinois, exhibiting closely spaced sutures, depressed profile, and angular

Fig. 14. The extremely compressed genus *Domatoceras sp.* from the Bond Formation (Lone Star Quarry), Illinois.

Of special interest is the Buckhorn Asphalt Quarry in Oklahoma. The section exposed at the Buckhorn quarry records one transgressive-regressive cycle with the highest concentration of cephalopods occurring near the peak of the transgression. It is generally accepted that the rocks of the Boggy Formation (Deese Group, Desmoinesian) "exposed in the Pennsylvanian Buckhorn Asphalt Quarry near Sulphur (Oklahoma) contain the best-preserved Palaeozoic molluscs in the world" (Seuß *et al.* 2009, p. 609). The reason for this superb preservation is that, during or shortly after deposition, hydrocarbons were introduced to the sediments and impregnated the shells—termed "Impregnation Fossil Lagerstätte". This depositional scenario resulted in mollusc shells preserving original aragonite, ornamentation, and microstructures (**Fig. 15**). When the hydrocarbons are removed chemically, the rocks often crumble into mineral grains and small fossils. Significantly, these smaller fossils are usually preserved unaltered as opposed to larger shells that are often deformed or even crushed. Thus, early ontogenetic stages of molluscs, rare at most sections, are often preserved at the Buckhorn pit, particularly apical ends of nautiloids (**Figs. 16 & 17**).

Fig. 15. "*Michelinoceras*" *directum* imbedded in a piece of Buckhorn Asphalt Quarry material.

Fig. 16. Section (X20) of apical end of *Pseudorthoceras knoxense* from the Buckhorn Asphalt Quarry. Visible are the chambers, septa (chamber walls), and siphuncle. The siphuncle has been replaced and re-crystallized by inorganic calcite. The protoconch (first chamber) contains the siphonal caecum—the bulbous initial section of the siphuncle. (Modified from Fischer and Teichert 1969, Plate 4.)

Fig. 17. Apical ends of nautiloids chemically extracted from Buckhorn Asphalt samples. Those with curved tips are *Pseudorthoceras knoxense* and those with blunt tips are "*Michelinoceras*" *directum*.

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Pennsylvanian Crinoids of Illinois

Thomas Williams

The substrate of the Mississippian, or Lower Carboniferous if you prefer, found crinoids related to classic limestone rocks. Many of such limestones were made up of crinoids themselves and then cemented together. Crinoids preserved in formations such as the Burlington and the Ft. Payne are referred to as crinoidal limestones. Limestone deposits with numerous crinoid assemblages are numerous throughout the period. The Mississippian Period was nearly perfect in both substrate conditions and ecologic conditions for crinoid evolution. Tropical conditions which were prevalent throughout what is now the Central United States show numerous fossil assemblages of crinoids and related fauna. However, in geologic time nothing remains the same; changes are inevitable. During the late Mississippian glaciation in the southern hemisphere along with continental collision made for active changes in the Illinois Basin. Worldwide glaciations tend to cause a lowering of sea levels which would cause existing rivers to cut deep into existing bedrock and the sea floor. As sea levels would rise the erosional features would be filled in sediment. Sea levels would continue to rise and fall throughout the Pennsylvanian Period related to glaciations and other geologic activity (Kolata and Nimz 2010) (See Figure 1).

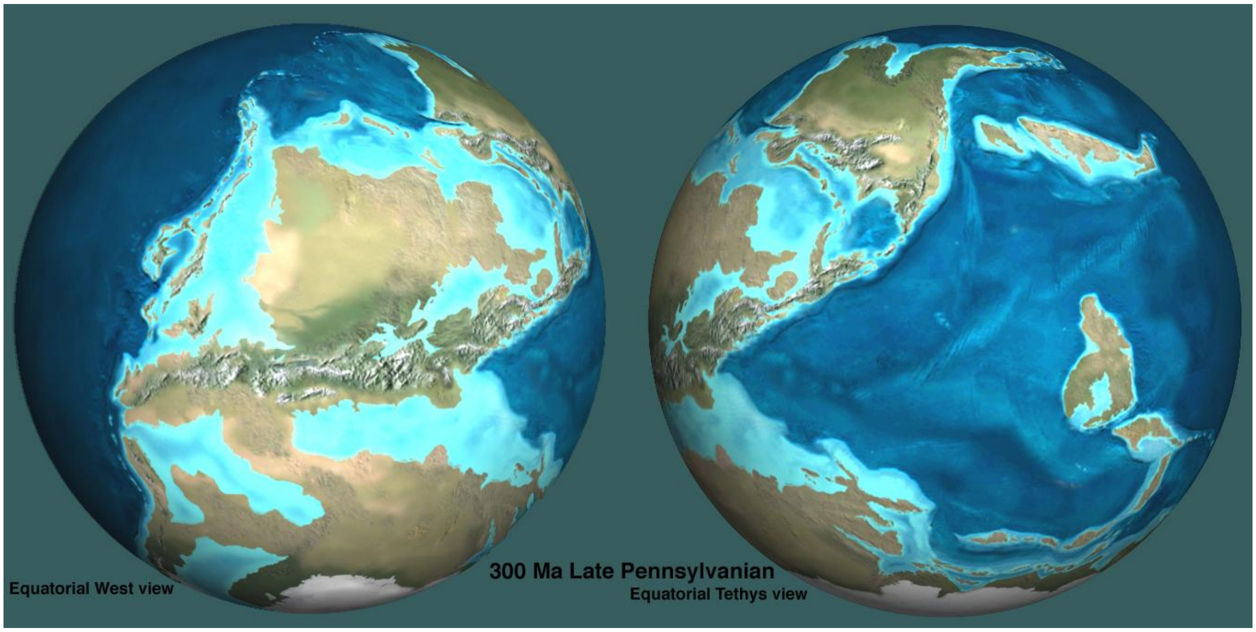

Figure 1. Paleogeography during the Late Pennsylvanian.

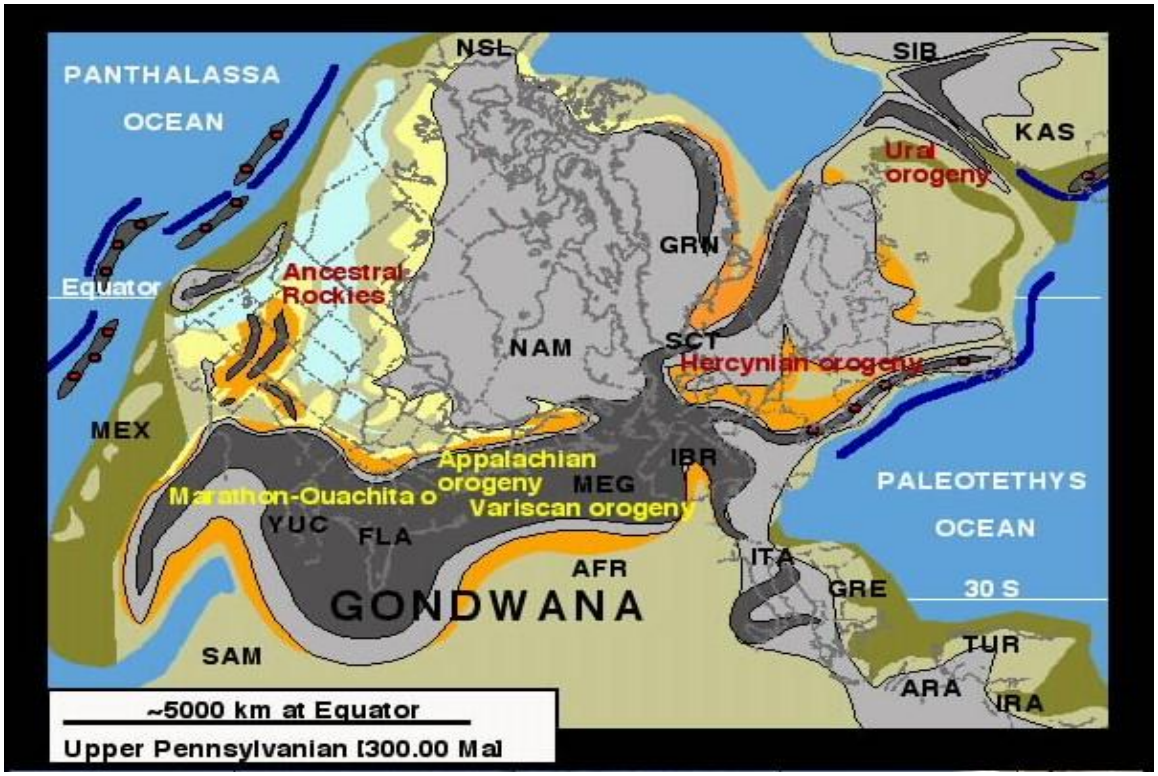

Figure 2. Paleogeographic map showing orogenic events and depositional environments.

The Pennsylvanian Period has been referred to as the era of mud which is the most common character of the sediments deposited. One of the characteristic sedimentation characteristics of the Midwestern United States is the cyclic sedimentation sequences. Ausich has characterized a typical Illinois cyclothem sequence to consist of "… 10 units 1 fluvial channel, sandstone; 2 grey shale; 3 non-marine limestone; 4 under clay; 5 coal; 6 grey shale 7 marine limestone 8 black shale; 9 marine limestone; 10 a marine grey shale." (See Figure 3). These cyclothem sequences represent transgressions and regressions of the sea across the continent. Sources of these sediments consisting mostly of sandstones siltstones and shales typically came from the east as the northern Appalachian Mountains and the Canadian Shield (See Figures 1 and 2). Sediments coming from these sources include feldspars, quartz, micas, clays, and other clastic materials. These cyclic deltaic deposits would migrate along the coastline as streams cut into existing deposits and meandered back and forth (See Figure 3). There is an extreme abruptness present in sedimentation sequences throughout Pennsylvanian deposition. Atherton and Palmer (1979) have reported over 500 specific sedimentary rock units extending over the entire Illinois Basin and possibly into Kentucky and Indiana. Many of these units are relatively thin but are laterally persistent. This does tend to indicate rapid changes in depositional environments relating back to dramatic changes occurring from rises and falls in sea levels and the tectonic collision of North America and Africa. As the sea would retreat non-marine sediment deposition occurred along the coast lines from streams in the form of deltas, stream deposits, and coal deposits (Kolata and Nimz 2010, Atherton and Palmer 1979).

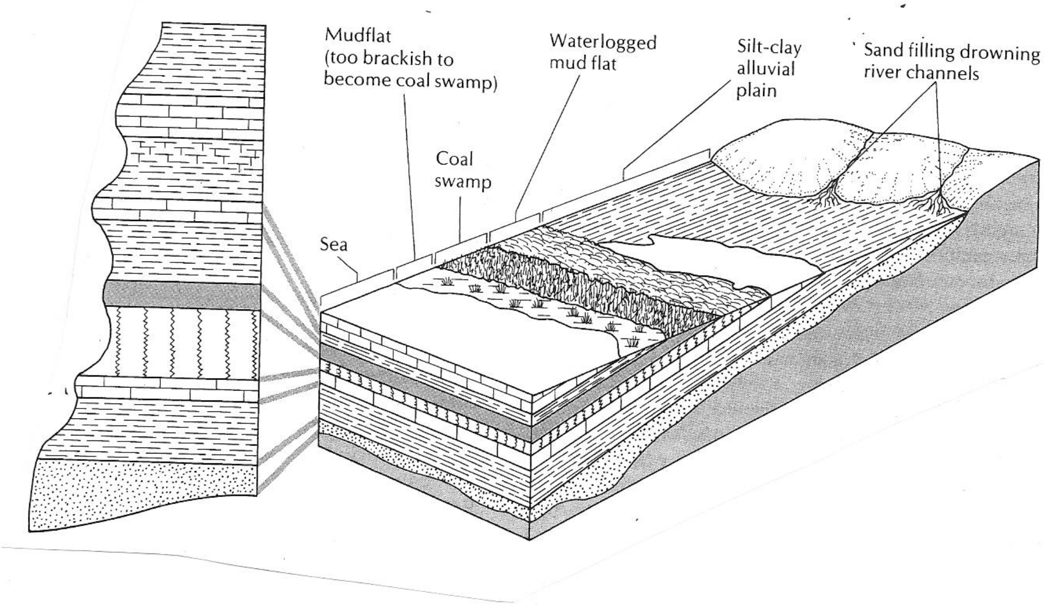

Figure 3. Recreation of a typical Pennsylvanian cyclothem. (Prothero and Schawb 1996).

Marine sediments were deposited in the Appalachian, Illinois, and other basins relating to advances in the sea and may have covered much of the current Midwest possibly as far north as the Wisconsin arch. Other major structural controls such as the Ozark Dome, Cincinnati Arch, and the Transcontinental Arch would have limited sea level advance. As the sea retreated, non-marine sediment deposition occurred along the coast lines from streams in the form of deltas, stream deposits, and coal deposits. Marine sediments would have been deposited outside the direct influence of the deltas, however, equally vulnerable to the rapid deposition occurring along the coasts (Kolata and Nimz 2010) (See Figures 1, 2, and 3).

The Bond Formation is one formation that shows a significant amount of marine limestone and is present in deposits in LaSalle County stretching at least as far south as Bond County near St. Louis. The Bond formation reaches thicknesses of up to 300 feet which is significant. Crinoids in the LaSalle Limestone near Pontiac were preserved in green shale pockets associated with the limestone. Sedimentation preserving these crinoids has been described by Strimple and Moore 1971 as "quiet water sedimentation in local areas where clayey sediment predominated over calcareous deposits." (See Figure 4). The shale with its clay components in this case may very well represent the influence of coastal sedimentation reaching out into the marine deposits (See Figure 3).

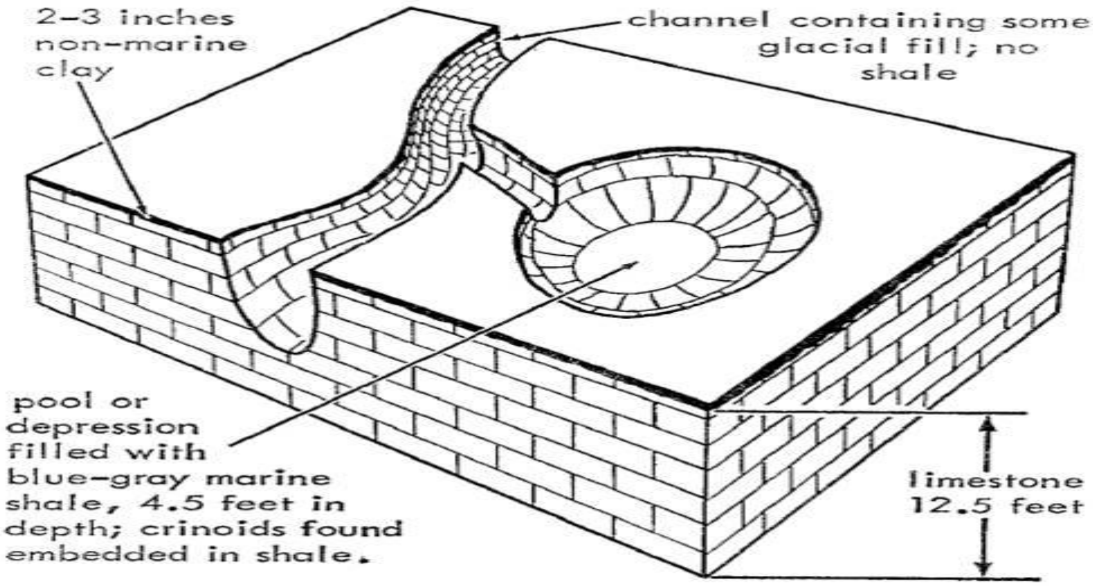

Figure 4. Depositional setting of the Bond Formation near Pontiac, Illinois (Strimple and Moore 1971).

Crinoids including well preserved calyxes have been found in the Bond formation in LaSalle County in contact with very weak green fissile shale units. Limestones in the quarries of this area do show some breccias. Quarries in LaSalle County contain other numerous, well preserved marine fauna including brachiopods, gastropods, cephalopods, fishes and shark teeth. Brusatte (2007) describes the LaSalle County deposits as “algal bank limestones with thinner alternating anoxic black shale units.” The faunas of the Bond formation definitely indicate a normal marine environment with relatively clear, clean water. But periodically influxes of sediment and changing paleoecological environments are noted by changes in deposition of different sediment types in the LaSalle County deposits. Another interesting feature of the Bond formation in LaSalle County is its relation to the Peru Monocline, part of a much larger structure the LaSalle Anticlinorium that borders the northern portion of the Illinois basin. The location of both the Pontiac and LaSalle sites is relatively close to the estuary at the Pennsylvanian shore but far enough out to sea as to not be affected by fresh water intrusion. However, from the deposits in both areas sedimentation from the land is evident from the shale deposits in both areas.

There are some remnant crevice fillings that are preserved in Ordovician and Silurian rocks which reveal deposition, but these deposits are not common and disappear as you travel north. Many questions abound here as to the environment with the crevice filling deposits not revealing much information for our purpose here, the presence of crinoids. Something else of interest here is that Pennsylvanian sediments are rare in Illinois north of this area. Was this a final result of the tectonic collisions? However, there is no question that the Pleistocene glacial events had an influence in the lack of remaining sediments and fossils, once again the geologic record leaving us with lots of questions (Kolata and Nimz 2010).

Tectonics from the late Mississippian period through the Pennsylvanian deformation occurred continually. This deformation was the result of three continental plates colliding South America, Africa, and North America (Kolata and Nimz 2010). There is little doubt that tectonic collisions along with the local structural elements acted as a control over the paleoecological environments regulating transgression and regression of the sea in this area (See Figures 1 and 2). Geologic record here does help us; the Bond formation is only about 75 feet in thickness in the north central areas of Illinois as opposed to 300 feet closer to St. Louis, telling us of the influence of tectonics on deposition. However, the best crinoids to this point have been reported in the north not the southern part of the state; the LaSalle Anticlinorium the potential reason. Did this structural control influence the environment or was it simply preservation preference (Kolata and Nimz 2010)?

The Mazon Creek deposits are slightly older than the Bond formation and represent more of an estuary deposit with active rivers and coal swamps (See Figure 3). The Francis Creek shale is near the base of the Carbondale Formation and there has been one crinoid found in a siderite nodule, but only one. Another partial crinoid was found by the author while collecting siderite nodules on a spoil pile. This crinoid, however, was found in the fissile black shale not in a siderite nodule. Both of these finds were partial crinoids so were they close to being in place or were they transported from much farther away. One may be able to conclude that these crinoids were transported to these locations and buried. The types of sediments found in the Mazon Creek indicate that they were not deposited in normal marine conditions but more of a fresh water source. There are many feet of just plain black fissile shale in the Mazon Creek sediments, but other areas very highly fossiliferous. Open marine environments were not that far away from the estuary of the Mazon creek so it is not inconceivable to believe that both of these crinoids were transported in. Crinoid stems have been reported from many sections of the Carbondale Formation from the shales and other thin limestones. So crinoids were there, just not completely preserved (Lane 1969, Kolata and Nimz 2010).

Crinoid types found in Illinois include Inadunates, Camerates, and Flexibles as reported by Strimple and Moore from the location south of Pontiac Illinois. The single crinoid from the Mazon Creek fauna in the siderite concretion is an Inadunate. This crinoid has been described as immature and has some unusual traits that include, as described by Lane (1969), “its arms branch on the third primibrach” making it difficult to assign it to a specific genus and species. It has a dorsal low cone shaped cup that is wider than it is high. Long, slender cirri were directed towards the crown. These features gave the impression that this crinoid may have been pelagic attaching itself to floating masses of material. Overall, the Mazon Creek fauna is a fresh to brackish water estuary so the presence of a crinoid is a bit unusual. Based upon the description provided by Lane you could probably assume that this particular crinoid may have floated in on a vegetation mat or another structure (Lane 1969).The other crinoid mentioned by the author has yet to be specifically identified.

Crinoids from the Wagner Quarry south of Pontiac is dominated by Inadunates primarily cladids which dominate other Pennsylvanian crinoid faunas. The Treatise describes a basic inadunate as having, “an aboral cup composed of close sutured plates fixed brachials and interbrachials lacking anal plates commonly present in aboral cups with pinnulate or non pinnulate arms.” Inadunates came into existence in the lower Ordovician Period and went extinct in the Triassic and it is thought that a cladid gave rise to articulate crinoids which are still alive today. Cladids in particular show a wide diversity starting in the Lower Ordovician and are well represented through the Permian (Ubaghs G, Moore R.C and others 1978).

However, cladids tend to have a basic aboral cup but remain diverse in the types of arms which contain, "atomonous, ramulate, renticular, universally pinnulate, cunelate, uniserially pinnulate and biserially pinnulate." Aboral cups tend to be restricted by the diversification of arm types which has been described as an arms race by Ausich. Arm diversification for these cladids is typically uniserially pinnulate and rectangular or cunnate brachials (Ausich 1999). Arms in cunnate brachials have taken on an unusual zigzag pattern as with genus *Clathrocrinus*. This pattern produced by *Clathrocrinus clathratus* is considered extreme development of this pattern. *Barbeocrinus christinae* has a unique zigzag pattern which according to Ausich produced a dense filtration feeding mechanism. Arms of these crinoids sometimes divide to have as many as thirty in total, such as *Haeretocrinus wagneri*. *Erisocrinus typus* and *Ebdelocrinus tumidus* all have developed ten arms and biserial pinnulation which is a hold over characteristic from the Mississippian Period and an arm form of camerates. Other adaptation on arm division is the fifteen arm *Parulocrinus pontiacensis* and the 20 arm *Stellarocrinus virgilensis* both similar to camerates with this design. A question that arises with this biserial pinnulation is its relationship of cladid crinoids to camerates. The single representative disparid, *Kallmorphocrinus lasallensis*, in the fauna is a typical crinoid of this type with only a few arms. A radial may bear more than one arm on this crinoid (Ausich 1999, Moore and Strimple 1971).

Only one crinoid representative from the Subclass Camerata has been found to this point which is *Dichocrinus nola*. Camerates have been described as box crinoids reaching their peak in the Silurian and were once well represented in crinoid faunas in Devonian and lower Mississippian. Lower Mississippian deposits could be dominated by numbers of species and individuals in faunas. After the Mississippian geologic time frame a definite fall occurs of this once common group. Strimple and Moore (1971) described this crinoid from two calyces and this follows with the geologic record showing a definite decrease in the number of species in the Pennsylvanian but they did manage to survive to the end of the Permian.

Flexible crinoids were a very successful group that first appeared in the Middle Ordovician and existed to the Upper Permian with characteristics that set them apart from other crinoids. This group has shown some of the most spectacular specimens throughout the Paleozoic and the Pontiac fauna is no exception. There are 2 flexible crinoids present in the Pontiac fauna which have only a few number of arms with ramulate branching which does appear to be unique to this deposit (Ausich 1999). Subclass Flexibila has Order Sagenocrinoidea and Taxocrinoidea. Typically these crinoids have aboral cup with three infrabasal plates combined with a combination of five basals and five radial plates. Arms of these crinoids are what tend to make them interesting—they tend to be uniserial, lacking pinnules, with brachials that are wider as opposed to higher. Theses arms tend to incurve at the top of the crown something that is observed in most if not all crinoids of this group (Ubaghs G, Moore R.C and others 1978).

Order Taxocrinoidea has an elongate crown with its rays above the radials which are partially or wholly separated all around. The branching of arms of taxocrinids are isotomous not heterotomous. (Strimple and Moore 1971) Taxocrinids were the first Flexible crinoid to appear in the middle Ordovician and persisted to the upper Pennsylvanian but with only one representative *Euonychocrinus simplex* in the Pontiac fauna. Despite *Euonychocrinus* being a taxocrinid it definitely shows differences from its Mississippian predecessors. The other flexible crinoid representative from Order Sagenocrinoidea is *Paramphicrinus oklahomaensis* has a round but compact crown showing many features typical of flexible crinoids. Arms of this crinoid curve inward near the top and can branch isotomously or heterotomously with bifurcations with only a few interbrachials or they can be entirely absent. This crinoid in particular has had several spectacular specimens uncovered from the Pontiac locality and does in its general appearance look like many of its Mississippian predecessors (Ausich 1999, Strimple and Moore 1971).

Conclusion

The Pontiac fauna shows a definite change in dominance of the type of crinoids which will carry on evolutionary development into the Permian. Inaduntes in particular cladids dominate this fauna with their varying arm structures in which Ausich has described as an arms race going on. Other crinoid groups are not particularly diverse in the different types as opposed to the cladids. Another interesting fact of the LaSalle County and Pontiac fauna is the absence of blastoids. It is not unusual to find them together, however, there doesn’t appear to any association between the two in this area at all.

Crinoid arm diversity may have occurred over the Pennsylvanian to improve a species ability to survive in food gathering system. According to Ausich (1999), this could have been to facilitate a particle size preference and a specific niche in the suspension for the Pontiac fauna. Possibly this filter feeding diversification may have a result of substrate changes which was a distinctive change from the Mississippian to the Pennsylvanian. Pennsylvanian sediment deposition patterns definitely favored shales and mudstones as opposed to limestones of the Mississippian. Did crinoids and their more intricate arms of this time period make an evolutionary adjustment to the environmental conditions? Perhaps the camerates which are defiantly on the decline could not adapt sufficiently and were simply out competed by inadunates for the same niche or tier. The decline of camerates may have been a factor allowing the cladids a better chance prior to this time frame allowing diversification. When one group of any organism cannot maintain its place in the environment for any reason another organism will usually step up to take its place. Flexibles have always been less common than the cladids in typical crinoid assemblages, but definitely tend to be not as common as they were previously in the fossil record. Flexibles did appear to make a comeback in diversification in the Permian surviving right up to the end of that time period. The cladid crinoids of the Bond Formation found in Illinois, found at Pontiac, and found in LaSalle County show unique and interesting adaptations. These adaptations do appear to continue through the Permian and may have possibly led to their surviving the extinction at the end of the Permian.

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Crinoid Photographs

The following examples of crinoid taxa (photographed by various MAPS members) are all from the Bond Formation and from Pontiac, Illinois, except for *Ulocrinus sp.* which is from LaSalle County, Illinois.

Clathrocrinus clinatus and *Stellarocrinus virgilensis*

Stellarocrinus virgilensis

Barbeocrinus christanae

Eristocrinus typus

Parulocrinus sp.

Haeretocrinus wagneri

Clathrocrinus clinatus

Plummercrinus erectus

Paramphicrinus oklahomaensis

Euonychocrinus simplex

Stenopeecrinus sp.

Ulocrinus sp.

Notable Pennsylvanian Localities and Paleobiotas in Knox and Peoria Counties, Illinois

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In the last forty years or so, most of the attention of those interested in Pennsylvanian fossils has been directed to the Mazon Creek Paleobiota and localities southwest of Joliet, Illinois. Numerous works by investigators such as Nitecki (1979), Foster (1988b), Shabica and Hay (1997), and many others have focused on this paleobiota and the localities in a limited geographic area. This attention, to an admittedly unique paleobiota, has unfortunately greatly reduced attention to other very good Pennsylvanian paleobiotas and localities in Illinois. I intend to partially remedy this situation here by examining some other Pennsylvanian paleobiotas and localities at four other areas in Illinois. One is in Knox County-the other three are in Peoria County. They are all in the Desmoinesian Series. Two are in the Carbondale Formation of the Kewanee Group and two are in the Modesto Formation of the McLeansboro Group. The first is at Wolf Covered Bridge in Knox County. The second is in the Vermilionville Sandstone in an area near Kickapoo Creek in Peoria County. The last two are in the Lonsdale Limestone and the underlying shale at localities in Peoria County that I call Hall Farm and Baudino Farm. All of the sections and units mentioned here were studied by many of my Stratigraphy students at Bradley University as part of their class work from the 1970's to the 2000's. At least five Bradley University Geological Sciences students did their Senior Projects on some of these localities and units. As Lead Teacher for an NSF sponsored Field Science Course for Elementary School teachers from 1979 to 1981 and a state funded Science Concepts Institute for Elementary School teachers from 1989 to 1990, I also took the teachers to many of these localities. I also visited these localities with other interested parties on various occasions. I discussed these localities in a general way and illustrated some of the fossils in my article on fossils of Illinois (Foster, 1988a).

The Wolf Covered Bridge Section

Along the west bank of the Spoon River, just north of the covered bridge, NE NE NW sect. 13, T.10 N., R3E, Maquon (15 min.) quad., Knox Co., Illinois.

Wolf Covered Bridge (also formerly often called "Old Wolf Covered Bridge") has been a show piece for Knox County for many years. It was built in the 1840's and its cover was added in 1874. It is listed in the National Register of Historic Places and has a prominent place in the annual Spoon River Drive. I first saw the bridge and its nearby section in the early 1970's. It was defaced then by obnoxious graffiti on its inner walls. Merrill (1979) also commented on this obscenity. On August 1, 1994, the bridge was burned down by three teen age boys high on LSD and possibly also alcohol. The Illinois Department of Transportation rebuilt the bridge completing it in 1999 at a cost of close to one million dollars. Unfortunately, in rebuilding the bridge, the workers destroyed the lower part of the section including the Colchester No. 2 Coal Member, the Francis Creek Shale Member, and the Mecca Quarry Shale Member. This destruction did have one good side effect. It caused more erosion resulting in better collecting in the upper part of the section, the Oak Grove Beds. I will illustrate and describe the entire section (fig. 1) and its fossils (fig. 2) prior to the tragic demise of the lower part of the section.

I don’t know when and by whom the geology of this section was first studied. It was mentioned in the literature in 1970 by Smith and his colleagues implying that the Illinois State Geological Survey had studied it before that date. I and my students have studied this section since 1970. Individuals from Monmouth College have studied this section in the 1970’s and possibly earlier (Merrill and King, 1971). Merrill (1979) mentions this locality in a guidebook to conodont localities. The cover of this guidebook has an excellent drawing of Wolf Covered Bridge and part of the geological section. A Wisconsin farmer, John Pohl, periodically collected at this locality. Other colleges and universities may also have visited this locality. Bradley student, Jack Pashin (1982), did a Senior Project on this section. I will discuss here (see fig. 1) the Carbondale Formation (Liverpool Cyclothem) from the underclay Wanless (1957 and 1958) Member 62 to the top of the Oak Grove Beds.

Colchester Coal No. 2 (Wanless Member 63) and the underclay (Wanless Member 62)

These units were only visible when the Spoon River was at an extremely low level. Member 62 has only yielded plant debris.

Francis Creek Shale Member (Wanless Member 64)

This unit has yielded few fossils here. Merrill (1979) reported finding a hindeodellid conodont here. There are very large concretions in this unit. I have found in the concretions and the surrounding shale occasional plant debris and pyritized specimens of *Desmoinesia muricatina*.

Mecca Quarry Shale Member (Wanless Member 67)

Recent works by Von Bittner and Merrill (1998) and Rigby and Von Bittner (2005) call this unit the lower unit of the Oak Grove Beds because they say it is not the time equivalent of the Mecca Quarry Shale Member in the type area of Indiana. I reject this suggestion because the same lithologic unit in different areas doesn’t have to be time equivalent and the unit here is virtually identical to the unit studied by Zangerl and Richardson (1955).

A distinctive feature of part of this unit is the numerous phosphatic concretions. I regard them all as shark coprolites. Some of these concretions contain well preserved three dimensional parts of fish usually exhibiting beautiful golden colored scales. There are large carbonized pieces of plant trunks. I found a large flattened orthoconic nautiloid, some *Petrodus* tubercles, and *Listracanthus* fin spines. Merrill (1979) reports numerous good conodonts from this unit including *Idioprioniodus*, *Idiognathodus*, and *Gondolella*. There are also natural conodont assemblages. Brad Wiscons, a Bradley Geological Sciences student found an edestid shark jaw (see fig. 2 and fig 17 in Foster, 1988a) in this bed. This find earned him a front page in the “Peoria Journal Star” newspaper showing him with his specimen and a reconstruction of the edestid shark. The “Bloomington Pantagraph” also discussed the find and spoke of blood flowing in the Spoon River from a shark attack. I received phone calls about the find from as far away as Wisconsin. Hexactinellid spicules of the stauractine type occur in this bed. Rigby and Von Bittner (2005) report similar spicules, a new complete hexactinellid, and a new complete demosponge from this bed at a locality eight miles away. The top of this unit contains large concretions that usually contain light colored trace fossils. There are also extremely elongate concretions and even one shaped like a dumb bell here.

Oak Grove Beds

The remainder of the most studied part of this section are the Oak Grove Beds. Wanless (1931, 1957, and 1958) uses this name for his members 68-81. Smith et al (1970) and Willman et al (1975) call them the Oak Grove Limestone Member. I avoid the latter usage and agree with Merrill's usage in his 1979 publication because Wanless has many other members in this unit and the beds contain distinctly more shale than limestone. Fossils tend to be most abundant and varied in the limestones and the shales adjacent to the limestones. I show the rough distribution of fossils in figure 1. I will single out for more detailed discussion the units that are particularly rich in fossils. These include the "Gray Septarian Limestone" (Wanless Member 72), the fossil hash just above it (the base of Wanless' "*Mesolobus* Shale" (Wanless Member 74), the "Pelecypod Limestone" (Wanless Member 77) the "*Linoproductus* Limestone" (Wanless Member 79), and the "Mold Ironstone Bed" (Wanless Member 81)

The "Gray Septarian Limestone"

This member contains bellerophontids, *Linoproductus*, three or four genera of gastropods, and other taxa.

Lower Part of the "*Mesolobus* Shale"

This unit is literally a fossil hash for at least several inches above the underlying limestone. Above this, the concentration of fossils diminishes. It is probably the easiest place in this entire section to collect a wide variety of taxa in some quantity. *Mesolobus* sp. is easily the most common taxon here. Higher in the section where the fossils are more widely dispersed, one can, with careful work, extract specimens of *Mesolobus* sp. with the marginal spines complete (see fig 2). *Desmoinesia muricatina*, often somewhat flattened, is also numerous here. *Composita sp.* is not uncommon at this horizon. Bellerophontids, including *Knightites* and *Euphemites* are not rare. At least five genera of gastropods occur here including *Ianthinopsis* and *Trepospira*. There are three or four bivalve mollusk taxa including *Nucula sp.* and *Astartella concentrica*. Both small orthoconic and coiled nautiloids, particularly the former, can be found here. Ostracods are not uncommon in this horizon as are small crinoid columnals and pluricolumnals.

The "Pelecypod Limestone

This unit is particularly notable for excellent specimens of *Lingula* and *Orbiculoidea* (see fig. 2 and Foster, 1988a, fig. 14). As the name of the member implies, it has many bivalve mollusks including *Dunbarella*. There are also bellerophontids.

The *Linoproductus* Limestone

This limestone is justly named for its numerous very good large specimens of *Linoproductus "cora"* that appear to be oriented in life position. They can be a bit hard to extract from the unweathered limestone using a sledgehammer, but are generally worth the effort. There are some large specimens of *Neospirifer cameratus*. Both the last two brachiopod taxa sometimes have *Petrocrania* attached to them (see fig. 2). Numerous *Crurithyris planoconvexa* occur in this member. There are some specimens of *Mesolobus sp.* and *Lingula carbonaria* here. Other fossils include bellerophontids, gastropods, and bivalve mollusks. The trilobite, *Ditymopyge sp.* is found occasionally. There are crinoid columnals and pluricolumnals.

The Mold Ironstone

Wanless (1957 and 1958) calls this member 81, "Ironstone". Smith et al (1970) call it the "Cast Band Limestone". I prefer to call it the "Mold Ironstone" because it contains molds, not casts, and is not a limestone. It contains a variety of molds including productid brachiopods, bellerophontids, bivalve mollusks and the trilobite *Ditymopyge sp*.

Trace Fossils in Limestones Member 72 and Member 79

Merrill (1983) reported numerous trace fossils in the "Gray Septarian Limestone" (Member 72) and "the *Linoproductus* Limestone" (Member 79). He particularly distinguished *Rhizocorallum*, *Chondrites* and *Planolites*.

Vermilionville Sandstone

This sandstone member of the Carbondale Formation, Brereton Cyclothem, and Kewanee Group was called by Wanless (1957 and 1958) Member 107. It was first mentioned, as far as I know, by Udden (1912). He called it Sandstone "f". Culver (1922) called it the Waupecan Sandstone. Savage (1927) and Wanless (1957 and 1958) called it the Cuba Sandstone. I follow Cady (1915) and Willman et al. (1975).

This sandstone is the most prominent geological unit in the Peoria area and can be found from north of Pottstown to south of Bartonville. It is best exposed as cliffs on the west side of Kickapoo Creek primarily in Limestone Township. It can be as much as 40 feet thick. A somewhat famous side canyon along Kickapoo Creek called "Rocky Glen" is underlain by exposures of the Vermilionville Sandstone. Local rescue crews use this member for rock climbing practice. Occasional chunks of this rock fall onto Kickapoo Creek Road causing traffic problems. The local paper, "The Peoria Journal Star" has on several occasions written of it as "majestic limestone cliffs" despite my complaints since it doesn't contain limestone and its only connection with limestone is the name of the township in which much of it is located. Michael Sullivan (1980) did a Senior Project at Bradley University on the stratigraphy and sedimentology of this unit.

I will discuss here the fossil plants in part of this unit above Kickapoo Creek. The location is in the bottom of a normally dry creek bed on a hillside west of Creek Road NW SE NW sect. 1, T. 8 N., R. 7 E., Peoria West (7.5 min) quad., Peoria County, Illinois. Prior to the discovery mentioned here, the only fossils known from the Vermilionville Sandstone were scattered small carbonized plant fragments. In the late 1970's, I took my two young sons to an abandoned sand pit along Creek Road where I had previously found some very nice "kindchens" with bizarre Disney like shapes in the silt. "Kindchens" are limestone concretions. On this occasion, we were not so fortunate in the search for "kindchens" finding only a few miserable specimens. However, one of my sons picked up a piece of

Vermilionville Sandstone that contained a beautiful tiny *Annularia* whorl. We excavated the sandstone a bit that day. On later occasions, I and some of my students dug out and split open the sandstone on a much larger scale. We were rewarded by finding a varied well-preserved Pennsylvanian paleoflora (see fig. 3). I speculate that the sandstone containing these plants accumulated in a quieter backwater than most of the Vermilionville Sandstone. To date we have found many seed fern leaves including *Neuropteris scheuchzeri*, possibly other species of *Neuropteris*, and *Cyclopteris*. There are also possible true ferns. The sphenopsids include at least three species of *Annularia* (the tiny one found by my son may be a new species) and one species of *Sphenophyllum*. There are also a variety of stems and at least one seed in our collections so far. William Trumbull (1983) did his Senior Research Project at Bradley University on these plants.

Lonsdale Limestone and the Underlying Shale

The Lonsdale Limestone (Wanless Member 140) is in the Modesto Formation, Gimlet Cyclothem, McLeansboro Group. It was named by Worthen (1873) for rock in the old Lonsdale Quarries in Peoria County. Udden (1912) called this bed limestone “s”. It is the only limestone to have been quarried commercially in this area. Some geologists believe it underlies the somewhat higher area along Farmington Road (Hwy 116) extending west from Peoria. It has also been postulated that it represents a Pennsylvanian algal bank. Where the Lonsdale Limestone is exposed in some creek in this area, it often makes a small waterfall. That is the case in the two localities I will discuss here: Hall Farm and Baudino Farm.

Hall Farm Locality

The locality I call Hall Farm has probably yielded more easy-to-obtain fossils than any other locality in the vicinity of the city of Peoria. It is located along a creek that often has a small waterfall south of Hwy 116 and east of Hanna City. In my paper (Foster, 1988a), I inadvertently said Bartonville instead of Hanna City. This locality is located specifically in NW NW SE sect. 7, T. 8 N., R. 7 E., Peoria West (7.5 min) quad., Peoria County, Illinois. It is Dunbar and Henbest’s (1942) Locality 545. It is Wanless’ (1958) locality 148. Dunbar and Henbest (1942) mentioned that it was sampled by Henbest and Cady in 1927. The last investigators mentioned that it was near the J.B. Armstrong house. I call this locality the Hall Farm because, in all the years I collected there, starting in the 1970’s, it was owned by Jim Hall. He freely allowed me, my classes, and many other people to study, measure, and sample and collect rocks and fossils here without restriction. He even pulled our university science van out of the mud here with his tractor on one occasion. Eventually, he sold the property to two young men who promised him to continue giving us access. They went back on that and other promises they made to Mr. Hall. Today, we can’t go on the property. Various Bradley University Geological Sciences students have done Senior Projects here: Bruce Fouke (1982) on fusulinids; Keith Dobrolinsky (1984) on petrology; and Mark Rosenberg (1986) on echinoderms.

I will divide the rock here into three units: the Lonsdale proper (Wanless Member 140), a rubbly shale in the lower part of Member 140 that I will call Member 140b, and a shale below Member 140 with limestone interbeds that Wanless calls Member 139. Figure 4 shows the units at three different positions at this locality.

Wanless (1958) using work by Waldo (1928) stated that the Lonsdale Limestone, and presumably the underlying unit, has the most varied fauna of any Pennsylvanian unit in the area with 194 species. My own observations support this. I would estimate that just at Hall Farm I have seen more than 60 taxa so far. See figure 6 for a few of the taxa at this and the next locality,

The Lower Shale (Wanless Member 139)

This unit is particularly rich in fossils at its upper levels beneath Member 140. The dominant fossil is the genus *Fusulina* (*Beedeina*). Five different species of this genus were reported here and it is the type locality for *F. acme* and *F. lonsdalensis* (Dunbar and Henbest, 1942). This is probably one of the best localities for *Fusulina* in the world. In a preliminary work, Fouke (1982) questioned the number of species and suggested that some may be variants of a smaller number of species. In many places here the fusulinids are so dense that they make a *Fusulina* coquina. Often the coquina seems to be filling burrows with a main tube radiating into a number of smaller tubes (see fig. 6). This shale contains numerous partial and complete spiny spines and plates of the echinoid genus *Archaeocidaris* (see fig. 6 and Foster, 1988a, fig. 15). There are many pieces of Aristotle's Lanterns here that presumably come from this genus. Shells of the chonetidine *Neochonetes granulifer* are common in this bed. There are many irregular lumps in this shale which have never been formally studied. I suspect they were made by cyanobacteria or algae. Microfossils abound in this unit and include small foraminifera, ostracods, and conodonts.

The Lonsdale Limestone (Wanless Member 140)

This member has an unusually large number and variety of easy-to-extract fossils particularly in the lower shale (my member 140b) There are far more taxa than the ones I mention below. The lumps that I think were formed by cyanobacteria or algae are common. *Fusulina* specimens occur, but are not as numerous as in Member 139. The microfossils mentioned in Member 139 are at least as numerous here. The solitary rugosan *Lophophllidium* is common in this bed. Cryptostome bryozoans are represented by *Rhombopora sp*. and at least two other taxa.

Most of the major articulate brachiopod orders found in the Pennsylvanian are well represented here. The orthides have *Rhipidomella carbonaria* and *Schizophoria texana*; the rhynchonellides have *Wellerella*; the orthotetidines *Meekella striatocostata* and *Derbyia crassa*; the strophomenides have the aforementioned *Neochonetes granulifer*, a few *Mesolobus*, and the common productid *Kozlowskia splendens*. The spiriferides are very well represented by the very common *Hustedia mormoni*, *Composita sp*., *Neospirifer sp*., *Phricidothyris perplexa*, *Crurithyris planoconvexa*, and at least four other taxa. Many of the *Composita sp*. specimens are translucent and one can see the spiralia if a light is placed beneath them under a low power microscope. The tiny lone terebratulid, *Cryptacantha compacta* is quite abundant.

Mollusks are rather common and include some scaphopods and a rare rostroconch, *Conocardium missouriensis*. There are four or five gastropod species including the very popular "bumpy snail" *Trachydomia nodulosa*. There are some bivalve mollusks and a limited number of coiled and orthoconic nautiloids.

Ostracods are rather common including *Bairdia spp*. and at least one highly ornamented species.

Complete and disarticulated exoskeletons of the trilobite *Ditymopyge sp*. are fairly common. Some of the complete exoskeletons are enrolled. I found one immature pygidium of this genus with posteriorly directed protrusions (see fig. 6).

Crinoid columnals, pluricolumnals, and partially complete columns are not uncommon. My students excavated part of a column that I estimate, when complete, would be over 6 feet long. There are also crinoid thecal plates and occasionally part of thecae. The echinoid *Archaeocidaris* is also represented here by spiny spines, tubercle-bearing plates, and parts of Aristotle's Lantern.

Conodonts are common and fairly diverse. There are a few fish tubercles *Petrodus sp*. and fish crushing teeth.

Baudino Farm Locality

This locality was named by me for the property owner, Mr. John M. Baudino during the years I sampled and collected at this locality. Merrill (1979) calls it Cramer South. It is located around a small waterfall and the west bank where the stream goes under the road. The formal location is SW NW sect. 28, T. 8 N., R. 5 E, Glasford (15 min) quad., Peoria County, Illinois. The waterfall here is probably the most spectacular waterfall, particularly in springtime, in Peoria County. The waterfall seems well known to local teenagers, but not to many others because it is not visible from nearby roads.

The units and fossils are similar to those at Hall Farm (see fig. 5), but are not nearly as easy to extract, as varied, or as abundant. Merrill (1979) reported phylloid alga fragments in the lower limestone. A rare large rugosan was found by one of my students in the Lonsdale. *Kozlowskia splendens* is rather common in the Lonsdale shale and lower limestone. I found a rare fenestelloid bryozoan in the shale beneath the limestone. Merrill (1970) reported a high abundance (4070/kg) and good preservation of the conodonts *Gondolella magna*, *Diplognathodus illinoisensis*, and advanced species of *Neognathus*. The majority of the conodonts were in the shale within the limestone with lesser numbers in the limestone proper.

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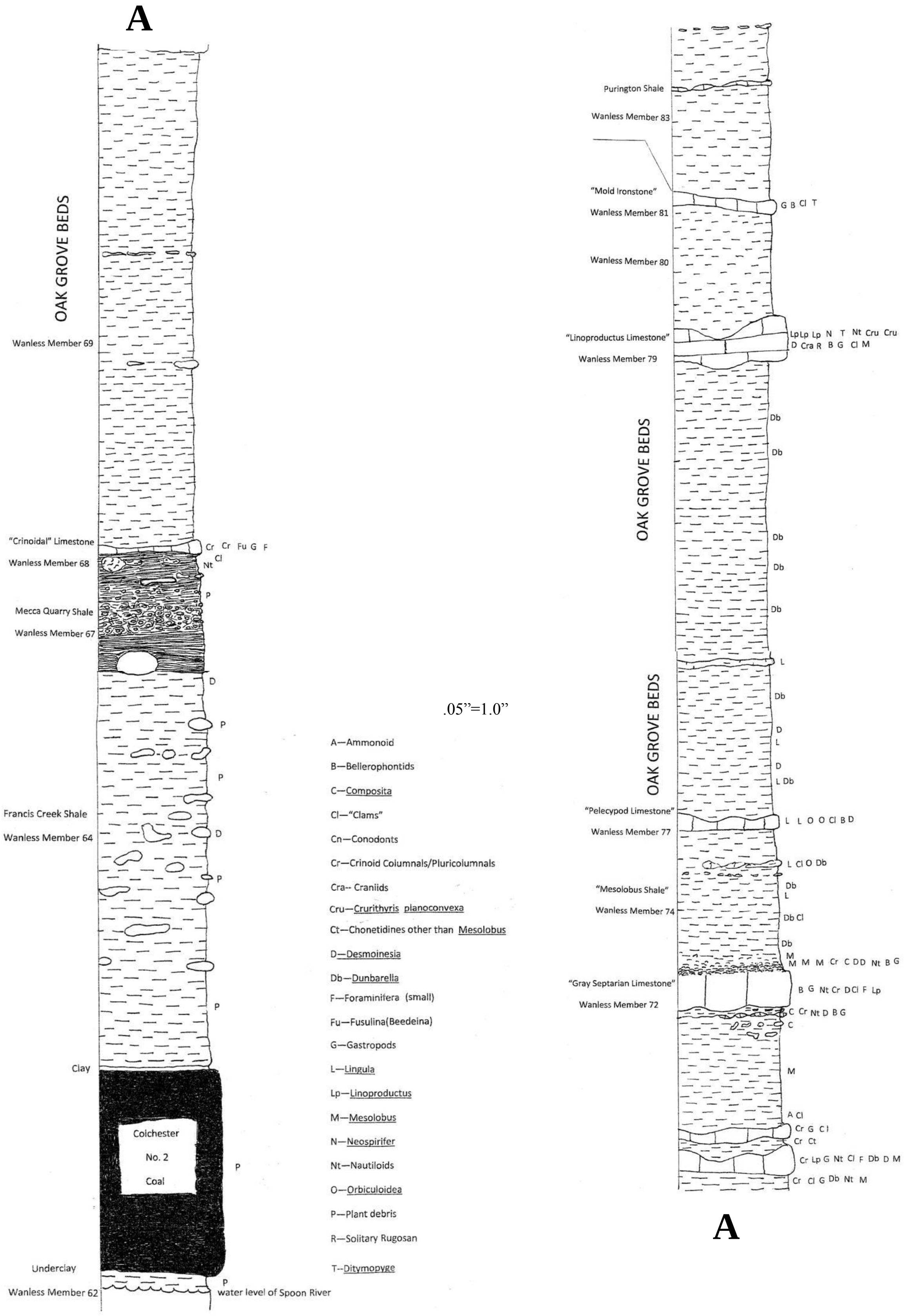


Figure 1. Wolf Covered Bridge Section.

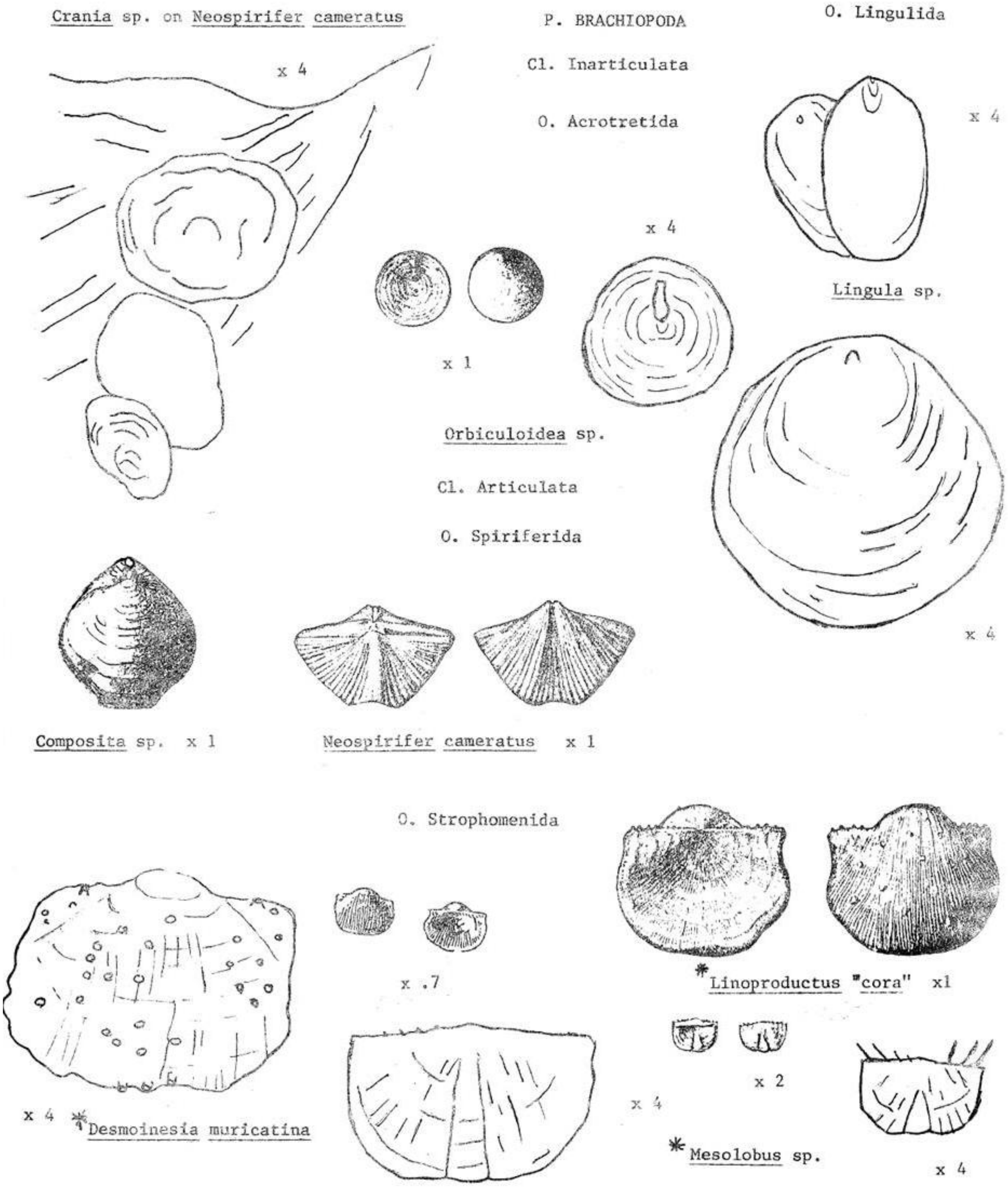
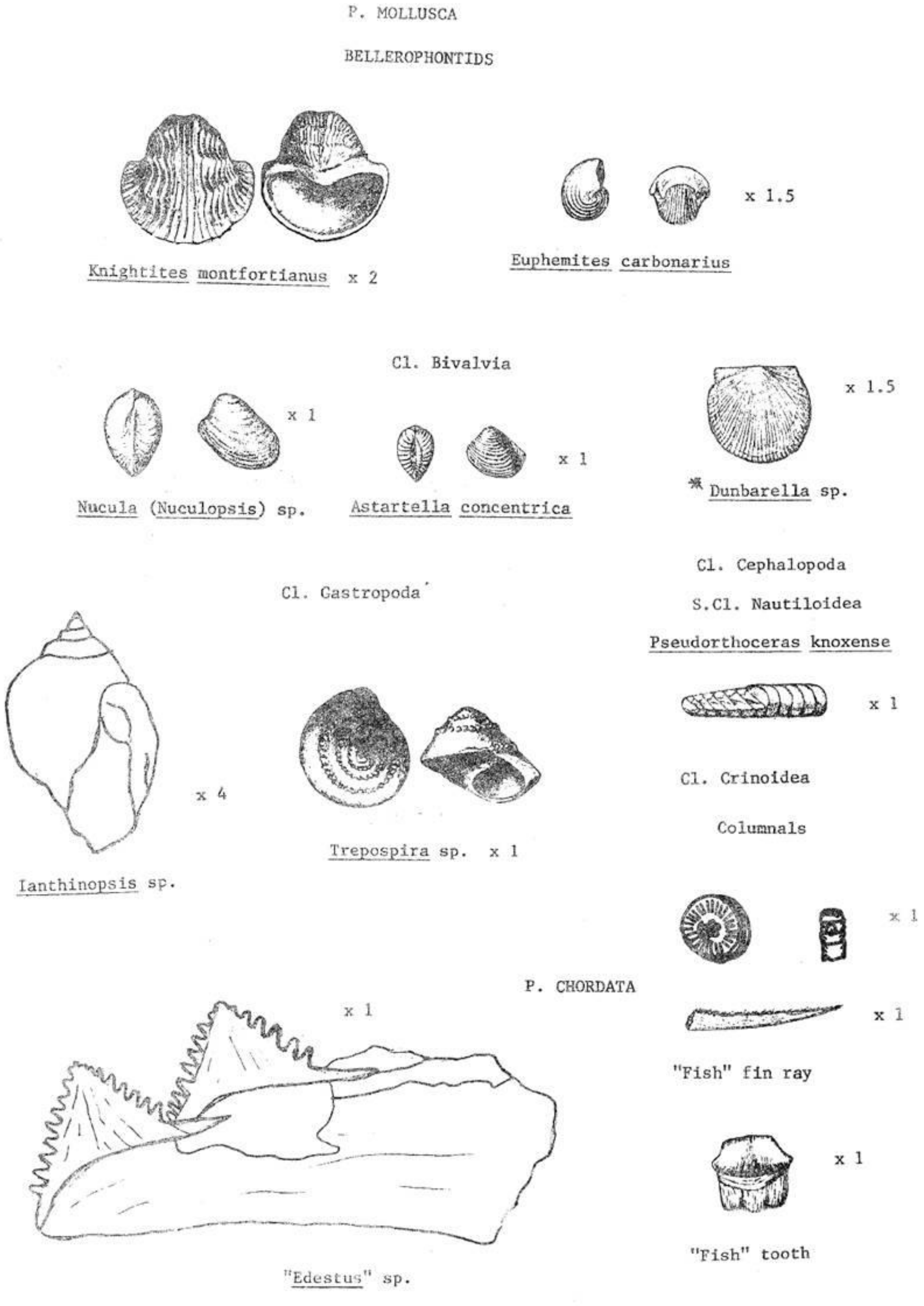


Figure 2. Selected fossils from the Wolf Covered Bridge Section.



P. MOLLUSCA

BELLEROPHONTIDS

Knightites montfortianus x 2

Euphemites carbonarius x 1.5

Cl. Bivalvia

Nucula (Nuculopsis) sp. x 1

Astartella concentrica x 1

*Dunbarella sp. x 1.5

Cl. Cephalopoda

S.Cl. Nautiloidea

Pseudorthoceras knoxense x 1

Cl. Gastropoda

Ianthinopsis sp. x 4

Trepospira sp. x 1

Cl. Crinoidea

Columnals x 1

P. CHORDATA

"Edestus" sp. x 1

"Fish" fin ray x 1

"Fish" tooth x 1

Figure 2. (continued)

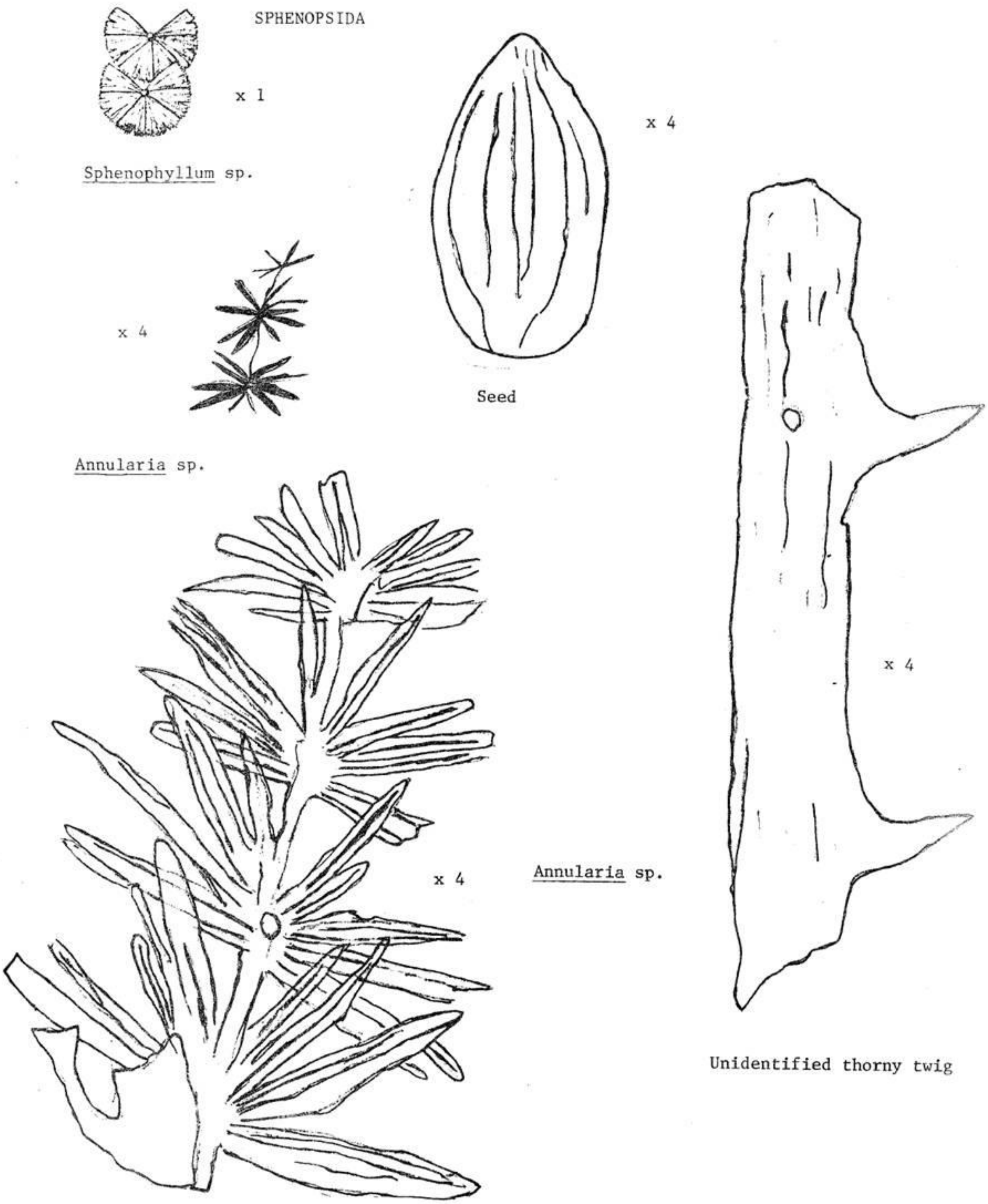


Figure 3. Plant fossils from the Vermilionville Section.

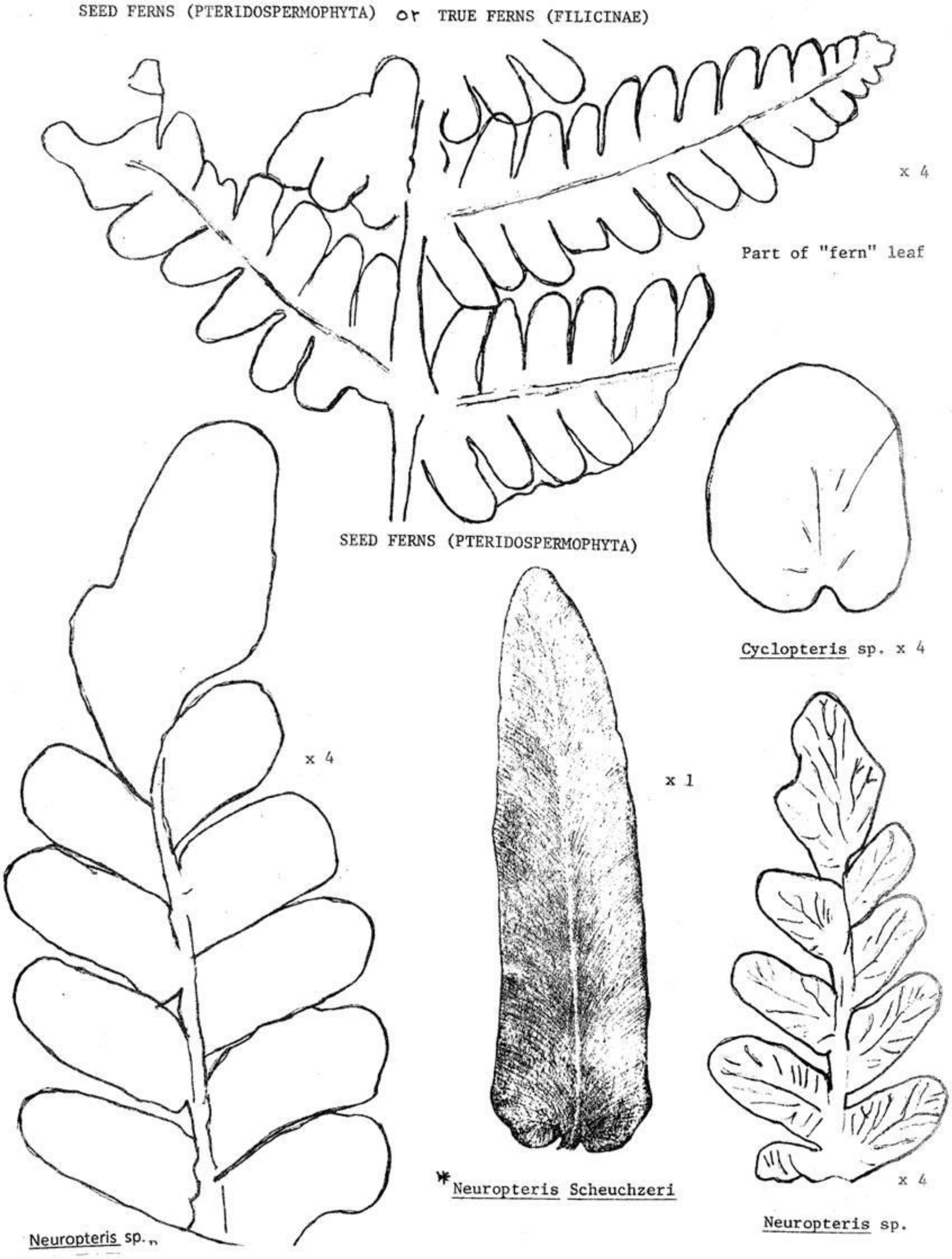
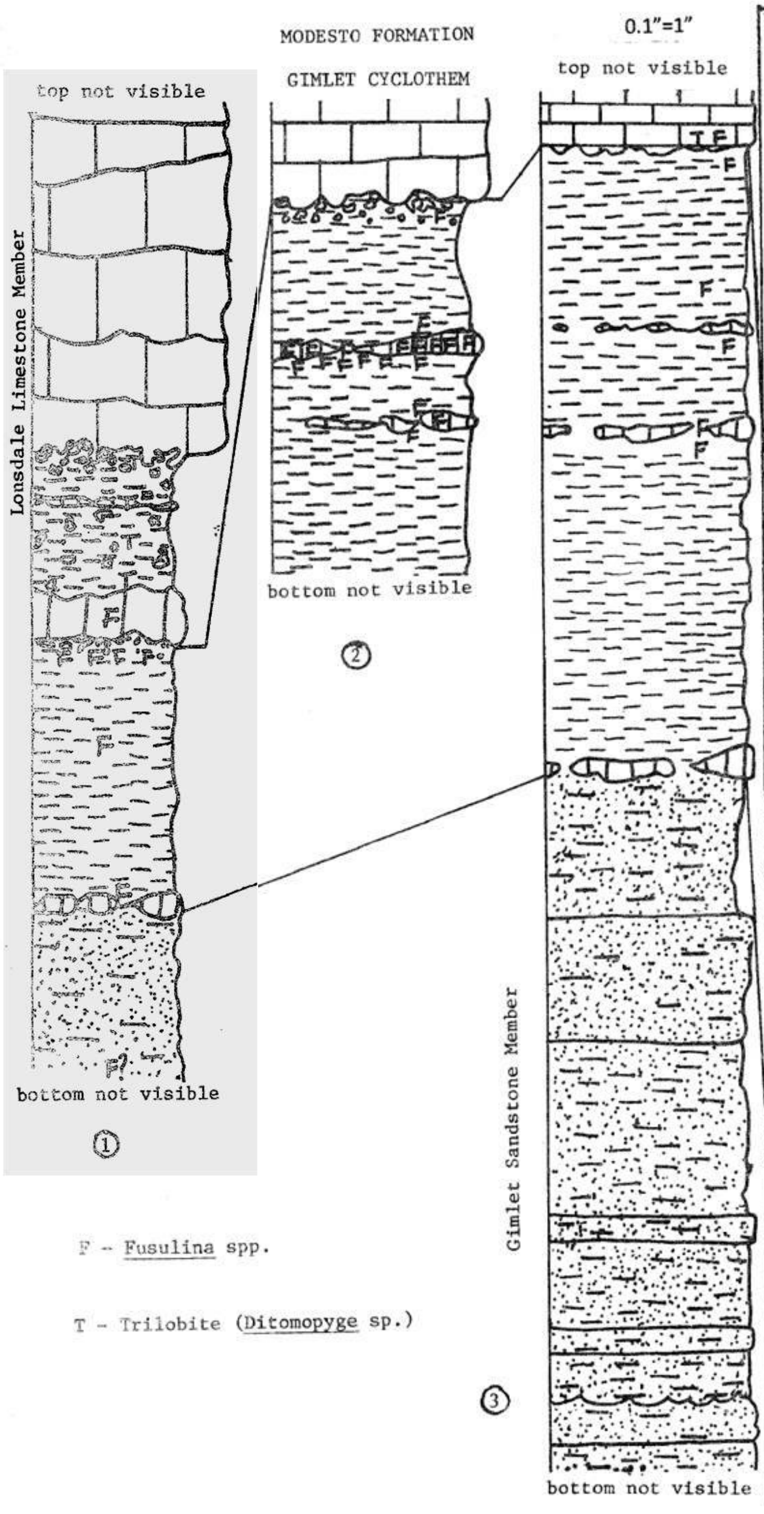


Figure 3. (continued)



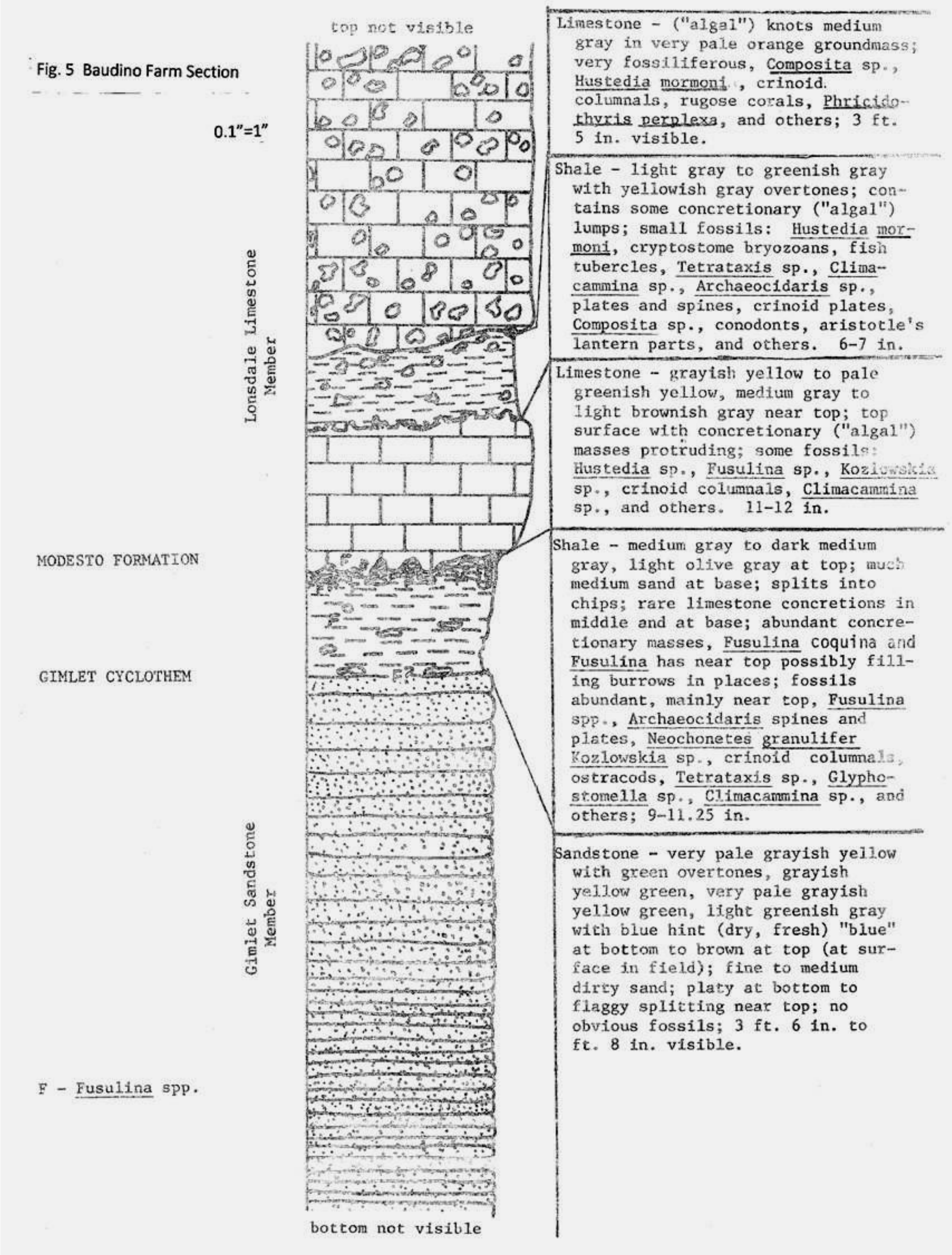
Limestone – yellowish gray groundmass containing medium light gray ("algal") lumps; thin bedded; ledge-forming; may contain ca. 10" shale bed near base containing thin lenticular limestone beds and abund. ("algal") masses particularly toward top; abundant and varied fossils content, particularly in shaly interbed, Hustedia mormoni, large crinoid columnals, Lophophyllidium sp., partial and complete Ditomopyge sp., Wellerella sp., Composita sp., Phricidothyris perplexa, many small foraminifera and ostracods, and other fossils at least 2 ft. 1 in. thick

Shale with some limestone interbeds ; shale between light olive gray and olive gray or medium light gray and light olive gray or yellowish gray – light gray or light greenish gray to greenish gray, yellow orange color beneath limestones (fresh, dry); nodular limestone masses may become very abundant near top; plastic particularly near limestone or breaks into chips; limestone interbeds greenish gray with hint of blue gray or or med. light gray concret. masses in yellowish gray groundmass; fossils abundant particularly towards the top of unit and around the upper limestones, agglutinated tubes near base, dense masses of Fusulina at one level in and around upper limestone interbeds, Fusulina spp., small crinoid columnals, Neochonetes granulifer Archaeocidaris sp. spines and plates, aristotle's lantern parts, many small foraminifera and ostracods; 2 ft. 2 in to 3 ft. 8 in.

Sandstone – between light gray and greenish gray, or yellowish gray with hint of green, or grayish yellow with hint of green (fresh, dry) appears "blue" at bottom to brownish" at top in field; mainly very fine to fine dirty sand; ripple marks on at least one internal surface; abundant muscovite in places; abundant orange-brown clumps in places; platy to flaggy splitting; no obvious fossils; at least 4 ft. 1 in. thick.

Figure 4. Hall Farm Sections:

1. Section just south of small waterfall.
2. Section est. 100 ft east of small waterfall north side of creek.
3. Section est. 15 ft east of Section 2.



Limestone - ("algal") knots medium gray in very pale orange groundmass; very fossiliferous, Composita sp., Hustedia mormoni , crinoid columnals, rugose corals, Phricidothyris perplexa, and others; 3 ft. 5 in. visible.

Shale - light gray to greenish gray with yellowish gray overtones; contains some concretionary ("algal") lumps; small fossils: Hustedia mormoni, cryptostome bryozoans, fish tubercles, Tetrataxis sp., Climacammina sp., Archaeocidaris sp., plates and spines, crinoid plates, Composita sp., conodonts, aristotle's lantern parts, and others. 6-7 in.

Limestone - grayish yellow to pale greenish yellow, medium gray to light brownish gray near top; top surface with concretionary ("algal") masses protruding; some fossils: Hustedia sp., Fusulina sp., Kozlowskia sp., crinoid columnals, Climacammina sp., and others. 11-12 in.

Shale - medium gray to dark medium gray, light olive gray at top; much medium sand at base; splits into chips; rare limestone concretions in middle and at base; abundant concretionary masses, Fusulina coquina and Fusulina has near top possibly filling burrows in places; fossils abundant, mainly near top, Fusulina spp., Archaeocidaris spines and plates, Neochonetes granulifer Kozlowskia sp., crinoid columnals, ostracods, Tetrataxis sp., Glyphostomella sp., Climacammina sp., and others; 9-11.25 in.

Sandstone - very pale grayish yellow with green overtones, grayish yellow green, very pale grayish yellow green, light greenish gray with blue hint (dry, fresh) "blue" at bottom to brown at top (at surface in field); fine to medium dirty sand; platy at bottom to flaggy splitting near top; no obvious fossils; 3 ft. 6 in. to ft. 8 in. visible.

Figure 5. Baudino Farm Section.

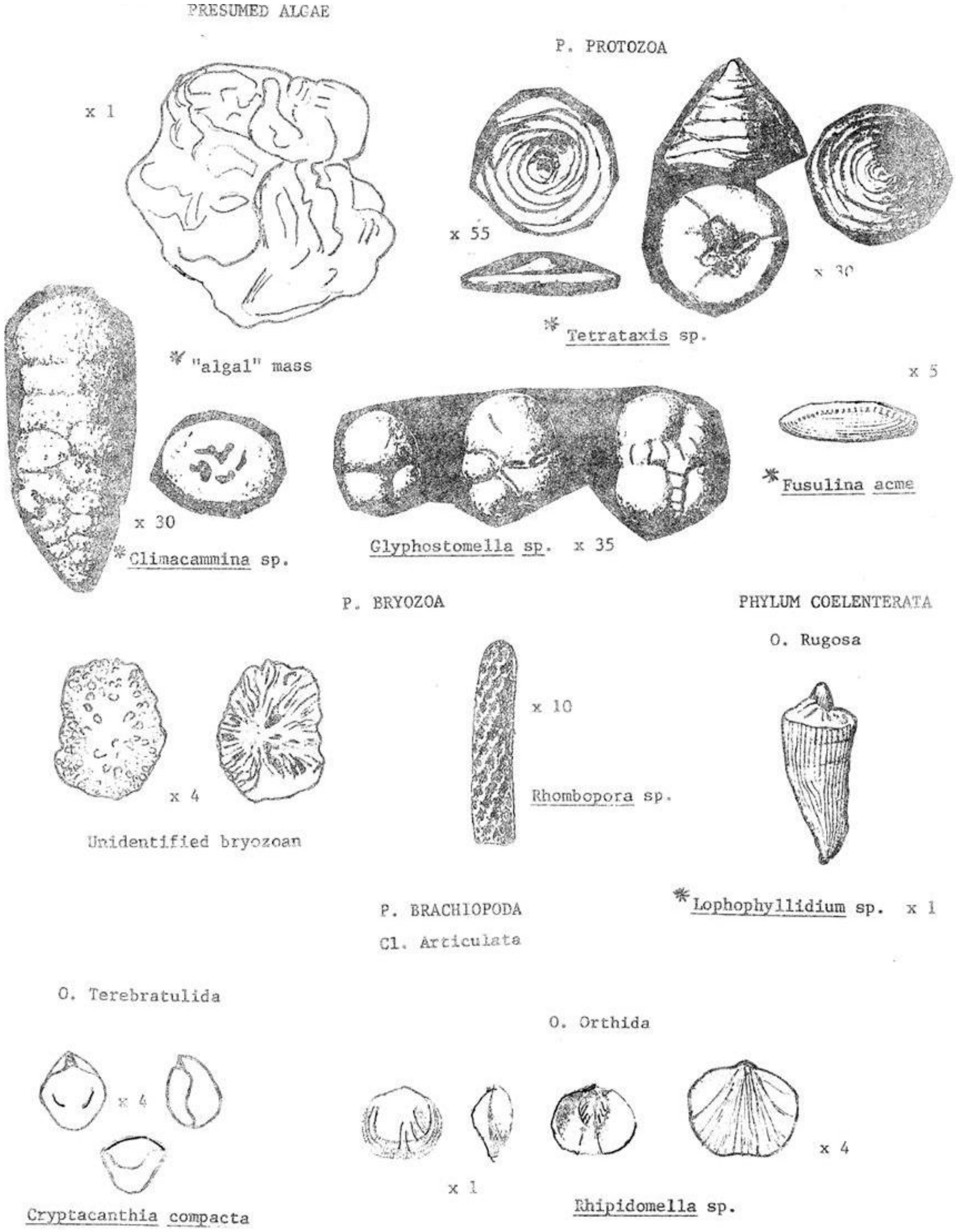


Figure 6. Selected fossils from the Hall Farm and Baudino Farm Sections.

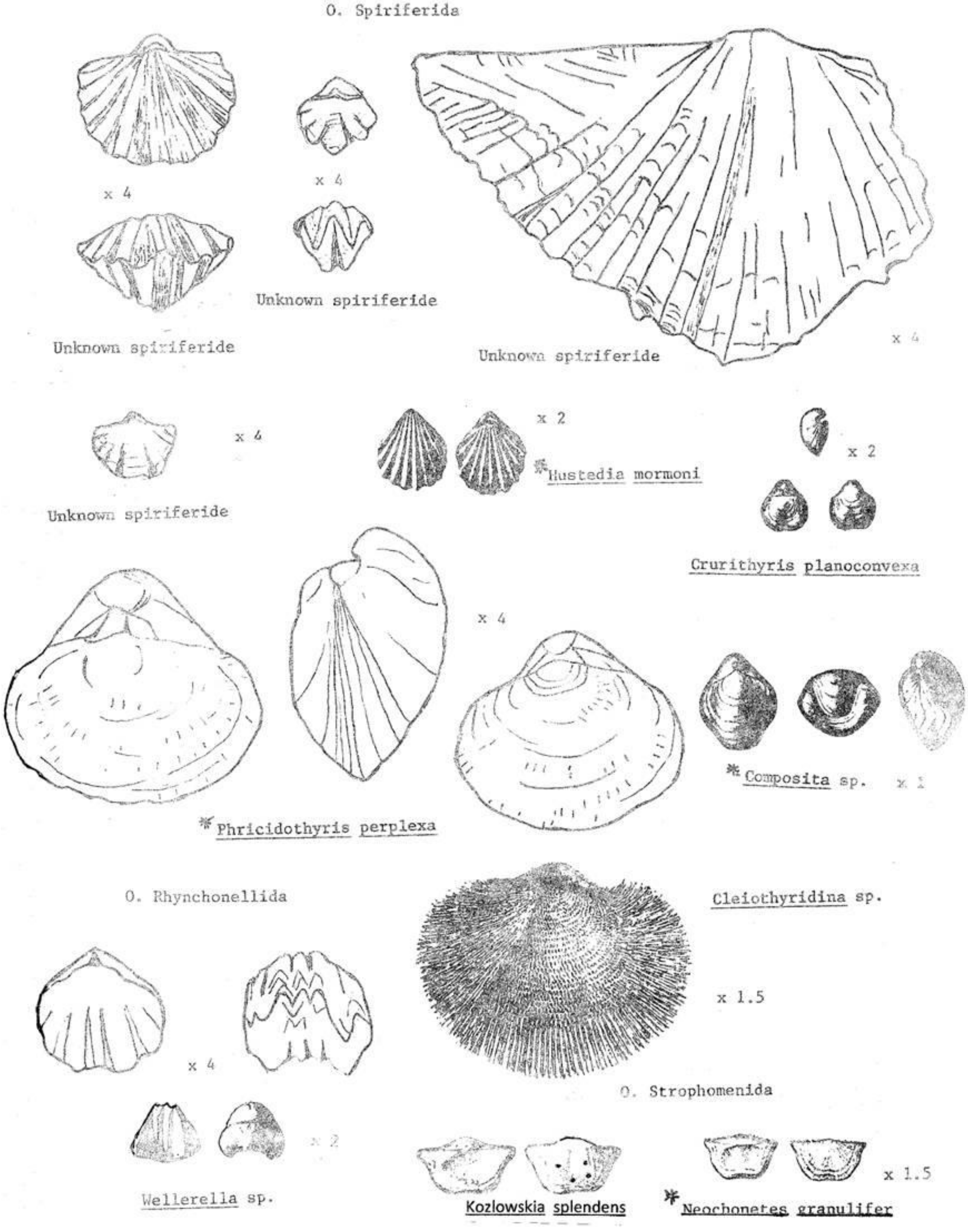
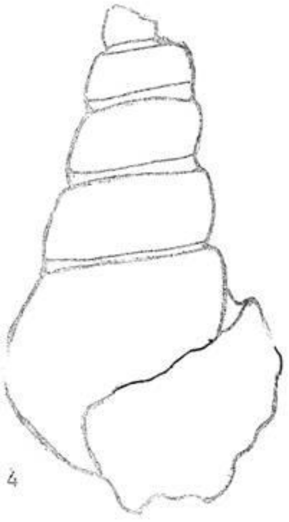


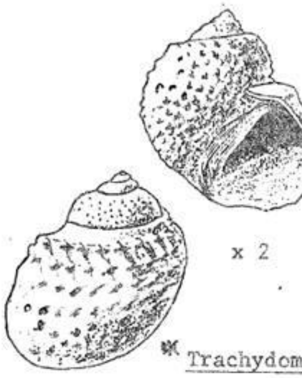
Figure 6. (continued)

P. MOLLUSCA

Cl. Gastropoda

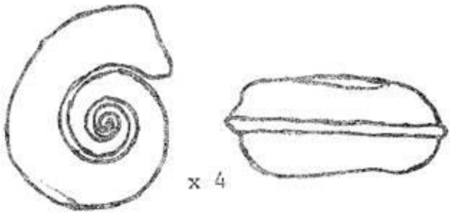


Unknown gastropod



* *Trachydomia* sp.

Phymatopleura sp.

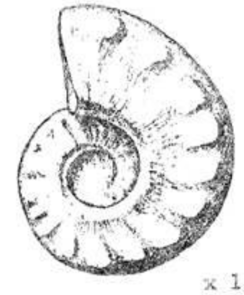


Porcellia sp.

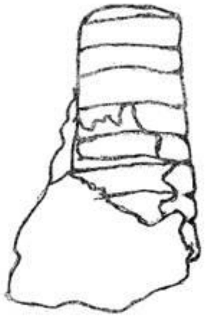
Unknown gastropod

Cl. Cephalopoda

S.Cl. Nautiloidea



Coiled Nautiloid

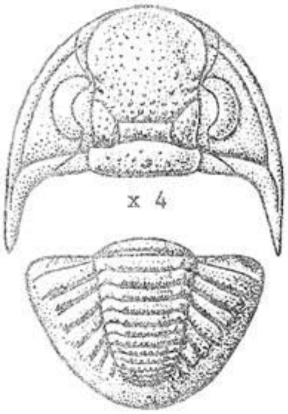


Straight Nautiloid

Figure 6. (continued)

P. ARTHROPODA

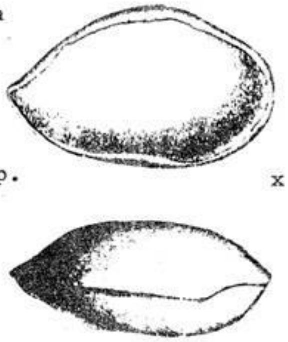
Trilobites



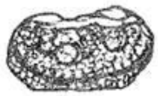
Ditomopyge sp.

Pygidium of an immature specimen

Cl. Ostracoda



*Bairdia sp.



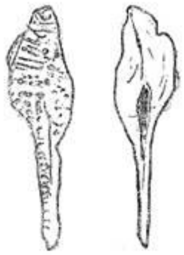
Unidentified ostracod

P. CHORDATA

Shark tubercle

"fish" tooth

CONODONTS



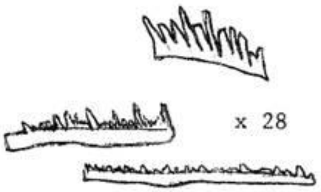


Figure 6. (continued)

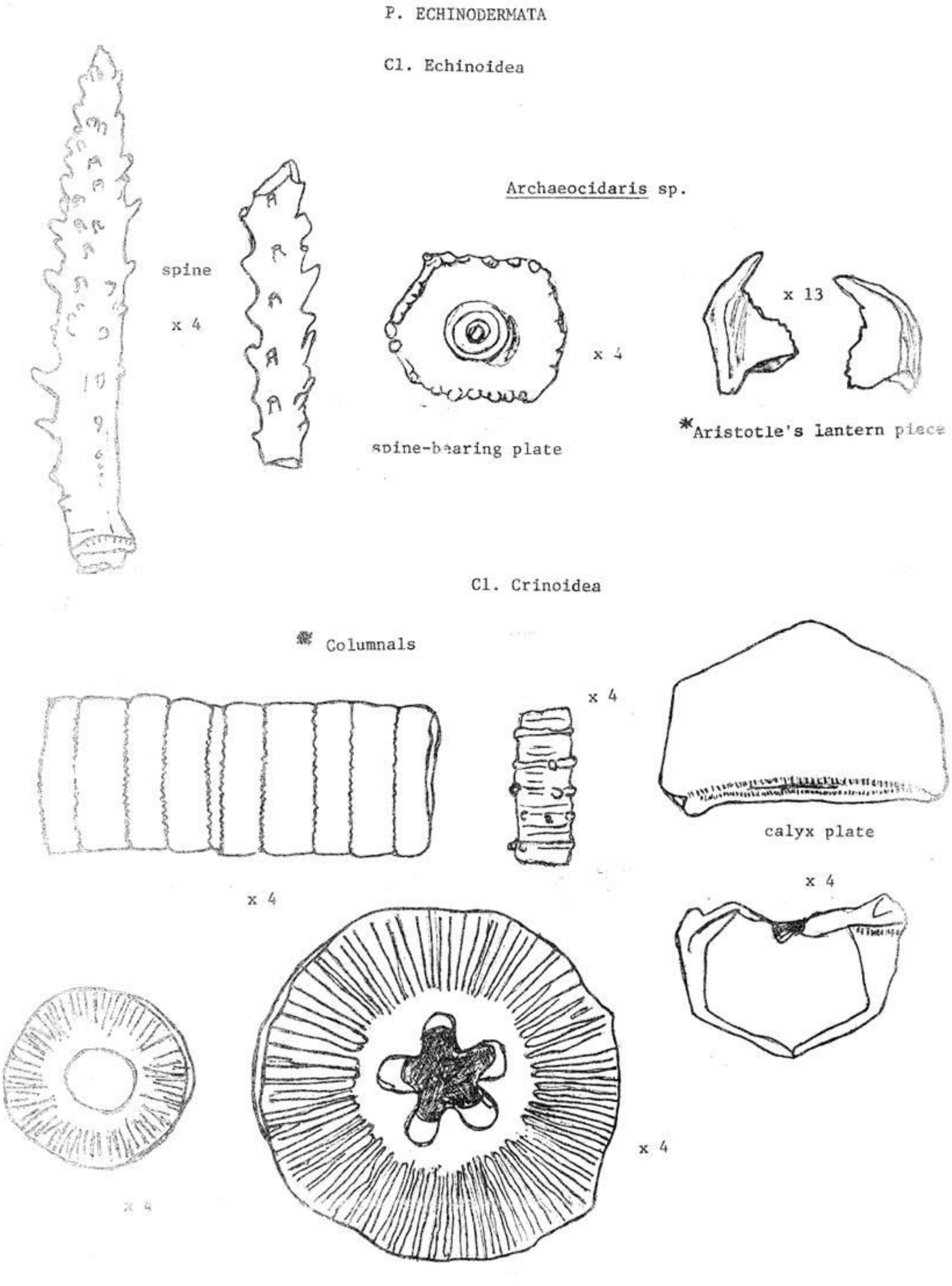
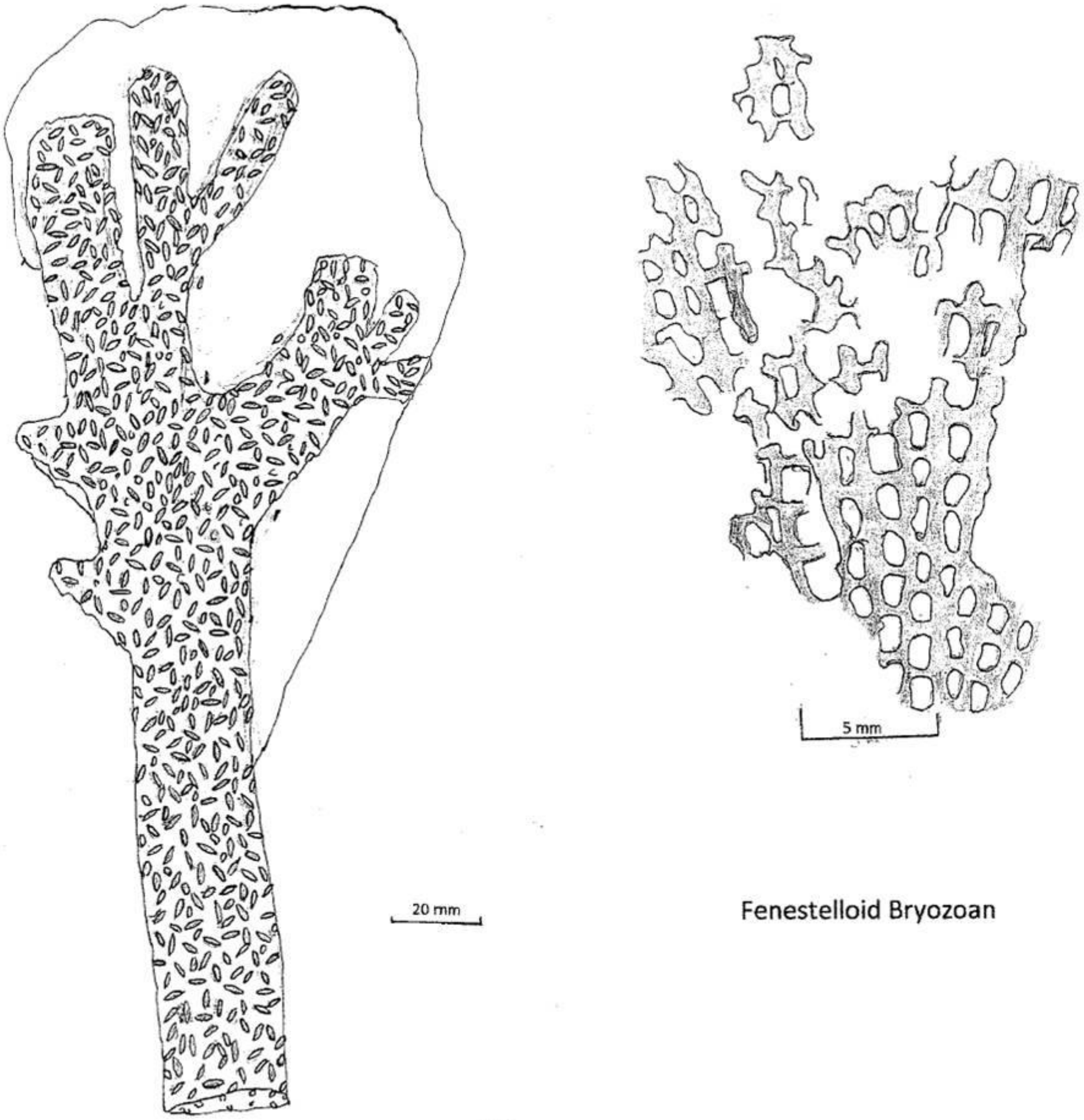


Figure 6. (continued)



"Burrows" containing Fusulina coquina

Fenestelloid Bryozoan

Figure 6. (continued)

PENNSYLVANIAN FOSSILS FROM McCOY, COLORADO

Dennis Gertenbach and Steven Reinhold

INTRODUCTION

The McCoy area of Colorado is well known for its variety of middle Pennsylvanian (late Atokan) invertebrate fossils, including brachiopods, crinoids and other echinoderms, gastropods, and horn corals. Also found are bryozoans, shark teeth, bivalves, cephalopods, and the remains of other organisms that were living in the sea over 300 million years ago in this part of Colorado. Additionally, plant fossils, including the early conifer *Walchia*, can be found.

The town of McCoy is located in the north-central mountains of Colorado, midway between Vail and Steamboat Springs, along the Colorado River. The area is high desert - sagebrush, pinon pines, and junipers - at an elevation of about 6,500 feet. Throughout the area, the Pennsylvanian Minturn Formation outcrops on the slopes. Typical fossil-bearing slopes near McCoy can be seen in Figure 1. Land ownership is a mix of public lands (Bureau of Land Management), on which collecting invertebrate and plant fossils is allowed, and private lands, which require permission to collect. Collecting is often done simply by walking along the outcrops and finding specimens that have weathered out. Some fossils, such as crinoids, are best found by quarrying into shale beds. Plant fossils are best found by splitting the rocks.

The fossils from McCoy have been studied by paleontologists for the past 100 years. In the University of Colorado collection are fossils collected and curated by Professor Junius Henderson beginning in 1911. The first faunal list of McCoy fossils was published in 1930 by Roth and Skinner, based on their exploration of the area in 1929. Their paper also describes new ostracods and foraminifera microfossils they discovered in the area. Dr. John Chronic of the University of Colorado and his student Calvin Stevens studied the area extensively in the mid to late 1950s. They realized that the sequence of strata in the area were quite similar to those near the town of Minturn, Colorado, and designated them as the Minturn Formation in Chronic and Stevens (1956). In his University of Colorado Master's thesis, Stevens (1958) studied several dozen locations in the McCoy area and described a comprehensive list of fossils. Additional studies have been published about specific McCoy fossil phyla during the past 50 years, including brachiopods in Stevens (1962); echinoderms in Strimple and Moore (1973), Webster and Houck (1998), and Itano, Webster, Houck, and Bateman (2003); and sharks in Itano, Houck, and Lockley (2003).

As fossil collectors and amateur paleontologists, many members of the Western Interior Paleontological Society (WIPS) and others have benefited greatly from the work done in the McCoy area by the professionals mentioned above, other amateurs such as Jordan Sawdo, as well as others who have gone before us. The secondary author of this article (Steven) would like to add that the other author (Dennis) is a key part of our on-going success in learning and discovering in this area; having studied many of the above mentioned documents and translated heaps of notes and comments (some from over a hundred years ago) into usable data for our adventures here in the 21st century.

Figure 1. The fossil-bearing slopes of the Minturn Formation near McCoy, Colorado.

GEOLOGY OF THE MCCOY AREA

About 300 million years ago, during the Pennsylvanian Period, Colorado was largely submerged by a tropical sea. What is now Colorado was then much closer to the equator and this is reflected in the fossil remains, such as corals, that are found in Colorado from that time. Within this ancient sea, two large islands and several smaller islands bisected the state. These two large islands are referred to as the Ancestral Front Range Uplift and the Uncompahgre Uplift (see Figure 2). The area near the present-day town of McCoy, Colorado, was then near the western shore of the Ancestral Front Range.

The rocks of the Minturn Formation in the McCoy area are two basic types. Much of the rock is red conglomerates, sandstones, and mudstones that contain very few fossils, except for occasional land plants. Alternating with these are dark gray and grayish green mudstones and limestones, usually containing abundant marine fossils. The alternating layers indicate that the area around McCoy was a marginal marine environment; sometimes above sea level, when the red sediments were deposited, and sometimes under the ocean, when the gray sediments were deposited. The species of fossil animals found in the mudstones and limestones indicate that the sea was very shallow in this area. For the fossil hunter, these gray and gray-green layers are the most productive for marine fossils. The sandstones containing the plant material may be from sand and silt that accumulated in a lagoonal environment. Stevens (1962) reports that the Minturn formation in the McCoy area includes nearly 2,000 feet of red conglomerates and sandstones containing the thinner fossiliferous gray and black shales and limestones.

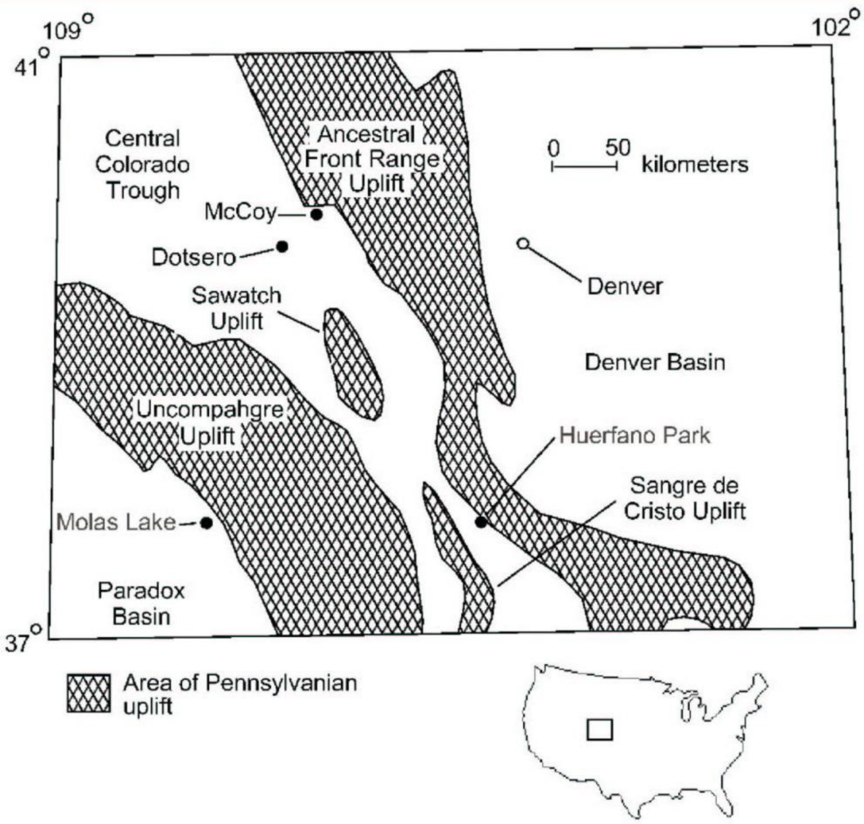


Figure 2. Colorado during the Pennsylvanian period, showing the location of McCoy, along with other fossiliferous Pennsylvanian locations in the state (from Itano, 2002).

FOSSILS

In the remainder of this paper, we present some of the more common McCoy fossils. This is by no means a comprehensive list of fossils from the area, but represents a collection of interesting specimens collected by the authors and other members of the Western Interior Paleontological Society (WIPS) throughout the first decade of this new millennium.

Brachiopods

Brachiopods are among the most common fossils found in the marine sediments in the McCoy area. Stevens (1958, 1962) provides the most comprehensive list of McCoy brachiopods, identifying 28 species. He used changes in brachiopod species to compare the ages of the various layers within the Minturn formation with other Pennsylvanian formations in the United States.

Some of the most common genera of brachiopods are *Antiquatonia*, *Composita*, and *Anthracospirifer*. Inarticulate brachiopods are not common at McCoy, although one is pictured in Figure 3. As might be expected, brachiopod species differ as one traverses from the lower to higher outcrops. Examples of McCoy brachiopods are shown in Figures 4 and 5.

Echinoderms

Crinoids are by far the most abundant echinoderm at McCoy. Disarticulated echinoid (sea urchin) fossils can also be found.

Most of the crinoid fossils found in McCoy are columnal (stem) segments, either single ossicles or longer sections of the column. They show wide variation in shape (Figure 6), with many showing the five-sided symmetry of echinoderms. The different columnal shapes are due both to different genera and to different locations along the column, from the holdfast where the crinoid attaches to and/or catches the seafloor, to the nodal columnals from where the cirri grow outward (Figure 7), to the proximal columnals where the column attaches to the bottom side of the crinoid's cup. Cup plates, crinoid cups with fully articulated basal and radial plates, and even calyxes (cups with arms attached) and crowns (with roof/crown arrays of tegmen spines) can also be found. Figures 8 and 9 show such two crinoid cups from different crinoid species.

Nearly all of the crinoid species identified at McCoy are found nowhere else. WIPS members have worked with researchers to identify several new crinoid species, including *Sciadiocrinus wipsorum*, named after WIPS (Webster and Houck, 1998), *Synarmocrinus cobbani* found by WIPS member Bill Bateman (Itano and Bateman, 2001), and *Eretmocrinus sawdoi* found by WIPS member Jordan Sawdo (Itano, et al., 2003).

At McCoy echinoids, commonly known as sea urchins, are usually found only as isolated plates or spines. The plates have a central knob where a spine attached. Two different types of spines are generally found, ones with three rows of small spikes (*Archaeocidaris triplex*), Figure 10, and ones with small densely packed spikes (*Archaeocidaris ourayensis*), Figure 11. Occasionally, associated spines and plates are found together, as these two figures show.

Gastropods (Snails)

Although the number of identified gastropod species from McCoy are nearly as great as the number of brachiopod species (27 vs. 28), they are much less abundant. The collection of gastropods in Figure 12 shows some of the variation found at McCoy. The shell structures range from planispiral (snails with shells that coil along a plane) to conispiral (snails with shells that coil to form a cone). One planispiral gastropod is shown in Figure 13. The spiral angle of conispiral McCoy gastropod species vary widely, as do modern gastropods. This is illustrated in Figures 14 to 17, with some species displaying quite ornate external ornamentation.

Cephalopods

In his study, Stevens (1958) identified two nautiloids from McCoy. The orthocone (straight-shelled) nautiloid *Pseudorthoceras knoxense* is somewhat common and has a smooth shell as seen in Figure 18. Coiled nautiloids, such as the cephalopod identified by Stevens as *Coloceras greenei*, are rare. Figure 19 shows another unidentified straight orthocone species.

Bivalves

While being much less common than brachiopods, bivalves are found at McCoy. Figures 20 through 22 show several McCoy bivalves.

Trilobites

Trilobites are not common at McCoy. Stevens (1958) described two species, *Ameura sagamonensis* and *Ditomopyge parvulus*. Complete trilobite fossils are rare; pygidium (tail) fragments are mostly found. Generally, these are *Ameura* specimens, as is suspected for the specimen in Figure 23.

Bryozoa

McCoy bryozoan species have not been well studied. Stevens (1958) identified three species and Roth and Skinner (1930) identified five. Most bryozoans found at McCoy encrust other fossils (Figure 24), but sheet-like (Figure 25) and branching species (Figure 26) are also found.

Corals and Sponges

Solitary horn or rugose corals are the most commonly found corals at McCoy. Positive identification of rugose corals generally requires sectioning to see the internal septa (plates) which radiate from the central axis. Colonial coral are also found at McCoy, but are much less common. Also found are sponges; difficult to identify as sponges, not to mention determining the genus and species. Several McCoy specimens are shown in Figures 27 through 29.

Microfossils

Microfossils from McCoy were first described by Roth and Skinner (1930). Figures 30 shows a foraminifera test (shell). The authors have not been able to identify the specimen in Figure 31. A micro gastropod is shown in Figure 32.

Shark Teeth and Spines

A number of diverse shark species have been identified from McCoy from the remains of teeth and fin spines. Itano, Houck, and Lockley (2003) made a detailed study of McCoy shark specimens, some with sharp tooth cusps for nipping and shearing and others with flat tooth plates for crushing prey. By far the most common tooth is *Petalodus ohioensis*. *Petalodus* teeth (named for the petal shape) show wide variation in dentition, as seen in Figures 33 and 34. Hansen (2008) has theorized that the range of high-crowned and low-crowned specimens indicates the location in the jaw, with high-crowned teeth in front and the low-crowned on the lateral margins of the jaw (Figure 35). Other shark teeth are shown in Figures 36 and 37.

Fin spines make up the other shark remains found at McCoy. These spines are positioned in front of the dorsal fin. A few modern sharks, such as the spiny dogfish, have similar fin spines. The most common shark fin spine at McCoy is *Ctenacanthus buttersi*, which is the likely species shown in Figure 38.

Land Plants

Within the layers at McCoy are thin-bedded sandstones and siltstones containing leaves and twigs. Large pieces of fossil wood have also been found. The early conifer, *Walchia*, is among the more common plant fossils found at McCoy, Figure 39. *Cordaites* (a kind of tree), *Calamites* (a relative of the modern horsetail rush), and seed ferns are also found. Several McCoy plant fossils are illustrated in Figures 40 through 42.

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About the Authors

Dennis Gertenbach and Steven Reinhold are both members of the Western Interior Paleontological Society (WIPS, http://westernpaleo.org/), which meets in Denver, Colorado. Although neither of them are professional paleontologists (Dennis is a chemical engineer and Steven is an IT professional), they certainly are amateur paleontologists. Both enjoy collecting fossils in the field and have lead numerous field trips to McCoy and other locations for WIPS.

Captions for Photos

Figure 3. Inarticulate brachiopod *Orbiculoidea capuliformis*.
Figure 4. Several articulate brachiopod specimens from McCoy. From left to right, top row: *Spirifer rockymountanus*, *Composita ovata*, *Mesolobus mesolobus* brachial and pedicle valves, bottom row: *Dictyoclostus portlockianus*, *Antiquatonia colorodoensis*, *Marginifera wabashensis, and Neospirifer triplicates*.
Figure 5. Two *Spirifer optimus* brachiopods on the bottom, contrasting the *Spirifer rockymontanus* on the top.
Figure 6. Crinoid columnals showing the variety of sizes and shapes found at McCoy.
Figure 7. Section of crinoid column with two attached cirri.
Figure 8. Probably a *Synarmocrinus cobbani* crinoid cup.

Figure 9. Probably a *Sciadiocrinus wipsorum* crinoid cup.
Figure 10. *Archaeocidaris triplex* echinoid (sea urchin) showing several ambulacral plates, plus several spines with three rows of small spikes.
Figure 11. *Archaeocidaris ourayensis* echinoid (sea urchin) with interambulacral plates and spines covered with small densely packed spikes.
Figure 12. A collection of McCoy gastropods.
Figure 13. Planispiral gastropod.
Figure 14. *Worthenia tabulate* gastropod.
Figure 15. *Ianthinopsis regularis* gastropod.
Figure 16. *Bellerophon* gastropod species.
Figure 17. *Goniasma copia* (White) gastropod.
Figure 18. The nautiloid *Pseudorthoceras knoxense*.
Figure 19. An unidentified straight nautilus species.
Figure 20. An *Aviculopecten* species.
Figure 21. Possible *Myalina* species.
Figure 22. The clam *Astartella concentrica*
Figure 23. Probably *Ameura* trilobite pygidium (tail).
Figure 24. Bryozoan encrusting a crinoid stem and brachiopod.
Figure 25. Fenestrate (window-shaped) bryozoan.
Figure 26. Branching bryozoan *Prismopora triangulata*.
Figure 27. An unidentified sponge.
Figure 28. Possible coral.
Figure 29. Rugose or horn coral.
Figure 30. Foraminifera test or shell, probably from the family Fusulinidea.
Figure 31. Unidentified microfossil.
Figure 32. A tiny gastropod.
Figure 33. *Petalodus ohioensis* shark tooth showing a high crown.
Figure 34. Another *Petalodus ohioensis* shark tooth with a relatively flat crown.
Figure 35. *Petalodus* teeth in the jaw, from Feldman and Hackathorn (1996). Bar is 1 cm.
Figure 36. *Peripristis semicircularis* shark tooth.
Figure 37. Ctenacanthid shark tooth.
Figure 38. Shark fin spine, likely *Ctenacanthus buttersi*.
Figure 39. Conifer sprigs, likely of the genus *Walchia*.
Figure 40. Unidentified leaf fossil.
Figure 41. Unidentified fern-like leaf.
Figure 42. Unidentified plant fossil.

Figure 3.

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Figure 27.

Figure 28.

Figure 29.

Figure 30.

Figure 31

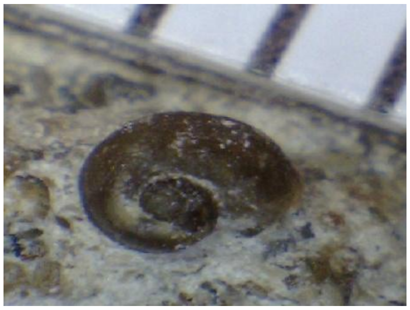


Figure 32.

Figure 33.

Figure 34

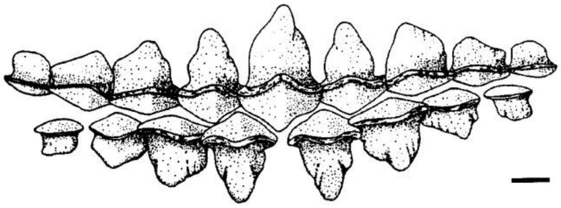


Figure 35.

Figure 36.

Figure 37.

Figure 38.

Figure 39.

Figure 40.

Figure 41.

Figure 42.

Additions to the Pennsylvanian Fossils of North Texas at Lake Bridgeport

John McLeod and Mark McKinzie

Since its publication in 2003, the authors of Pennsylvanian Fossils of North Texas (McKinzie and McLeod) have continued intensive collecting of the many Missourian (late Pennsylvanian) localities around Lake Bridgeport as described in their book. Multiple drought events that intermittently expose and inundate shoreline exposures result in ongoing renewal of the prolific fossiliferous exposures. As a result of the renewed exposures and intensive collecting, many new taxa have been recognized, including a new sponge-echinoderm community discovered by MAPS member Curvin Metzler that ultimately yielded several new species (Rigby, McKinzie, and Britt, 2008). The authors are currently developing second edition of the book, this time in full color that will contain the new material as well as expand on the stratigraphic range of fossiliferous Pennsylvanian. This paper is intended as a summary update of some of the new taxa that have been discovered since 2003.

Solenochilus Meek and Worthen 1870

Characteristics: Smooth involute shells with a siphuncle in contact or nearly so with the venter.

Left: Dorsal view of cast (shell exfoliated) of *Solenochilus* showing the distinctive siphuncle (x 1.5).

Comments: *Solenochilus* is a characteristic Mississippian-Permian coiled nautiloid. It was a figured drawing by the authors (page 33, Figure 2-47) but at the time was not recognized in the Bridgeport cephalopod fauna. It is known from a single specimen.

Coelocladia spinosa Girty, 1908

Characteristics: *Coelocladia spinosa* is the third of the three most common sponges found in the Lake Bridgeport area. This sponge consists of a basal portion of small branching cylinders as shown below. In large mature specimens the sponge expands outwards into a large funnel or concave frond like a giant flattened martini glass. The body wall is thin and the cloaca is large (approximately one third of the sponge diameter). The external surface is composed of short tubular "spines" that occur regularly but are not in definitive rows.

Above: Fairly complete *Coelocladia spinosa* sponge. The more tubular base of the sponge is to the right and the anterior portion is to the left. Scale bar in millimeters.

Comments: Formerly "Undescribed Calcisponge A")

Dermosphaeroidalis irregularis Rigby, McKinzie and Britt, 2008

Characteristics: A medium to very large sponge with a maximum diameter of well over twelve inches. Body form is variable. In smaller, less mature specimens the sponge is conical vase shaped with a well-developed pointed basal end that attached to the sea floor. Larger, more mature forms show a range of morphologies, bowl to jar shaped with a variable sized osculum. They stood upwards to a few feet above the seafloor. The outer dermal layer is quite thick and irregular. The outer surface is perforated by abundant large ostia which increase in size from the base of the sponge to the upper oscular rim. Individual spicules are hard to define in hand samples due to overprinting by calcite overgrowths.

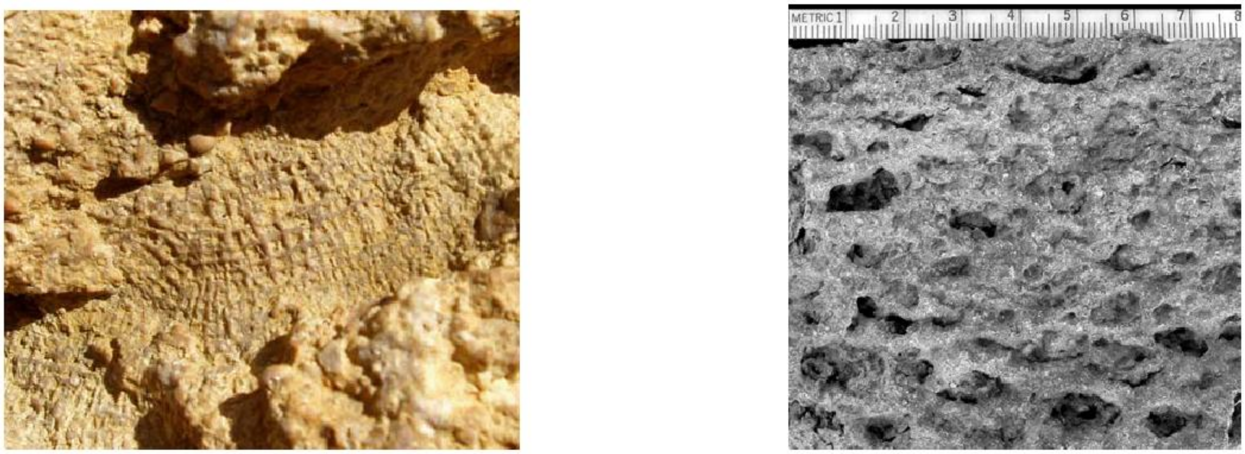
Above: Oral (left) and lateral (right) views of smaller specimens of *Dermosphaeroidalis irregularis* collected along the shoreline of Lake Bridgeport in the summer of 2006. Note the more classic vase shape to these immature sponges. The smaller (immature growth form?) sponges are easily identifiable by their shape.(x 0.6)

Occurrence: Known from abundant specimens collected by the authors from the sponge-echinoderm facies along the shoreline of northeast Lake Bridgeport. Only known occurrence is the Graford Formation (= Upper Lake Bridgeport Shale) of Late Pennsylvanian age (Missourian Series) in north Texas, USA.

Endoplegma calathus Finks, 1960

Characteristics: These unusual sponges are large vase-shaped forms that expand upwards and have a base with four, six or eight stout "legs" as shown below. Broad osculum with thick walls and occasional low protuberances near the oscular end. Dermal layer is composed of pentact spicules that form a regular quadrate mesh as shown in below. The ostia of the inhalant canals are well developed on the outer dermal layer as large pores. Circular to ovoid outline in dorsal view. A majority of sponges with four legs but Finks described one specimen with six legs. One sponge was recovered in the course of our field work with eight legs. Six to eight legs appears common in larger specimens collected here.

Above, lateral, basal and oral views of *Endoplegma calathus* collected along the shoreline of Lake Bridgeport in the summer of 2006. Note the pedestal “legs” at the base of these sponges. It is the distinguishing field characteristic for this genus of sponge.



Above, Left: Close-up view revealing the quadrate mesh network of the outer dermal layer from *Endoplegma calathus* collected along the shoreline of Lake Bridgeport in the summer of 2006. x 3.0 Right: Large pores in the interior wall of the osculum. Scale bar in millimeters.

Comments: The occurrence of this sponge at Lake Bridgeport extends the known range of this genus down into the Missourian of the late Pennsylvanian. The holotype described by Finks, 1960 is from the Leonardian lower Word Formation of extreme west Texas. All known occurrences from Texas, USA.

Aesiocrinus magnificus Miller and Gurley 1890

Characteristics: Cup is low and bowl shaped with a gently concave to flattened base. Radial facets are wide and relatively long. Cup ornamentation consists of densely spaced coarse nodes giving the cup a “bumpy” appearance. Ten uniserial arms that are extremely long and slender (much like *Erisocrinus*) except that they also are pustulose. The anal sac is also long and slender and terminates near the summit but is still hidden from view when the arms are in the closed, non-feeding position. The stem is transversely pentagonal.

Above: Two views of a complete crown of *Aesiocrinus magnificus* from the sponge-echinoderm facies at a low-water locality along the northeast shore of Lake Bridgeport. The cup has been crushed and flattened and appears taller than it would be in an undistorted specimen.

Comments: Known from only one specimen, a complete crown collected by Mary McLeod. Easily distinguished from *Erisocrinus* by the nodose nature of the cup and arms. The genus ranges from the early to late Pennsylvanian (Morrowan to Virgilian Series) in the midcontinent region of North America. This species is also known from the Missourian age Lane Shale of Kansas City, Missouri.

Sciadiocrinus disculus Moore and Plummer 1939

Characteristics : Cup form is a very shallow saucer shape with the base nearly flat except for the slight indentation where the transversely round stem attached to the calyx. The surface of the cup is smooth. Three anal plates in cup. Arms are uniserial, round, long and slender and branch isotomously two or three times in each arm ray. Mushroom-like anal sac rises above outstretched arms and terminates in a cap of horizontally directed marginal spines with an interior of small polygonal plates as shown above.

Above left to right: Two lateral and oblique-anterior views of a well-preserved crown. Collected by Mark McKinzie during the summer of 2006 from the shoreline of Lake Bridgeport. Note the well-developed anal sac summit composed of interior polygonal plates and at least 18, outwardly directed marginal spines. Scale bar in millimeters.

Comments: *Sciadiocrinus* is strictly a Pennsylvanian form from the southern mid-continent region of North America (Texas – Oklahoma – Kansas – Illinois). The basal portion of the cup and the marginal anal summit spines are commonly found in the sponge echinoderm biofacies of the Graford Formation.

Ulrichocrinus ramosus

Characteristics: Crown slender and elongate with a cup that is low bowl-shaped at the bottom with a basal impression where the stem attached to the calyx. Overall cup shape is conical. Infrabasals are planate to downflaring and the radials are outflaring. Anal tube is slender and elongate. Arms ten, uniserial, pinnulate and isotomously branching on the first or second secundibrachial. Circular stem becomes transversely pentagonal proximal to calyx.

Above left to right: Two lateral views of a well-preserved crown collected by Curvin Metzler in the spring of 2006 from the shoreline of Lake Bridgeport. Note the interior pinnules exposed near the distal (upper) tips of the arms. Two crowns collected by Mark McKinzie (2011) showing the size variation in the crowns. Scale bar in millimeters. Only four specimens known from Lake Bridgeport. The genus was previously reported from Middle Pennsylvanian sediments (Morrowan and Desmoinesian) of Texas and Oklahoma. This is the youngest reported occurrence from the late Pennsylvanian (Missourian) in North America.

Comments: Only four specimens known from Lake Bridgeport. The genus was previously reported from Middle Pennsylvanian sediments (Morrowan and Desmoinesian) of Texas and Oklahoma. This is the youngest reported occurrence from the late Pennsylvanian (Missourian) in North America.

Striatopora cf. kohmani Strimple and Cocke 1973

Characteristics: Regularly to irregularly branched cylindrical colonies with trumpet-shaped corallites that are exposed normal to the colony axis but intersect it at an angle. Walls are moderately thick with mural pores. The tabulae vary in packing and thickness. Septa may be present. Species are differentiated based on the number and spacing of tabulae and the size of the corallites (as determined by thin sections).

Comments: *Striatopora* is a ramose (branching) colonial tabulate coral known from other midcontinent Pennsylvanian localities. At Lake Bridgeport *Striatopora* is represented by a single unique specimen from the molluscan biofacies. Other than the equally rare *Paleacis*, we are not aware of any other colonial corals from the molluscan or sponge-echinoderm biofacies. It is likely that the rapid peri-deltaic sedimentation that so effectively preserved other fossils was an impediment to the growth of sessile attached colonial filter feeders.

Left: Nodule from shore of Lake Bridgeport that reveals partially-exposed *Striatopora* colony.
Right: Close-up of branch and corallites.

EUGENEODONTID SHARK – Family Caseodontidae – genus indeterminate

Characteristics: Eugeneodontid sharks are a bizarre group of Paleozoic fish whose phylogenetic relationships are poorly understood. One feature that the various genera have in common is a unique “tooth whorl” of various morphologies at the symphasis of the lower jaws. The body is spindle-shaped and the pectoral fins are supported by long radials (skeletal elements). The family Caseodontidae possesses lateral teeth along the lower jaws that form transverse tooth batteries with comb-like roots of various sizes. The parasymphysial tooth whorl contains teeth with an overall “V”-shaped outline but still possessing the comb-like roots.

Top: anterior, **middle**: right-lateral, **bottom**: occlusal view of a single tooth from the parasymphysial “tooth whorl” to an unknown caseodontid shark. The root of the tooth is still imbedded within the ironstone nodule. The anterior tip of the tooth is missing. Scale bar in millimeters.

Comments: Extremely rare. This is a first occurrence of a caseodontid shark from the Lower Lake Bridgeport Shale. Shark teeth are uncommon in general from this formation. This is just a single tooth and there would have been a series of similar shaped teeth in front and/or behind it forming the parasymphysial “tooth whorl”.

Macroneuropteris (= Neuropteris) scheuchzeri Hoffman and Langford 1958

Characteristics: This pteridosperm (“seed fern”) features pinnules that are elongated ovoid to tongue shaped in outline. The pinnules are rounded at the base with a narrow point of attachment. The midvein on each pinnule is distinct and the lateral veins arch and fork numerous times off the midvein to the pinnule margin. Each pinnule is slightly offset from its’ counterpart on the other side of the branch. The terminal pinnule (at the apex of the frond) is large and polymorphic in shape as can be seen below.

Above: Part and counterpart of an ironstone nodule containing the terminal portion of a frond from the seed fern *Macroneuropteris* (= *Neuropteris*) *scheuchzeri*. An American quarter for scale.

Comments: Rare in the Missourian Series of north Texas. This species of seed fern was common in the Pennsylvanian coal forests and adjacent lowlands of North America and Europe. In north Texas it can be found in Desmoinesian age-sediments (Mineral Wells Formation) up through the Virgilian (Markley Formation). This is a first occurrence from the deltaic facies of the Lake Bridgeport Shale but was expected as abundant but indeterminate lycopod wood material is also found in this formation. The fossil represents a small frond section that drifted out to sea and was quickly buried and encased within an ironstone nodule prior to decomposition.

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A Window into a Catastrophic Coal Age Flood Event: The Mazonian Fossil Bonanza

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GENESIS – A Poem by Mildred Williams

He reads concretions like the books of the Bible
Turns the pages of the Word made Stone
Written forever unchanging on red ovals
Oblong capsules of recorded time.

Closed, sealed
They lay stored
On a shelf by a creek,

Reference stacks for the ages,
Whoever can open and decipher

Fronds of ferns
Stars of rushes
Fish
Shrimps
Flies

Tails, segments, tendrils, antennae
Curls, strokes and serifs of letters,
Calligraphy.

What author, whose colophon, what publisher?
Whence, how and wherefore - - shall he have a
Crack at the answer?

A bucketful of rust colored cakes of shale
Pulled from a bank,
Like scrolls in an ancient scrinium,

He splits each nugget,
Scans beautiful pages,
Lefthand page mirroring righthand
In perfect symmetry

Introduction

The story of the Mazon Creek Biota began in a diverse equatorial coastal ecosystem that flourished 307 million years ago. A rare combination of circumstances led to the preservation in siderite concretions of this extraordinary group of Pennsylvanian Age fossils. Known as the Mazonian Deltaic Event, it left us a clear view into in a tropical tidal estuary on the coast of Laurasia.

According to Wikipedia, the word “estuary” is derived from the Latin word *aestuarium* meaning tidal inlet of the sea. Estuaries form a transition zone (ecotone) between terrestrial, river and ocean environments and are subject to both marine influences, such as tides, waves, and salt water; and riverine influences, including a source of fresh water and fine sediments. The river provides high levels of minerals and nutrients, making estuaries one of the most productive natural habitats in the world and in this case, a hothouse for the earth's first primitive forests of giant arborescent lycopods, ferns and seed ferns. Further, estuaries are nursery grounds for many marine species. The river-born fresh water floats over the higher density “salt wedge” on the bottom, acting as a protective barrier for larval and juvenile forms close to the bottom. But estuaries are also potential places of peril. It was a lethal cocktail of rising sea level and a catastrophic influx of river sediment that consigned a broad array of coastal plants and animals comprising the renowned Mazon Creek Biota to a rapid entry into the fossil record through methanogenic concretion development.

The Story

The weather was typical for equatorial Laurasia (Figure 1). It was the height of the monsoon season with temperatures hovering around 95 degrees Fahrenheit. In the humid oxygen-rich atmosphere, flying insects were abundant; and some of them had wing spans of 2 feet or more. Cumulonimbus clouds presaged an event that would become near unprecedented; even the insects were quiet...a lull before the storm (Figure 2). The color green was pervasive in the limpid tropical light. Broad river levees, only a few feet higher than the vast Mazonia delta complex of floodplains, wetlands and bayous, were thickly vegetated with large arborescent seed ferns, notable *Medullosa noei* an upland species that reached heights of 30 feet or more. Held by an extensive system of prop roots, *Medullosa* sported a magnificent spiral crown of fronds bearing large seeds (Figure 3).

The flanks of the levee were dotted with tree-sized true-ferns, notably *Psaronius*, another arborescent fern giant that often attained heights of 35 feet (Figure 4). Beneath the tropical canopy, the archaic, giant uniramian *Arthropleura* and related millipede genera scuttled about on the forest floor in the leaf-litter and low herbaceous forest understory dominated by Sphenopterids (Figure 5). Closer to the water's edge, were the horsetail-like, but tree-sized *Calamites*. On this day, even the amphibians, ordinarily active in their pursuit of small insects, were lethargic. It is said that some animals can sense the coming of bad weather; perhaps the falling barometric pressure was the trigger (a known cause of headaches in the much later evolved human species).

The river, born in the emerging Appalachian Mountains to the south, flowed sedately across upland coastal plains toward the Laurasian inland sea. Dragging a bed-load of fine sand and suspended silt and clay, the river was the lifeblood of this tropical estuarine deltaic ecosystem. In the Earth's south polar region, the vast Gondwanan ice sheet was melting due to global warming. Local coastal drowning, associated with sediment compaction due to delta abandonment was soon to be overtaken by a longer-term rise of the ocean (global marine transgression) fed by the melting glaciers.

Beyond the levees, vast coastal wetlands (swamps), extending to the horizon, were forested with gigantic, rapidly growing cone-bearing Lycopsids, and rooted in thick watery peat deposits that would later become the Colchester (No. 2) Coal. This coal represents a regional portion of the greatest coal deposit known on Earth. Well adapted to wet fresh-water conditions, these pulpy, large-based trees rose to heights of 100 feet or more, dominating the landscape and are the primary species making up the coal. As sea level rose, incursion of salt water rang the death knell for these magnificent trees. High levels of bacteriogenic sulfur found in the coal today attests to the poisonous influence of the sea water invasion).

Monsoonal rains recorded by annual variations in thicknesses of tidal rhythmites preserved in the Mazonian Delta deposit (Francis Creek Shale), attest to an alternation of wet and dry seasons. These monsoons grew in intensity as latitudinal temperature gradients steepened and the intertropical convergence of winds accelerated. During an extremely wet season, upland areas of the coastal plain, ordinarily stable, began to erode, supplying vast amounts of sediment to the coast. A quantum increase in river discharge, coupled with global sea level-rise would have overwhelmed the existing levee systems, leading to major levee breaks and consequent rerouting of large lowland rivers. It is the suddenness of these rerouting events that may explain the sharp contact between the Colchester Coal and the overlying gray, silty, nodule-bearing fossil beds of the Francis Creek Shale seen in so many places. This episode of accelerated sediment discharge produced complex, localized, gray sediment wedges (Francis Creek Member) above the Colchester Coal and time-equivalent coals in Missouri, Iowa, and Oklahoma that were linked to local river sources across the U.S. Midcontinent Region. This time-synchronous pulse of sediment influx to the sea, we herein term the "Great Mazonian Deltaic Event."

Imagine being transported back in time to witness this remarkable spectacle. As equatorial convection accelerated, immense thunderstorms would have introduced the coming of the monsoon. Over saturated ground, small rivulets were transformed into raging streams, cutting into silty coastal plain soils. The lower coastal plain distributaries and wetlands in the Mazonian Embayment would ultimately provide a relief valve for this deluge as flood water made its way relentlessly to the sea. Coalescing, sediment-engorged tributaries feeding into trunk rivers would have created a juggernaut resulting in levee breaches or "crevasse splays." This rerouting of delta distributaries (delta switching) reshapes deltas, creating robust advancing lobes linked to the new channels, abandoning portions cut-off from the sediment feed. It is possible that a slug of river-born sediment of this magnitude might have been generated by an earthquake or flood induced breach in a watershed divide or breach in a large upland lake. Future research may shed light on these possibilities.

As the flood overwhelmed and blasted through levees, it steadily filled the embayment, drowning hundreds of square miles of wetlands and coastal lagoons with sediment-laden flood waters in a real-time-frame of hours to days (Figure 6). Recently uprooted upland plants, insects and tetrapods (Braidwood Terrestrial Biota) were the first to die; transported seaward, and rapidly-buried as standing coastal waters countered the force of the river, allowing sediments to drop out in a shallow fresh- to brackish-water lagoonal environment. Riverine flood waters, less dense than the more saline brackish marine water wedge, distinctly flow over the marine layer, creating a stratified water column; fresh water above and tidal brackish lagoonal water below. Despite its load of suspended fine sediments, the flood waters would have spread-out on the surface, depositing only fines that dropped out of suspension as tidal rhythemites. The Braidwood Aquatic Biota, dominated by crustaceans and clams, and juvenile fish, were soon buried and later preserved in siderite nodules (Figure 7). Some large marine predators like Xenacanth sharks making their presence known through coprolites and teeth, may have escaped the flood waters.

Several miles farther offshore, a more-marine, but still estuarine community of nektonic, planktonic and benthic organisms (Essex Biota) next succumbed to the soupy flood's rain of suspended sediments. The absence of fully marine articulate brachiopods and corals and the rarity of cephalopods and crinoids attest to the estuarine nature of this "marine" zone. A few species of active burrowing clams like the solemyoid bivalve *Mazonomya mazonensis* (misidentified as "*Edmondia*"), unsuccessfully tried to escape the rain of sediments on the lagoon floor. This calamity lasted for weeks as indicated by the extraordinary record of daily tidal layering in the flood deposits (Figure 8). Perfect preservation of fragile and soft bodied organisms like worms and jellyfish and upright Lycopod stumps in the coal, are evidence that the Mazon Creek organisms were overwhelmed by the rain of fine sediment (Figure 9). As the flood continued, a thick wedge of sediment accumulated above these lagoonal, finely laminated deposits of silt and clay. Coarsening upward, the "prograding-delta" sequence exhibits tidal lenticular bedding overlain by cross-beds and convolute bedding of silt and sand, characteristic of higher flow velocities. At the top of the sequence are terrestrial underclays and thin coal deposits, evidence that the constructive progradational pulse had played itself out (Figure 10). Farther offshore or farther down the coastline at the margins of the estuary, sedimentation rates were lower as attested by a thin layer of Francis Creek Shale overlain by Mecca Quarry Shale. Supporting a marine community of articulate brachiopods and high levels of bioturbation (burrowing) in sediments, the system was likely fully marine.

The Story of the 307 million year-old Mazon Creek Biota would not have been told without the economic coincidence of coal mining near the Chicago metropolitan area. Coal mining in northeastern Illinois, especially strip mining, commencing in the 1920s and ending in1976, exposed the fossils in spoil heaps accessible to a large community of fossil hunters. The catalyst that built this cottage industry of specialists and collectors was the Field Museum and its group of dedicated paleontologists, notably George Langford, Eugene Richardson and Ralph Johnson who published numerous scientific papers on this biota and its geological context.

The Mazon Creek story is by no means complete. More work needs to be done locally to help with understanding the transition from the thick estuarine deposits of the Francis Creek Shale to thinner fully marine beds rich in brachiopods and other shelly fossils. Active strip mine and creek exposures remain to be explored by scientists and experienced amateurs. Drill cores have already proven to be a critical source for the study of neap-spring tidal cycles as well as the finer, record of twice-daily flood and ebb depositional events associated with the nodule biotas (Baird, 1997 A, B; Baird, et al., 1985A; Baird, et al., 1985B; Kuecher, 1983). The long string of bank exposures along Mazon Creek, southeast of Morris, Illinois, still awaits a serious sedimentological investigation at the graduate level. The bacterial geochemistry of the siderite concretions and fossil preservation gradients within nodules has many remaining mysteries.

Today, the role of the scientifically-minded amateur collector and the graduate student cannot be overlooked. The pressure on faculty, state survey workers, and museum staff to perform in the short-term is currently immense, given the slow economy, a general reduced support for education, and the digital automation of the workplace. What this means is that there may be no more Langfords, Richardsons, and Johnsons who had the time in their day to indulge pure science as adventure. This responsibility now falls on the passionate and informed collector who may still be able to refill this role. When Gordon Baird left Illinois in the early 1980s, he located new "Mazonian" fossil-bearing nodule occurrences in southwestern Indiana, east-central Illinois, two areas in Missouri, and one in Oklahoma, simply by driving around, working from topo sheets and mined out maps (Baird, 1985). This cursory sweep of promising areas convinced him that we have been scratching the proverbial "surface" with respect to new localities. Already, Braidwood-type fossils from the new Knob Noster concretion locality in central Missouri have appeared on E-Bay and on Google in recent years. Macomb, Illinois is surrounded by mines cut into the Francis Creek Shale; concretions yielding plant fossils and coprolites can be found on shaft mine dumps in the immediate vicinity of the town. Perhaps some of these may turn up new and exotic critters. It is the role of courageous amateurs with the energy, time, and passion willing to risk short-term disappointment, to explore for new sites.

Acknowledgements

The primary sources of illustrations for this story are *Richardson's Guide to the Fossil Fauna of Mazon Creek* edited by Charles Shabica and Andrew Hay, and *The Mazon Creek Fossil Flora* by Jack Wittry. Wittry's work on Mazon Creek plants provides a setting for the Mazon Creek terrestrial arthropods including insects and amphibians. We are grateful to the chapter authors who helped put Richardson's Guide together especially Don Auler, Andy Hay, Sam Kruty and Steve Sroka. Many thanks go to Mid America Paleontological Society (MAPS), Earth Science Club of Northern Illinois (ESCONI), Des Plaines Valley Geological Society, Chicago Area Paleontological Society (CAPS) and Chicago Rocks and Minerals Society. They collectively kept the Mazon Creek fires burning!

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Figures

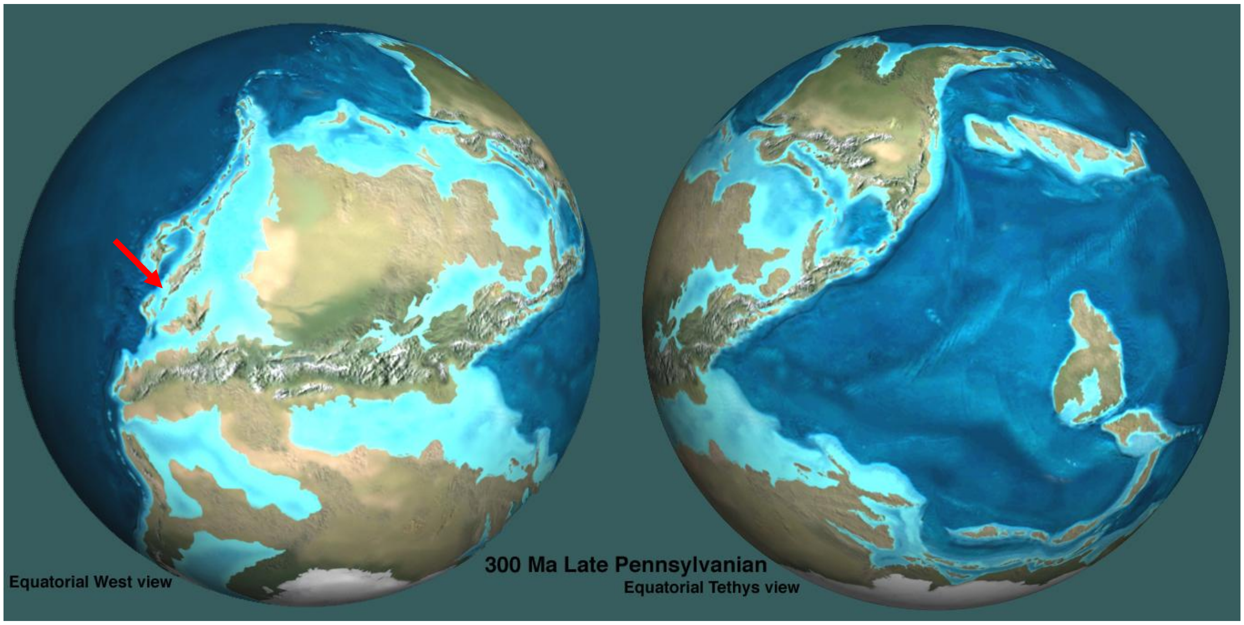

Figure 1. Global Projection of the World 300 Million Years BP. The world's Carboniferous coal swamps developed in equatorial Laurasia, north of the ancestral Appalachians shown just below the equator in left global view. A glacial ice cap covered the South Pole in Gondwanaland. Map courtesy Ron Blakey NAU Geology.

Figure 2. Ganges River Delta, a tidal estuary and modern counterpart to the Mazonia Delta. (Courtesy NASA Earth Observatory.)

Figure 3. *Medullosa noei* a large arborescent seed fern and upland species reaching heights of 30 feet or more. Held by an extensive system of prop roots, Medullosa sported a magnificent spiral crown of fronds bearing large seeds. © The Field Museum.

Figure 4. The flanks of the levee were dotted with tree-like true ferns notably Psaronius, another giant, sometimes 35 feet tall. Beneath the tropical canopy, Arthropleura and millipedes scuttled on the forest floor in the leaf-litter and low herbaceous forest understory dominated by Sphenopterids. © The Field Museum.

Figure 5. A small section of the "Mazon Creek Coal Forest" that was a featured exhibit at Chicago's Field Museum for decades. It is a composite of the many plant species occurring in the Mazon Creek Biota. Shown are *Calamites* on the right, arborescent Lycopsids on the left and center background, herbaceous Sphenopterid forest understory plants in foreground. 307,000,000 years ago, the Illinois region was part of a vast coastal delta wetland complex located in the equatorial tropics. A warm climate and higher levels of oxygen produced lush plant communities of giant ferns and some of the largest insects in earth history. © The Field Museum, #GEO85637c.

Figure 6. Ganges River Delta during monsoon flood stage. Note plumes of sediment-laden fresh water spreading out over denser more saline waters. (Courtesy NASA Earth Observatory.)

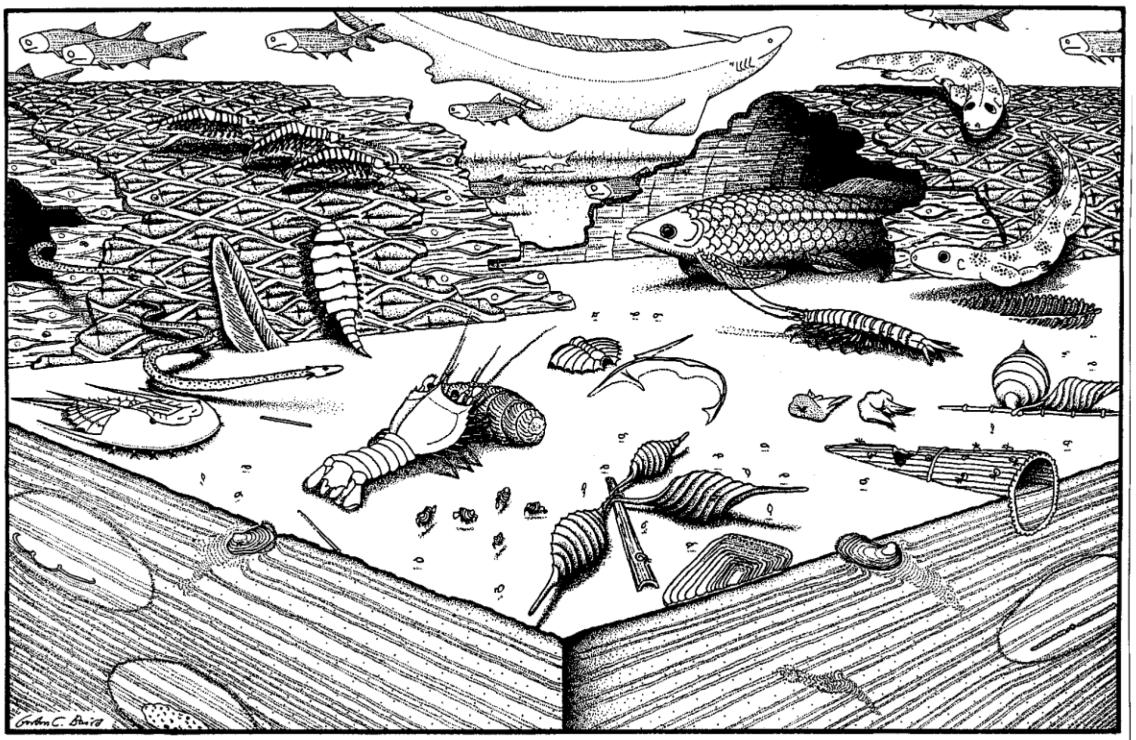

Figure 7a. Diagrammatic reconstruction of “Braidwood Biota.” Nearshore aquatic fresh to brackish water community dominated by crustaceans and clams perished in the sediment-laden flood waters (Braidwood Aquatic Biota). The community was probably not as densely populated with vertebrates as shown. Plant fragments and a few insects and amphibians from upland areas and levees (Braidwood Terrestrial Biota) were carried in with the flood waters and also rapidly buried and preserved. Predators like Xenacanth sharks may have been able to escape the initial floodwaters leaving only coprolites and shed-teeth as evidence of their presence. Sediments document rapid deposition as evidenced by minimal bioturbation (burrows). Tidal flood, ebb and slack water laminations record the changing velocity of the flood waters as affected by tidal currents. Species shown include: a) *Elonichthys peltigerus*. b) Xenacanth shark. c) Terrestrial/aquatic amphibian and predator *Amphibamus grandiceps*. d) lungfish *Conchopoma sp*. e) *Paleocaris typus*, a predator. f) Snake-like aquatic/terrestrial predator *Aonerpeton (Plegothontia) mazonense.* g,h) Lycopod trunk with bark leaf-cushion pattern typical of *Lepidodendron aciculatum*. Lycopods are the dominant plant species making-up the underlying Colchester Coal. i) Euthycarcinoid *Kottixerxes gloriosus;* possibly related to miriapods and insects. j) Transported from higher ground *Macroneuropteris scheuchzeri* is a pinnule (leaflet) from the seed fern *Medullosa noei*. k) Also transported from drier areas of the swamp *Pecopteris sp.* is a pinna (leaf) from the arborescent true fern *Psaronius sp.* l) *Acanthotelson* a syncarid shrimp. m) *Euproops danae* or horseshoe crab, a scavenger or predator. n) Undisturbed molt of *Euproops danae*. o) *Anthracaris gracilis.* p) Spiral coprolite (fossil feces) of shark. q) Xenacanth shark teeth. r) *Paleoxyris sp.* Chondricthyan (shark) egg case(?) attached to plant fragment. s) Stem of *Calamites sp*. encrusted by calcareous polychaete worms *Spirorbis sp*. t) *Ctenodus sp*. a lungfish scale. u) Concostracan *Pemphilimnadiopsis ortoni*, a bivalved crustacean. v) Brackish water bivalve and escape burrow. w) Concretion forming around Euproops. x) Concretion forming around coprolite. y) Concretion forming around *Pecopteris pinna*. Recon. by Gordon C. Baird. From Shabica & Hay, 1997.

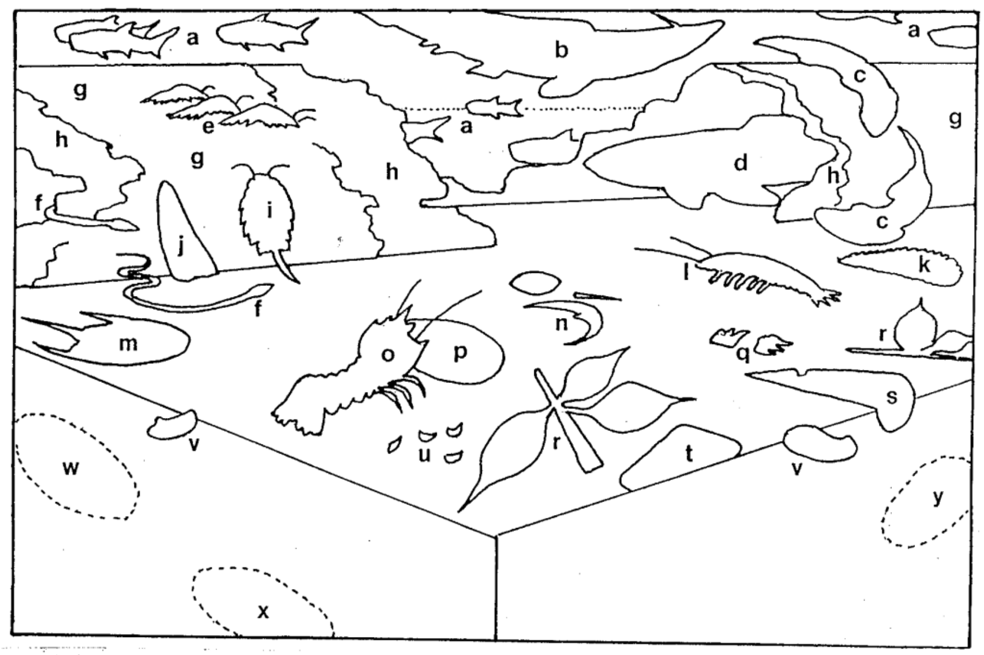

Figure 7b. Key to species illustrated

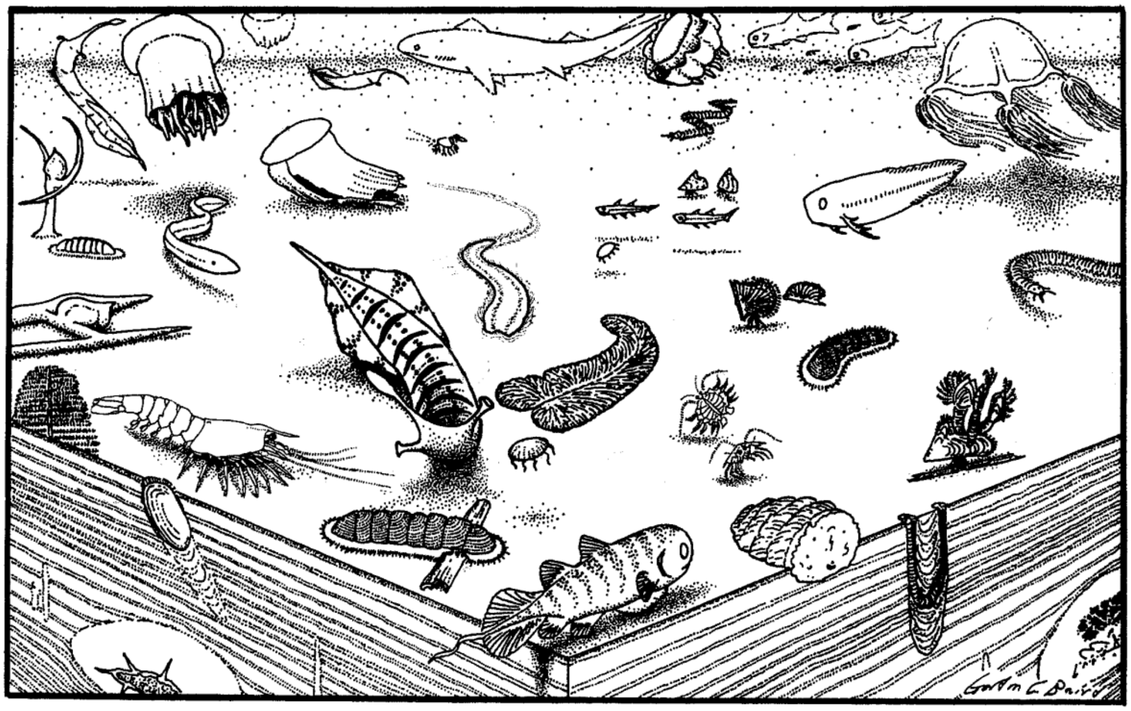

Figure 8a. Diagrammatic composite reconstruction of "Essex Biota." Farther offshore but still estuarine community of marine to brackish organisms not found in Braidwood sites. Tidal flood, ebb and slack water laminations record the changing velocity of the flood waters as affected by tidal currents. Geographic distribution of Essex species is not uniform but varies, likely due to different environmental conditions in the estuary. In some areas, notably the southwest areas of Pit 11, pelagic

and nektonic forms are dominant and rapid deposition of silts and clays are evidenced by minimal bioturbation (burrowing). In other areas, including Braceville, Braidwood and Coal City, a higher level of burrowing is seen with abundant polychete worms and clams, probably the result of a lower sedimentation rate (and thinner flood deposits). Species shown include a) *Essexella asherae* a medusoid jellyfish and predator that comprises about 50% of the Essex Biota. None are found in Braidwood sites, further evidence for a river-born flood event rather than a storm where marine forms would be carried inshore. b) Holothurian *Achistrum sp.* a deposit feeder. c) Chondricthyan (shark) a marine predator. d) Paleoniscoid fish also a marine predator. One specimen died with an Acanthodian in its mouth. e) *Tullimonstrum gregarium,* Illinois State Fossil of uncertain taxonomic affinities, probably a marine predator. f) Cubomedusan *Anthracomedusa turnbulli* a predator. g) *Etacystis communis* possibly a planktonic hydrozoan according to Foster. h) Agnathan or "jawless fish" based on the morphology of the mouth, *Gilpicthys greeni* was probably a parasite. i) *Octomedusa pieckorum* a small medusan and predator. j) *Acanthodes beecheri,* juveniles, some with ostracods found in the gut. k) Myalinid bivalve with byssal attachment. l) Goose neck barnacles *Illilepas damrow,* attached to Myalinid. Both species are filter feeders. m) Agnathan? *Esconichthys apopyris,* possibly a larval form, is the most common vertebrate in the Mazon Creek fauna. n) *Aviculopectin mazonensis* is an epifaunal filter feeding bivalve. o) *Glafurochiton concinnus,* a deposit feeder. p) Shrimp, *Belotelson magister,* a predator/scavenger. q) *Cyclus americanus,* a crustacean and predator. r) Eunicid polychaete *Esconites zelus,* a predator. s) *Pecopteris sp.* pinna, transported by flood waters from the arborescent true fern *Psaronius sp.* t) Also transported from higher ground *Macroneuropteris scheuchzeri* is a pinnule (leaflet) from the seed fern *Medullosa noei.* u) Spiral coprolite (fossil feces) of shark. v) Juvenile coelacanth *Rhabdoderma sp.* with yolk sac. w) *Mazonomya mazonensis* bivalve, an active burrower and filter feeder. x) Worm burrow Diplocraterion. Rapid sedimentation has caused the inhabitant to migrate upwards. y) Protoconcretion in early phase of diagenesis. z) Protoconcretion around arthropod with pyrite, also in early phase of diagenesis. Figure modified after Shabica & Hay, 1997.

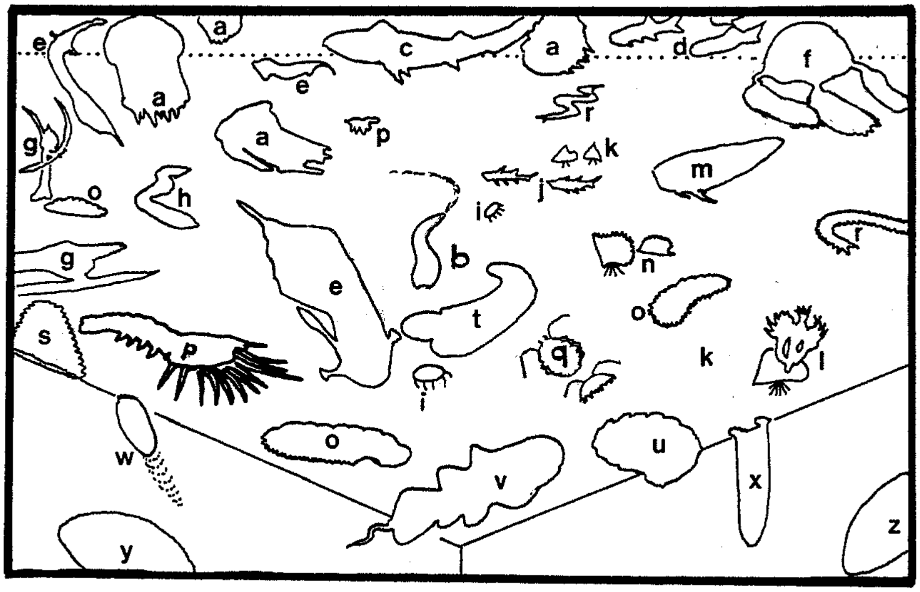

Figure 8b. Key to species illustrated.

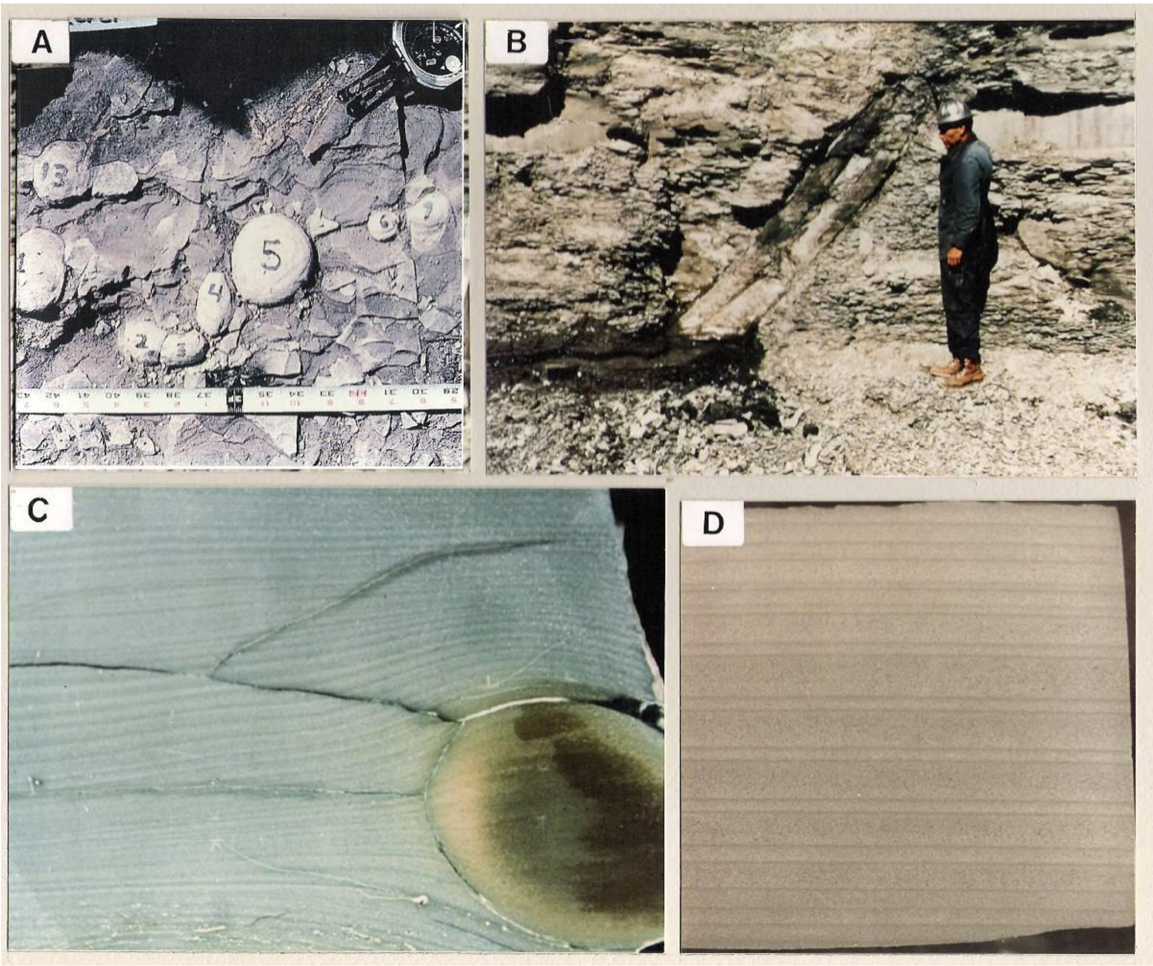

Figure 9. Sediments from the lower levels of the Francis Creek Shale, Peabody Coal Companies Pit 11. A) Concretions in silty mudstones just above the No. 2 Coal at base of headwall. b) One of many lycopod trees observed in the headwall, rooted in No. 2 Coal and buried in place; evidence for rapid deposition. Melbourne (Mack) McKee, Mine Chemist for scale. c) Vertical cross-section through Francis Creek Shale and siderite concretion; shows compaction of sediments around concretion. d) Laminations (rhythmites) in siltstone, evidence for semi-diurnal (twice daily) flood-ebb tide events in Mazonia estuary. Vertical section through Dames and Moore drill core collected near location of Braidwood Nuclear Power Plant at Pit 11 (from Kuecher, 1983). Note: Variations in tidal rhythmites found in the Late Pennsylvanian Hamilton fossil site in Kansas are evidence for seasonal wet-dry cycles (Feldman et al., 1993). Modified after Shabica & Hay, 1997.

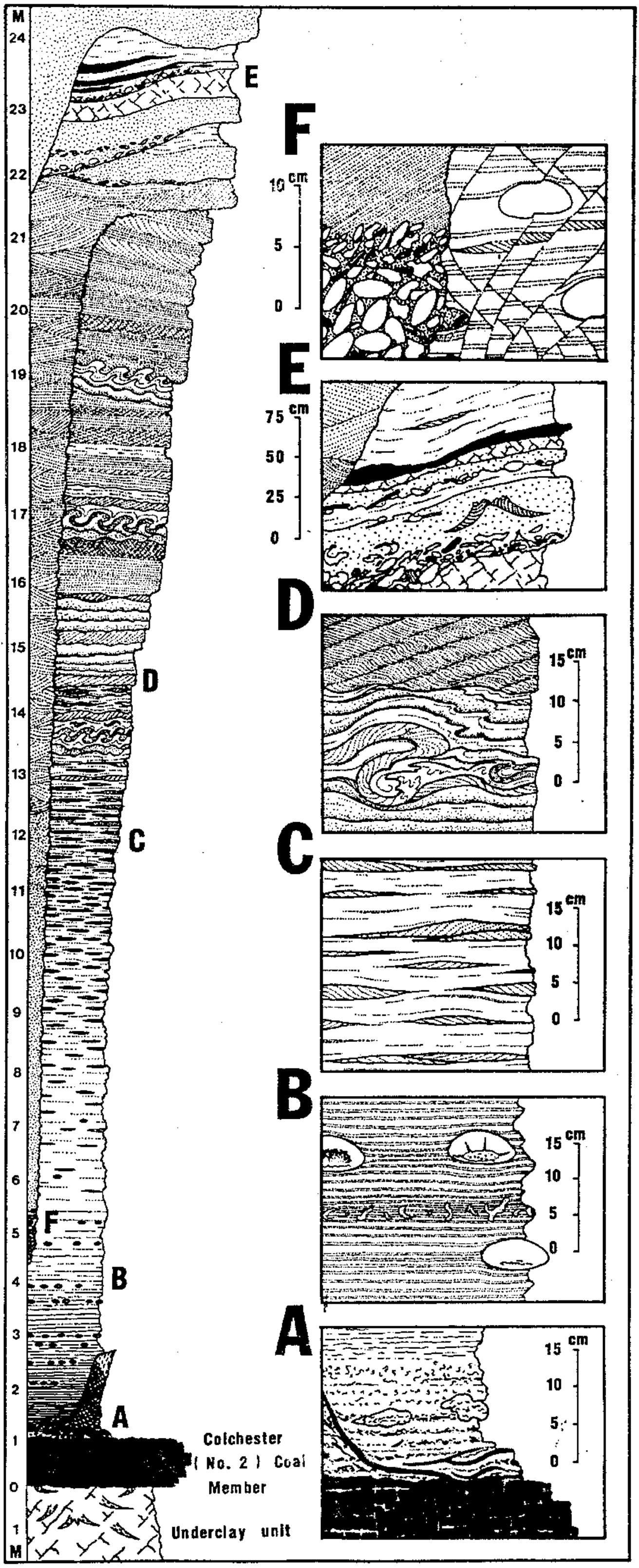

Figure 10. Coarsening upward flood-induced crevasse splay "delta switching" sequence over drowned coal swamp. Diagrammatic stratigraphic section is through Francis Creek Shale Member of the Middle Pennsylvanian Carbondale Formation. The sequence of layers is considered typical of the area near Godley, Illinois and Pit 11. At the base is the Colchester (No. 2 Coal) drowned swamp with rooted Lycopods, overlying an underclay interpreted as a terrestrial soil. A) Transgressive plant debris-rich blocky mudstone over No. 2 Coal. B) Silty mudstone with tidal laminae enclosing Mazon Creek concretions yielding Mazon Creek plants and animals (brackish lagoon). C) Silty mudstone with tidal lenticular bedding, indicating higher velocity currents and sediment load. D) Siltstone and sandstone with convolute bedding and climbing ripples typical of high velocity crevasse splay deposits. E) Channel sandstone cutting underclays and thin coals representative of levee and flood plain deposits. F) Distributary channel bedload accumulation of reworked concretions, underclay clasts, vitrinite shreds and fusain. Shows early diagenesis microfaulting of mudstone cut by channel. From Shabica & Hay, 1997.

Supplemental Figures

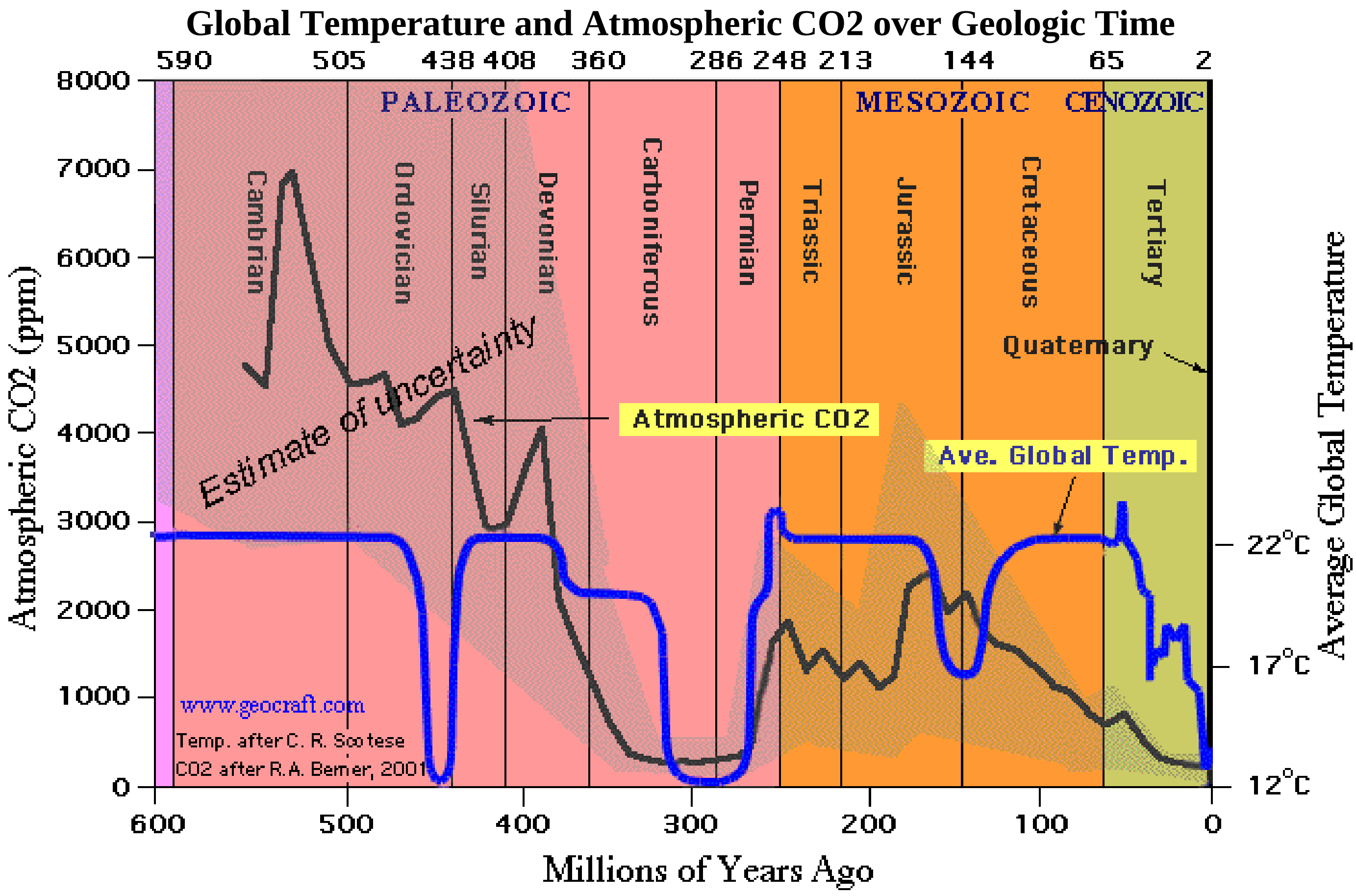

Figure 11. Late Carboniferous to Early Permian Periods along with the Ordovician, included ice ages where global temperatures were as low as they are today (Quaternary Period). The Ordovician was unusual in that atmospheric CO2 concentrations were nearly 12 times higher than today at 4400 ppm. Factors other than atmospheric carbon dioxide may have influenced earth temperatures and global warming. Ref. Monte Hieb.

Figure 12. Carboniferous Forest Fire. Ferns, seed ferns, and giant lycopsids (primitive club mosses with long slender leaves) flourished during the Carboniferous period, from about 360 to 300 million years ago. Some lycopsids, such as the arborescent Sigillaria illustrated here, grew as high as 130 feet. Other tree-like plants included several varieties of Calamites, extinct relatives of modern horsetails. From left to right can be seen an amphibian, a couple millipede-like creatures, Paleopteran (?) winged insects and a scorpion. Artwork by Walter Myers www.arcadiastreet.com.

The Concretion Conundrum: Current Research at Mazon Creek

David Dolak, Columbia College Chicago and **Victoria McCoy**, Yale University

i. Background

The Mazon Creek fossils of north-central Illinois are famous worldwide for the unparalleled window that they provide into the Late Carboniferous environment. The fossils are known not only for their exquisite preservation of plants and soft-bodied organisms but also for the aesthetic appeal of their symmetric concretions. Many scientific studies of the area have focused on understanding the depositional environment of the area and the fossil organisms found in the concretions; less has been published regarding the processes that formed the concretions. While the geochemical understanding of concretion formation has advanced steadily, there remain unanswered questions worth pursuing. This paper will attempt to outline the history and scientific importance of the Mazon Creek concretions, review the current understanding of concretion formation, introduce some still unanswered questions regarding concretion formation, and outline options for continued research in this field.

ii. Acknowledgements

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I. Introduction

The Mazon Creek *Lagerstätte* records a comprehensive record of terrestrial, swamp, and near shore plants and animals, and is especially famous for the quality of soft-bodied preservation of organisms such as jellyfish and worms which are not typically preserved as fossils. At least 200 species of plants (Wittry, 2006) and 320 species of animals (Niteki, 1979) many of which are unique to the area have been identified, making Mazon Creek the most complete record of late Paleozoic shallow brackish to terrestrial life (Selden & Nudds, 2004). Many species are unique to the area. Indeed, more jellyfish are known from the various collecting locales than are known from any other fossils site worldwide (Sroka, 1997). Perhaps the best-known animal from the deposit is the Tully Monster (*Tullimonstrum gregarium*) a problematic soft-bodied organism of undetermined affinity that is now famous as the State Fossil of Illinois. Collectively, the Mazon Creek Fossil Beds were designated as a National Historic Landmark in 2002 (NPS, 2012).

The Mazon Creek fossils have been collected and studied by both amateurs and professionals since the 1840s. Many of the most important scientists of early American paleontology, including Lesquereux, Cope, Scudder, and Worthen have studied the area or described specimens collected here (Nitecki, 1979). And less usual among fossil sites, amateur fossil enthusiasts also have made, and continue to make significant scientific contributions to the understanding of the late Carboniferous flora and fauna found in the Mazon Creek fossils. At least 70 animal type species are named for collectors who have worked the exposures (Hay and Kruty, 1997). Significant collections of the fossils are housed at the Field Museum in Chicago, Smithsonian Institution, and the Illinois State Museum. Mazon Creek fossils are much-sought after by rock hounds throughout the world and are common sale items in the fossil marketplace.

A major factor contributing to the continued interest in Mazon Creek fossils is their unique method of preservation as concretionary molds. Although other fossil locales, especially in Carboniferous strata, are known to contain fossiliferous concretions, it is in rare company as arguably the best known and studied of the world's major recognized concretionary *Konzervat Lagerstätten* (including the Cretaceous Santana Fm. of Brazil and the Wenlock Series in England). For the Mazon Creek fossils, ironstone concretions, cemented by siderite are the exclusive means of the extraordinary preservation and the detailed fossil record.

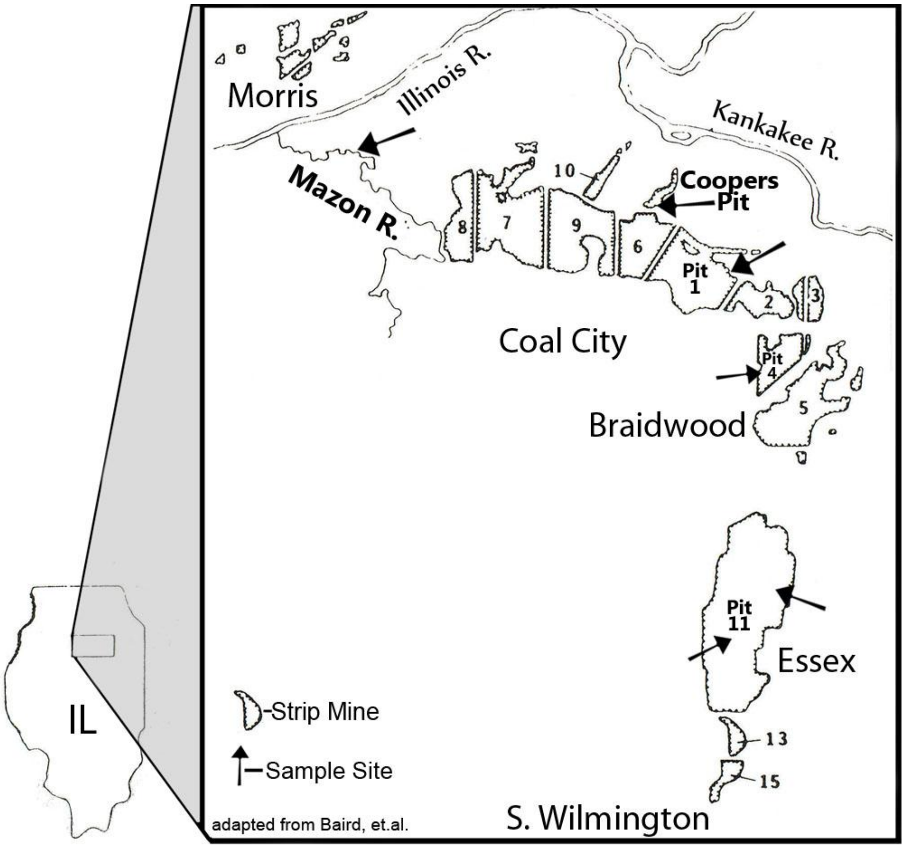
In the past 150+ years, many millions of concretions have been unearthed. Collecting has been done at a limited number of *in situ* sites along the Mazon Creek proper, but vastly more concretions have been picked from the spoil heaps of the numerous coal shaft mines and especially, the vast open pit coal mines that were active in the area from the 1870s through 1976. One well-known collector, George Langford, began his fossiling career as an amateur exploring the outcrops as exposed in coal mine tailings piles, and eventually became the curator of Paleobotany at the Field Museum. He estimated that in the summer of 1938 alone, he had examined over *5 million concretions*, collecting 200,000 of them which eventually yielded at least 20,000 high quality fossil specimens (Langford, 1964). There have been dozens of other collectors working the area continuing to the present, continually adding to the number of concretions collected. Truly astounding numbers of concretions have been found in the five counties that contain the fossil exposures.

Over 250 scientific papers have been published on the Mazon Creek fossils (Richardson 1997). While much effort has gone into documenting the wonderful flora and fauna record, the actual method of concretions formation is less studied. Even a cursory examination of a medium sample size of representative concretions reveals great variety in concretion composition, fossil content, specimen orientation, and preservation quality both across, and within individual Mazon Creek fossil sites. Early observers, impressed by the fine internal preservation and the symmetric weathering of the outer concretion nodule hypothesized rapid burial and mineral encapsulation around an organic nucleus with continued concentric growth outward from the nucleus (Worthen, 1870; Langford 1958). The current more nuanced understanding of concretion growth will be discussed later in this study.

While additional work over the past several decades based on both laboratory and field studies at other concretion sites has refined the understanding of the geochemical mechanisms likely to promote this type of fossil preservation, many questions remained unanswered about the formation of the ironstone concretions. In this study, the authors will introduce some of these questions and describe ongoing research to better illuminate this aspect of the Mazon Creek fossils.

II. Geographic Setting

The area that yields the Mazon Creek fossils ranges along a 60-mile southeast trending arc from the city of Ottawa on the west to just south of Braidwood on the east in north central Illinois. The vast majority of fossils are found in the approximate 100 sq. mile area from Morris to South Wilmington, the focus area of the present study. See Figure 1. The fossil area straddles the upper Illinois River to its confluence with the Kankakee River at the eastern margin and is of low relief with an elevation range of 525-590 feet above sea level. The Mazon River itself flows north through the study area, discharging into the Illinois River near Morris. Of approximately 100 fossil producing sites in the area, perhaps one dozen natural fossiliferous outcrop exposures lie along the lower 8 miles of the Mazon River before its confluence with the Illinois.



adapted from Baird, et.al.

Figure 1 Mazon Creek Study Area

The vast majority of the concretions collected have come from the numerous spoil pile dumps associated with the earlier period of shaft and surface coal mining in Northern Illinois. The bulk of spoil pile surface area is associated with the open-pit stripping operations (areal coverage of 20-25 square miles) that dominated coal extraction from approximately 1920 until

1976. Mines were typically numbered in consecutive order as they were opened, with Pits #1 - 10 operating first along the northern margin of the area and ceasing operations before 1950 with the later, vast complex of Pits #11 – 15 operating from around that date until 1976. In the collecting literature, fossil locations are typically identified by pit number, or in some cases, a name designation.

As the era of active outcrop exposure of the fossil beds is but a memory, collecting sites and opportunities are greatly reduced. The days when hundreds of thousands, even millions, of concretions could be examined by any one individual, even over many years, let alone in one season as noted above, are long in the past. The older, northern tier of sites is long overgrown and privately owned; public collecting is restricted to the former Pit 11 which is managed by the State of Illinois Department of Natural Resources. And even if ground cover can be removed and access granted, one important collecting resource, the exposed strata along the various mine headwalls is now submerged by water. Only a handful of small *in situ* strata outcrops remain visible, on restricted private lands along the Mazon River.

This study focuses on concretions collected by the authors over the 15-year period from 1997 to the present. During this period approximately 25,000 concretions were collected from spoil piles in ten of the remnant strip pits. For the present study, data is presented on only 12% of these concretions. Many other concretions were collected and opened before the census project began. Another 20% or so remain to be measured. The bulk of concretions studied are from Pits #1, #4, #11 and the ”Coopers Pit,” and several sites along the Mazon River, including the well-known “Bensons Farm” site. See Figures 2, 3, and 4.

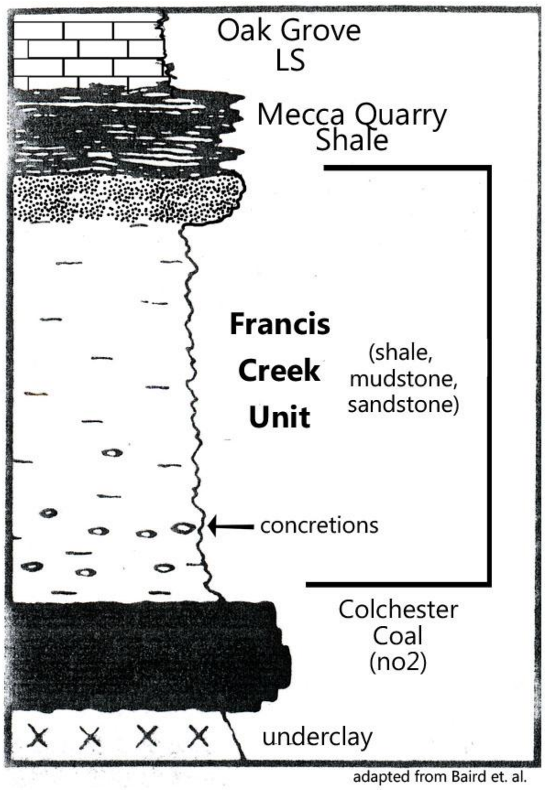
Figure 2 MZ River - Bensons Farm

Figure 3   MZ River strata - White Tie Rd.

Figure 4 Coopers Pit Spoil Pile

III. Geologic Setting

The Mazon Creek fossils are found in the Francis Creek Shale (FCS), a unit of the Carbondale Formation, of Westphalian D age of the later Carboniferous. Dates ascribed to the unit range from 296 MA (Baird, G., et al., 1985) to 307 MA (Wittry, 2006) and The unit rests above the Colchester #2 coal, the most widespread coal bed in the world, which underlies tens of thousands of square miles of Indiana, Illinois, Missouri, and Oklahoma (Baird, 1997c, Shabica, 1971). Due to the presence of numerous distinct bands of coal, both above and below this unit, the term “Coal Measures” is commonly applied to this time during the Carboniferous. The unit encompasses much of northern Illinois and varies in thickness from a thin facies unit of less than 3 ft. (1 m.) along the western margins (outside of the study area), gradually thickening to a maximum of 80 ft. (25 m) thick facies unit at Pit 11. It is generally interpreted that the FCS was deposited in a deltaic to near shore bay/estuary environment. Stratigraphically, it is capped by the Mecca Quarry Shale and the Oak Creek Limestone, which are Carboniferous formations deposited under marine conditions. These units are not present in the study area; here the Francis Creek is truncated by the uncomfortable contact with Quaternary glacial deposits. Beneath the coal is a Carboniferous underclay unit. The observed lithology represents a section of a larger *cyclothem*, which is typically a sequential ten-layer column of strata deposited during the fluctuating water levels and sediments sources typical of the active margin between a delta and near shore environment (Wright, 1979). Sections of equivalent nature to the FCS overlie the Colchester #2 Coal in adjacent states but these are not as concretion-rich as those in the Mazon Creek area (Baird, 1997a). See Figure 5.



adapted from Baird et. al.

Figure 5 Site Lithology

In actuality, the Francis Creek can only marginally be described as shale; through its vertical sequence in the study area can be found mudstone, siltstone, sandstone, and conglomerate deposits. The mix between these various clastics varies both within and across individual sites. Clearly, the unit represents more than one depositional environment (Shabica, 1971). The ironstone concretions that yield Mazon Creek fossils are only found in the thick facies deposits that exceed 50 meters in thickness and are found typically in the 20 ft. (up to 5 m) of strata above the coal (Baird, et al., 1985).

A typical section of the unit in the study area is given in Figure 5. Concretions are typically embedded specific zones or horizons (Baird, et al., 1985). Depending on the site, this lower section rises from a basal blocky or laminated mudstone, grading upwards to siltstone and/or fissile shale higher up in the concretion bearing horizon. Poorly preserved plant compression fossils are locally common in some of these lower sections, but this matrix alone does not preserve the soft-bodied organisms found in concretions. The laminations in this horizon are consistent with fine silt deposition resulting from diurnal and monthly tidal inputs, although there remain questions on the timing of concretion formation if this were the case (Baird, et al., 1985). Sandstone/conglomerate clastic wedges or lenses may finger through this zone, and often the unit is capped by up to several meters of fine sandstone. The sandstone cap rock is prominent along the lower section of the Mazon River, notably at the Bensons Farm site. Re-deposited concretions can often be found in the conglomerate. The re-worked concretions are not part of the current study.

While the same floral species are found throughout the area, the Mazon Creek animal fossils are separated into two distinct faunal groups. The Braidwood Association represents the plants and animals associated with the primarily fresh water environments at the delta margin to upland. The Essex Association comprises washed-in plants and the fauna that lived in the brackish bay/estuary environments (Baird, 1997a). Although the thin facies of the FCS in the west contain marine fossils, the ironstone concretions in the study area do not contain fully marine species.

Given the vertically and laterally diverse nature of the Francis Creek Shale through the study area, inferred depositional events and sequences are site specific and have been interpreted in detail in a number of studies (Shabica, 1971, Baird, 1997c). For this study, the following general depositional regime is representative of the regional conditions.

1) During the Upper Carboniferous, the mid-continent of early Pangaea (the area that includes the present-day Midwest) was astride the equator, subject to a wet, tropical climate.
2) The study area was at the southern/southeastern margin of a deltaic system draining upland areas to the north and east. Progressing south and west from this continually advancing/retreating boundary, was a tidal bay/estuary grading into a fully marine environment. Many areas of the delta complex may have been periodically isolated by levees, providing quiet water brackish habitats.
3) A lycopod-dominant swamp forest peat, precursor to the #2 Coal was deposited then inundated by a brackish estuary. Lower mud-dominant margins of the FCS appear to record the regular tidal fluctuations at this stage (Baird, 1997c).
4) Pro-delta and delta deposits of mud and silt were deposited over the estuary muds, perhaps reworking them in some locations.
5) Periodic catastrophic flood events caused crevasse-splay and channel deposits through and/or over the silts and muds. These events were likely localized although the entire area centered on present Pit 11 is interpreted as a large crevasse-spay (Shabica 1971). This is also the area with the thickest section of FCS. The total FCS unit was deposited quickly in a geologic sense, perhaps in as little as 15 - 50 years (Selden & Nudds, 2004). Generally there is little bioturbation of the sediments, again indicating rapid burial, although some of the southern strip pits, #13 and #15 in particular do contain appreciable numbers of concretions with indications of scavenger burrow markings (Baird,1997b).

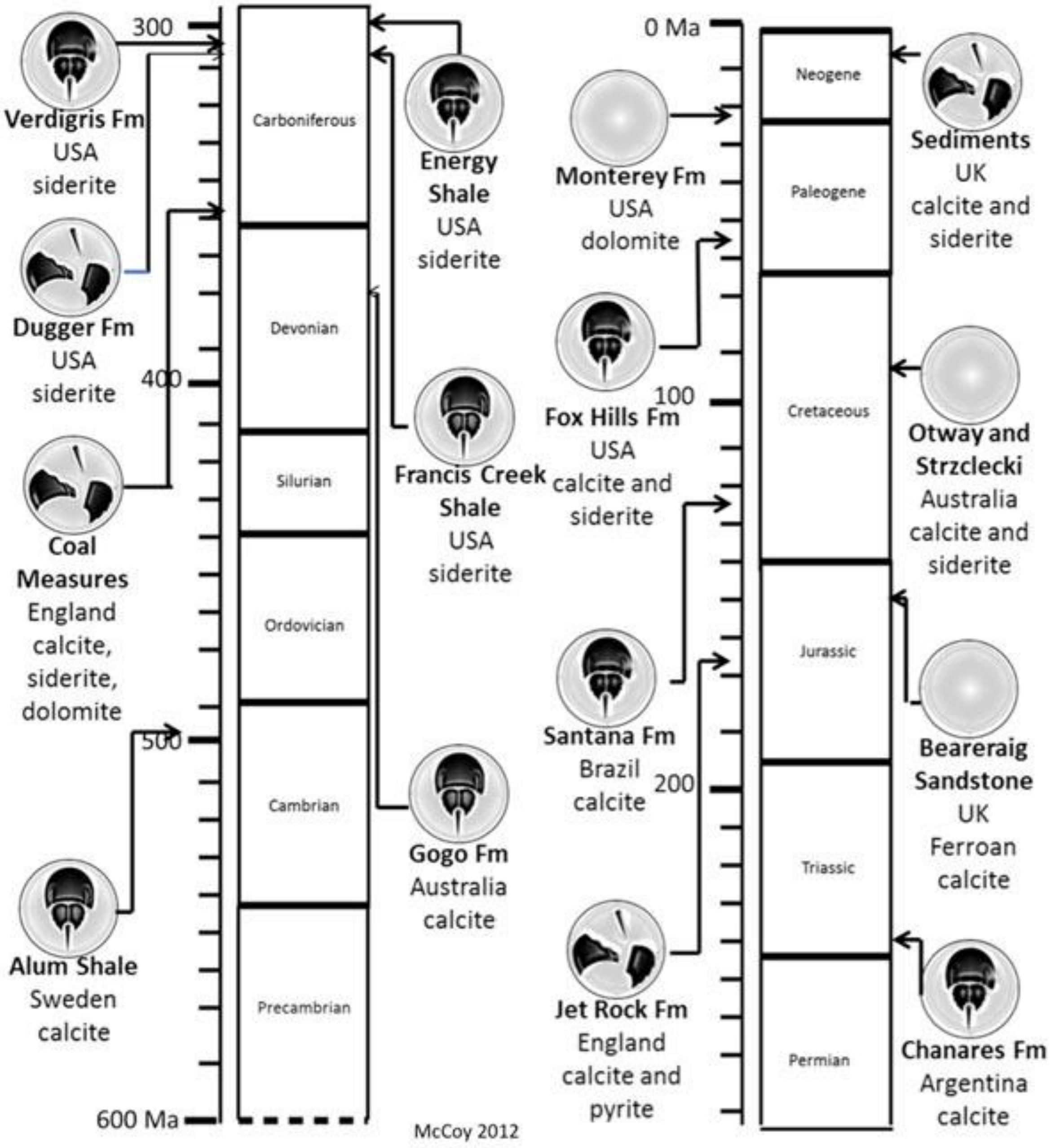
6) Plants and terrestrial animals of the Braidwood Fauna found in concretions were likely transported from delta border and upland areas during deltaic discharge events and quickly buried. In-washed plants and animals of the Essex Fauna that actually lived in the estuary or bay regimes were also buried by the discharge events, and perhaps the earlier tidal inputs.
7) Eventually, the area was invaded by the sea.
8) Any subsequent deposits of Paleozoic through late Cenozoic strata were eroded during Quaternary glaciations.

IV. Concretions in the Fossil Record

Concretions, literally “to grow together,” are typically ball structures that are self-contained and somewhat symmetric, formed by the preferential mineral precipitation (cementation) of deposited sediments. The important distinction between concretions and other geological nodular structures are that they are not replacement structures (like geodes), but are self-contained structures cemented within existing sediment. Typically, they accrete around a nucleus, which serves as to initiate growth. However, many concretions have no obvious nuclei. The cementation may also be initiated by microbial action, perhaps working around a diffuse organic source of nucleation. But it is reasonable to assume that something must cause the geochemical change from the ambient conditions in the surrounding sediment to create the localized changes that result in the concretionary enclosure.

Although many minerals can, in theory, precipitate as the cement (e.g. phosphate, sulfide) by far the most common concretions, especially those known for containing fossils, are composed of carbonates, especially calcite ($CaCO_3$) or siderite ($FeCO_3$). The Mazon Creek fossil concretions are primarily siderite (ironstone), sometimes containing pyrite/marcasite (FeS_2). Concretionary fossil preservation is known throughout the geological record. See Figure 6. Especially well-known sideritic fossiliferous concretion sites date from the Carboniferous (Allison & Briggs, 1991). Of these, the Mazon Creek fossils are among the best known and most studied.

Concretions often contain well-preserved fossils because the rapid (geologically at least) mineral precipitation serves to harden the sediments such that they are only minimally compacted by subsequent sedimentation, which fosters the preservation of even soft tissue structures prior to eventual organic degradation (Maisey, 1991).



Concretions through time: A selection of concretions sites and their approximate stratigraphic position, illustrating the ubiquity of concretions through geologic history. An empty concretions indicates no reported fossils, a concretion with a disarticulated horseshoe crab indicates poor fossils, and a concretion with an articulated horseshoe crab indicates exceptional fossil preservation.

Figure 6 Concretions in the fossil record

V. Concretions at Mazon Creek

High quality fossil preservation is the result of factors occurring sequentially: 1) isolation of the organisms remains from predation, scavenging, and rapid oxidative breakdown, most commonly via rapid burial; and 2) initiation of the delicate chemical balance between decay and mineralization The first of these factors essentially has a threshold effect: the organism is either safely buried away from disturbance in which case it can become a fossil, or it is exposed to disturbance, in which case it is very unlikely to become a fossil. Variation in the second factor leads to a continuum of fossil preservations from too much decay – the organism decayed away and did not become a fossil – to too much mineralization, with ideal exceptional fossilization occurring in the midpoint of this continuum. Intuition would suggest that more mineralization would equal better fossils, but in fact excessive mineralization which too-quickly outstrips decay leads to featureless mineral blobs lacking much of the organism's original detail. The best-preserved fossils are formed when mineralization of each structure is initiated and controlled by the chemical reactions involved in the decay of that structure. Typically, the finer the particle size of the sediment matrix (e.g. silt/clay vs. sand), the better the preservation of delicate features. The Mazon Creek concretions typically preserve fossils as compacted molds with distinct dorsal and ventral features (Schopf, 1979).

Early on, the apparent growth of the concretions outward from the fossil was recognized, leading to the hypothesis that bacterial mitigation causing the initial nucleation to harden the sediments much "like plaster of Paris, could hold the plant in its original state until the silt was set" (Langford, 1958). The concentric layering often noted in weathered specimens led to a concretion formation model that implied continued outward growth (Worthen, 1870). The more modern interpretation implies rapid fixing of the specimen, perhaps within weeks, within a gelatinous carbonate mass across the entire concretion (Fischer, et al., 1998). The mass then hardened rapidly enough to minimize further sediment compaction within the concretion, even as surrounding sediments were compacted (Schopf, 1979). The noted concentric peeling during weathering is likely caused by differential degradation across the finely laminar strata in which many concretions formed.

Although the dominant mineral cement is siderite, the concretions often contain other minerals that fill in spaces in the concretion. Except for pyrite, which most likely precipitated first due to the assumed sequence of microbial-mitigated chemical reactions in the sediments, other minerals migrated into the concretions as secondary deposits. These include sphalerite, calcite, kaolin, and rarely, galena.

The typical Mazon Creek ironstone concretion is actually slightly asymmetric, flattened on the downward surface, likely due to compressional loading from accumulating sediments (Baird, 1997b). Up to 80% of the central portion of high-quality ironstone concretions is siderite cement. The spherical/ovoid concretions range in size from less than one inch in diameter to bowling balls-size objects greater than one foot (30 cm) across weighing twenty or more pounds. The dominant matrix for most concretions is clay and silt, the primary components of the lower 15-20 ft. of the FCS. Sand matrix concretions are uncommon. Calcite concretions are rare. The authors have found only a handful of these.

Although relative fossil species abundance distributions have appeared in several studies, the authors could find only one census of Mazon Creek concretions that enumerates information about overall concretion fossils abundance vs. non-fossiliferous concretions ("duds") between the two paleofaunal groups in the area (Baird and Anderson, 1997). A summary of these results appears below in Table #1. The sample size is large, nearly 300,000 concretions sampled across nearly 100 sites. Most of the data was collected in the 1970s through the early 1980s when the last of the strip mines in the Essex Association were either still in operation, or had only recently closed, providing large areas of still eroding deposits with freshly exposed concretions in which to collect large numbers of specimens. Thus, the bulk of specimens in the census are from this southern-tier grouping. As the northern tier of strip and shaft mines were closed before 1950, and were, by the 1970s heavily overgrow with vegetation, or off limits due to development or access issues, fewer concretions in the census are from the Braidwood Association. Sites along the Mazon River are relatively small in area compared with the large areas covered by spoil piles.

Corresponding data from two representative sites collected since the year 2000 appears in Table 2. Although from a much smaller sample size, this data on fossil abundance vs. duds mirrors closely the earlier data. From the data, it is clear that the percentage of fossil-bearing concretions at Braidwood sites is much greater than at Essex locations. No reason for the reversal in fossil abundance between the two faunal associations is given in the literature. However, the larger, better preserved floral specimens are found in the Braidwood grouping, presumable because of a shorter transport distance from source to burial in the freshwater deposit.

Table 3 data reflects the authors' initial effort to conduct a more detailed delineation of the variety of concretion matrix types (Braidwood Fauna). Although no detailed statistical analysis has yet been done on the data, the higher percentage of fossiliferous concretions (70% vs. 60%) in this newer data may simply reflect the inclusion of indeterminate "blobs" as fossils. The earlier study does not segregate blobs in this grouping and it is not clear as to how they were recorded in the earlier tabulation.

The further discrimination of concretion abundance vs. type as shown in the later data, shows that over 90% of the concretions are comprised of the fine-grained silt/clay matrix common in the lower margins of the FCS. Only 8% of the concretions have a larger clastic matrix, commonly micaceous sandstone. Of particular note is that the fine-grained ironstone concretions are composed almost equally of those with a siderite-dominant tan-colored matrix and concretions with a dark-colored matrix, presumable containing a greater amount of pyrite as these concretions are often observed to have free pyrite associated with the fossil. The limited data on the respective densities of the two matrices indicate the dark matrix is slightly more dense (3.4 g/cc vs. 3.25 g/cc) than the tan matrix. This would be consistent with a greater pyrite concentration (density: 5 g/cc) than in the more pure siderite (density: 3.5 – 4 g/cc) cement matrix. The bulk density of the surrounding shale is 2.42 g/cc (Woodland & Stenstrum, 1979). A larger sampling of representative densities combined with laboratory analysis of the mineral species in the two concretion types are important areas for further study (see Section VII).

Table 1.
Mazon Creek Concretions/Fossil Abundance
(adapted from Baird & Anderson, 1997)

Concretion #s	**Braidwood Association**	**Essex Association**
Total	59,974	229,979
Fossiliferous	34,192 (57%)	85,180 (37%)
Duds (no discernable fossils)	22,802 (38%)	144,799 (63%)

Table 2.
Mazon Creek Concretions/Fossil Abundance
(Dolak, unpublished 2011)

(2001-02 season)

Concretion #s	**Braidwood Association (Coopers Pit)**	**Essex Association (Pit 11)**
Total	778	990
Fossiliferous	473 (61%)	410 (41%)
Duds (no discernable fossils)	305 (39%)	580 (59%)

Table 3.
Mazon Creek Concretion Matrix Distribution
Braidwood Association
(Dolak, unpublished 2011)

(2002-03 season: Coopers Pit site)

Concretion #s	**All Matricies**	**Gray-Tan Matrix - siderite**	**Black Matrix – pyrite rich**	**Sand Matrix - siderite**	**Calcite**
Total concretions	**1,200**	**652 (55%)**	**540 (45%)**	**8 (<1%)**	**3 (<0.3%)**
Fossiliferous	**846 (70%)**	**460 (71%)**	**382 (71%)**	**4 (50%)**	**3**
Single fossil	*477 (56%)*	*217 (47%)*	*260 (68%)*	*3 (37%)*	*1*
blob	*63 (<4%)*	*33 (7%)*	*30 (8%)*	*1 (13%)*	
Diffuse mash	*302 (35%)*	*210 (46%)*	*92 (24%)*	*0*	*2*
Duds (no discernable fossils)	**354 (30%)**	**192 (29%)**	**158 (29%)**	**4 (50%)**	**0**

More detailed quantification of variation in concretion types is a primary goal of this study. Examples of the wide variety of the basic concretion types commonly found in the Mazon Creek deposit are given in the Figures 7 – 18 (Scale bars to 10 cm). See Section VIII for more details.

Figure 7 Concretion Shapes

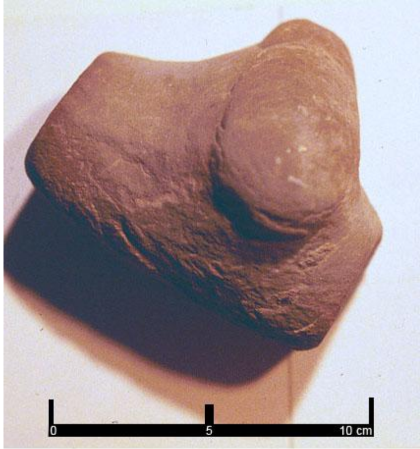


Figure 8 Twinned Concretion

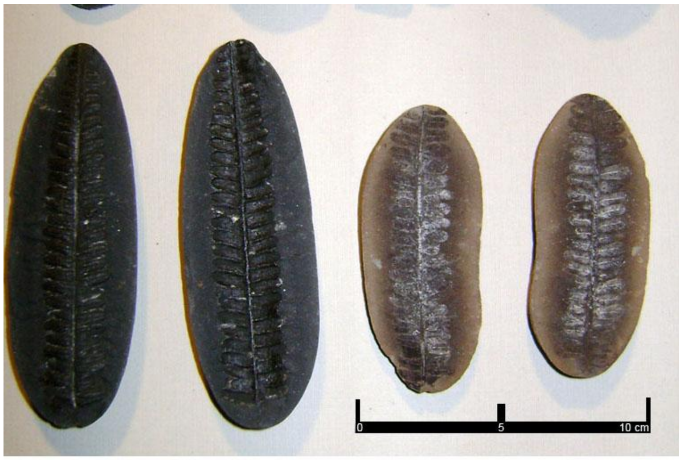


Figure 9   Black Matrix (l) vs. tan matrix (r)

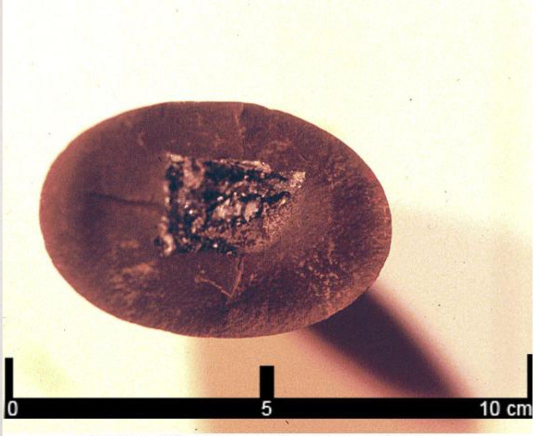


Figure 10 Cross Section of Stem

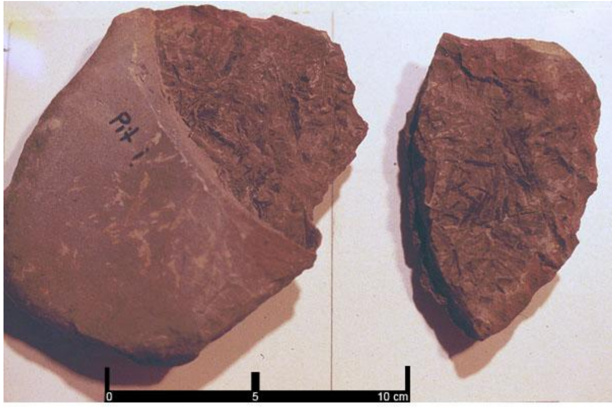


Figure 11 Plant Mash Concretion

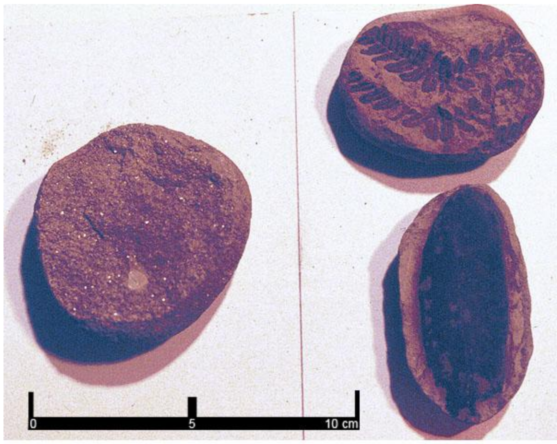


Figure 12 Sandstone matrix Concretions.

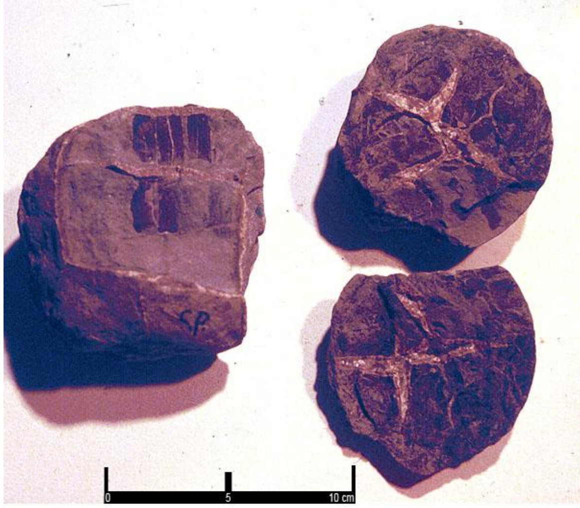


Figure 13 Calcite concretions

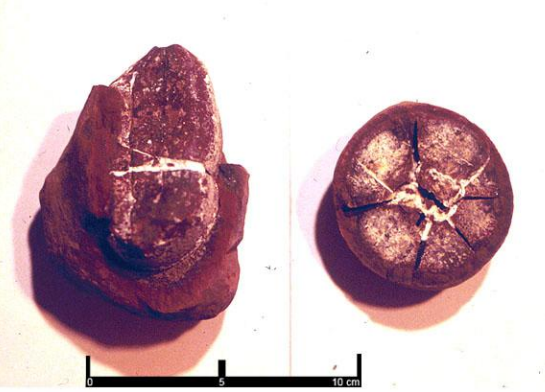


Figure 14 Cracked and infilled concretions.

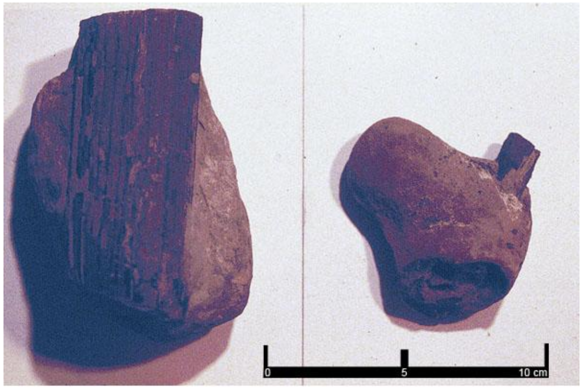


Figure 15 Fossil-through concretions

Figure 16 Pyrite halo around fossil

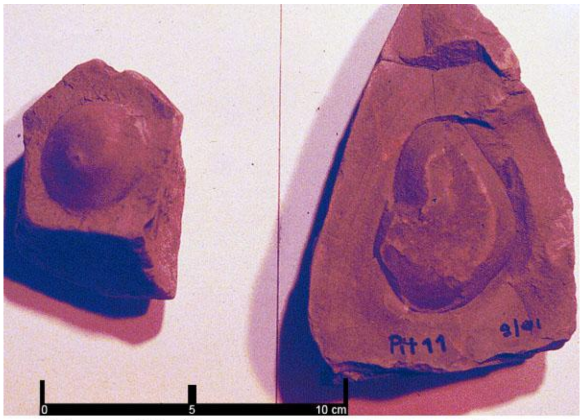


Figure 17 Non-concretion ball growths

Figure 18 Irregular “upwelled” concretions

VI. Concretion Formation Processes

Precipitating carbonates in the shape known as a concretion, requires a suite of suitable factors, such as proper particle size distribution, the mix of other chemical species (e.g. Fe, Mg, Ca, CO_2, SO_4), the pH and redox (Eh) environment, isolation from physical disturbance, as well as a mechanism for developing a localized super saturation of carbonate and a suitable nucleus that can trigger carbonate precipitation. At Mazon Creek, the exquisite preservation and non-compaction of the fossils argues for rapid burial and concretion set-up (Woodland & Stenstrom, 1979; Baird et. al., 1985). The boundary delta/offshore, fresh-to-brackish water, and rich clastic depositional environment would provide a wide range of raw material in which concretions could be formed. The dynamic nature of the rapid sedimentation of the system would provide rapid burial of distinct environments across a wide area.

Three models of carbonate concretion formation have been proposed: the Equilibrium model, the Local Equilibrium model, and the Fluid Mixing model (see Raiswell & Fischer, 2000 for a thorough review of these models). See Figure 19.

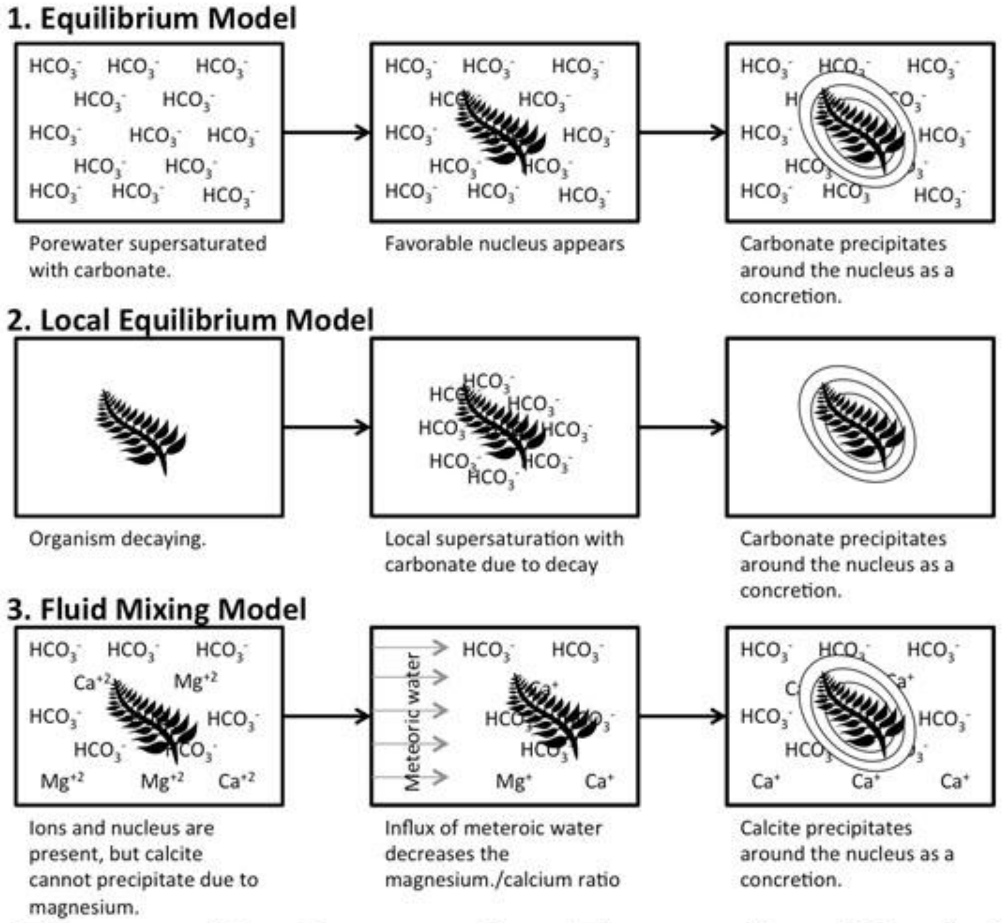


Figure 19 Concretion Formation Models

The key idea of the equilibrium model is that a pre-existing super saturation of carbonate within the sediment pore water which, when confronted with a favorable nucleus, will drive carbonate precipitation to restore a more stable saturation in the system as a whole. Such a nucleus can be organic debris from decaying organisms, a localized point of high microbe concentration, or even shelly debris (Raiswell, 1976). Ideally, the most favorable nuclei (e.g. decaying organisms or spots of high microbial activity, which facilitate concretion formation through the microbial activity) will be the first nuclei used, followed by less favorable nuclei such as shelly debris (Raiswell, 1976). The equilibrium model seems theoretically sound, but has yet to be experimentally verified. In particular, observations of modern pore waters supersaturated with carbonate do not lead to carbonate precipitation in observable parts of the sediment, which suggests that this mechanism requires great depths or great lengths of time to result in concretion formation (Coleman & Raiswell, 1995; Raiswell and Fisher, 2000).

The local equilibrium model proposes a mechanism for concretion formation that could operate in the absence of pre-existing carbonate super saturation. In this case, microbial activity provides the necessary carbonate super saturation in a localized microenvironment around the center of microbial activity (Coleman et al., 1993). The possible nuclei again include decaying organisms and this model would likely require sediment with a heterogeneous distribution of microbes. However, unlike the equilibrium model, this mechanism would require large amounts of organic material be present, which suggests it occurs at shallow depths and over short periods of time, but experiments have also failed to grow concretions using this mechanism (Raiswell & Fisher, 2000).

Each of these two models involves essentially the same chemical growth mechanism, but occur at opposite ends of the carbonate saturation gradient. However, only rarely would either of these extremes actually occur; most environments likely fall somewhere in between. Thus, concretion formation may occur through some intermediate model in which the carbonate naturally present in the pore water needs to be augmented through carbonate produced by decay in order for a concretion to form (Raiswell, 1976). Furthermore, carbonate saturation may not be constant throughout an environment or through time, so both of these mechanisms may contribute to the growth of different concretions at one locality, or even to different growth phases in the same concretion (Raiswell & Fisher, 2000).

There are four factors to consider when assessing these two models for a site of concretion formation such as Mazon Creek: timing of formation; depth of formation, possible nuclei; and initial dissolved carbonate gradients.

The best evidence for the timing of concretion formation at Mazon Creek is the exceptionally well-preserved fossils, including intact polychaetes (Johnson & Richardson, 1966). Polychaetes have been shown experimentally to decay almost completely (leaving only the jaws) in approximately four days (Briggs et al., 1993) suggesting that the concretions at least began to form within that time period, in order to inhibit decay. This matches best with the short time to formation proposed in the local equilibrium model.

There is little analysis in the literature of the depth of formation of the Mazon Creek concretions. However, as previously described, the depositional environment of the Francis Creek Shale is well understood to be a combination of shoreline precession and recession along a deltaic and open water environment suggestive of moderate to rapid sedimentation with the concretions forming at depths likely similar to the final observed strata thickness. Thus, the Mazon Creek concretions were most likely formed at depths of (< 25 meters) which again best matches the local equilibrium model.

Cleary, many Mazon creek concretions nucleated around organic debris, often preserved as fossils, or around inorganic nucleation debris, such as shell parts. Still, large numbers of concretions appear devoid of any nucleus. Regarding these empty concretions, the local equilibrium model would predict concretionary initiation around random areas of high microbial activity. Of course this begs the question as to why the localized concentration of microbes if not due to some organic substrate? In the literature, such "dud" concretions are often simply assumed to have formed around fossil nuclei, and the happenstance of opening the concretion merely did not capture the location of the fossil (Baird, 1985). It is a goal of this study to seek a more robust explanation for the apparently empty concretions.

Initial carbonate saturation is difficult to determine, as the literature is limited in this data. One source that describes CO_2 conditions (as an analogue for carbonate) in the current Francis Creek Shale indicates a likely enrichment in carbonate in *in situ* concretions by a factor of 3x compared with the surrounding shale (14% as CO_2 in concretions vs. 5% CO_2 in the shale) (Feliciano, 1924). It is likely that the sediments at the time of deposition were not saturated with dissolved carbonate species because although there are limited compression plant fossils, poorly preserved in the friable shale, shelly organisms are not reported from this same matrix. However, these are preserved in concretions, suggesting that any unpreserved carbonate shells dissolved before lithification of the sediment. This could indicate that the overall carbonate content was low, providing a better match with the local equilibrium model.

The previous two models do not put any specific constraints on the composition of the resulting concretions, except that they should be similar to the surrounding sediment/chemical environment at the time of formation. Indeed, concretions typically grow in equilibrium with the pore water around them, whether it is pore water constant throughout the environment (Coleman & Raiswell, 1995), or pore water in the localized microenvironment (Coleman & Raiswell, 1995; Curtis et al., 1972). However, there are concretions known that contain anomalous isotopic or chemical compositions. For example, the calcite concretions in the Jurassic Oxford Clay of England (see Fig. 22) appear to have formed in marine environments depleted in O^{18} (Hudson, 1978). The fluid mixing model (Hudson, 1978; Raiswell and Fisher, 2000) attempts to explain this anomaly through the influx of meteoric water (typically lower in the O^{18}/O^{16} ratio than marine sources) which could, for example, decrease lead to a depleted signal. Isotopic variation between concretions and the matrix sediments would be due to varying isotopic ratios of specific elements as they occur in the environmental source materials, not due to isotopic fractionation due to concretion formation. Thus, any observed isotopic differences can be a clue to source inputs of material.

In the depositional environment of the Francis Creek Shale, the upland input of freshwater through buried sediment may meet the criteria of an influx of meteoric water. However, non-withstanding the carbonate enrichment shown above, the limited data as yet developed regarding Mazon Creek concretions do not demonstrate any anomalous isotopic or chemical components in concretions significantly different than the surrounding sediment. Meteoric pore water perhaps upwelling from the peat mat below or transported though sediment channels from upland has been suggested as a key element of the Mazon Creek concretion formation system by various authors (Woodland & Stenstrom, 1979). Clearly, this is an area where more data needs to be collected. See Section VII.

The three models of concretion formation provide a useful tool for understanding the general regional processes and environments of concretion formation. However, they do not explain the observed variations in individual concretions at Mazon Creek as noted in Section V, above. These variations are likely due to heterogeneous conditions such as small- scale chemical anomalies and sediment microenvironments, nested with the larger homogeneous site/regional conditions.

In a carbonate concretionary environment, formation of any individual species, whether calcite, siderite, dolomite, and pyrite (which often co-occurs in carbonate concretions) is due to a combination of factors including the cation/anion mix, the pH and Eh conditions, direction of ion flow through the sediment, and local microbial conditions. Regarding ionic sources, water upwelling from the peat mat below would likely have been a source of carbon and iron and sulfate would likely originate from marine/brackish water input. Timing also affects the species formed. For example, more pyrite-rich concretions often occur because soluble sulfate prevents carbonate from initial precipitation, only solidifying once sulfur has been removed through anaerobic microbial reactions form pyrite (Coleman et al., 1993). Only then could methane and perhaps ammonia-generating reactions, mitigated by different bacteria feeding on organic debris, alter redox conditions, creating conditions necessary for carbonate (esp. siderite) precipitation.

Concretion size and shape is also likely influenced by immediate local conditions. In a strict topological sense, the vast majority of concretions are simply ‘spheres,’ (or balls, implying the entire in-filled structure) which vary only in size. This general topological viewpoint fits well with the general model of growth mediated by diffusion from a central nucleus (Coleman et al., 1993). Intuition suggests that the size and shape of any concretion would be influenced by such factors as the size/shape of the nucleus, flow-direction of ions through the system, and the rate of carbonate precipitation but this has never been very well quantified or explained.

Although the pattern of weathering around some Mazon Creek concretions suggest that concretions appeared to have grown in concentric layers (Worthen, 1870; Langford, 1958) this most likely is due to differential erosion along the bedding planes in the concretion which typically follow the bedding of the surround sediment, with slightly less compaction. The current thinking is that of relatively quick cementation as a final, self-contained nodule (Schopf, 1979), even if some concretions did continue to cement outward after the initial hardening stage. Each of the listed models allow for either pattern of growth (Raiswell and Fisher, 2000).

Finally, concretions do not usually occur homogeneously throughout a site, neither vertically nor laterally; they appear to concentrate in certain growth horizons (Shabica, 1971; others). This is also most likely due to local environment heterogeneity. That is, one concretion zone will have heterogeneous occurrences of microbes, organisms, and carbonate, leading to different areas with different concretion densities (Coleman et al., 1993). See Figure 20. Figures 21 and 22 show concretions in situ along the Mazon Creek at the Bensons Farm site. Figure 23 is a CT scan through an Essex fauna specimen; light inclusions are likely pyrite.

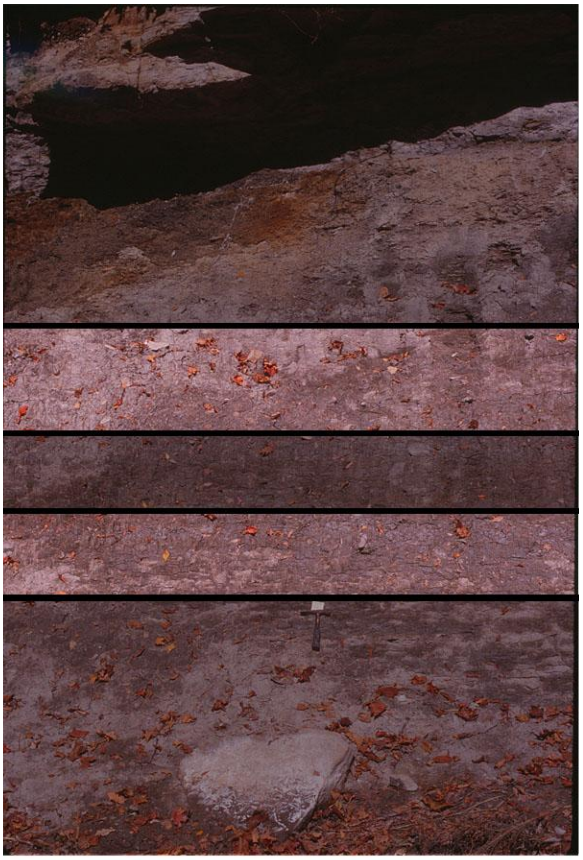


Figure 20 Concretion Zones - Mazon River

Figure 21 Concretions *in situ* - Mazon River

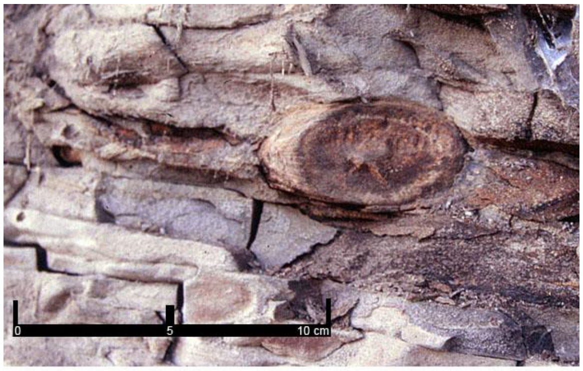
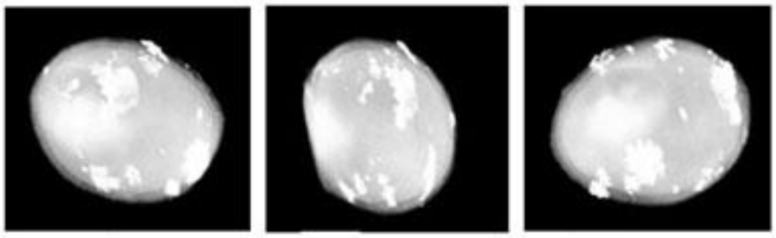


Figure 22 Concretion *in situ* x-section MZ River



Right Center Left

Figure 23 CT scan of Essex concretion

VII. Current Research

Overall similarities in chemical/mineral composition, general appearance, and contents suggest that at Mazon Creek there was one basic concretion-forming process. However the extent to which concretions vary in size, shape, composition, and fossil quality suggest the presence of many sub-environments for preservation yet to be understood.

Some questions proposed for further study include:

1) What are the differences in chemical/mineral composition between the concretions with a dark matrix compared with light-matrix concretions? Are any differences correlated with variables that might suggest where they formed within different zones (e.g. vertical or lateral) within in the Francis Creek Shale? What might have been the differences in chemical conditions responsible for the different formation processes?
2) Why do some concretions appear to have grown upwards through the sediment, rather than by accretion around a nucleus that, presumable would have settled horizontally during burial? Many of these are duds.
3) Are "mash" fossils formed adjacent to single specimen fossils, or in distinct zones?
4) Why do some spherical growth structures fail to mineralize into concretions? Are these limited to the blocky mudstone horizon? Are these more likely to contain fossils than adjacent sediments?
5) Are concretions formed only in distinct zones within the FCS?
6) What might be factors limiting the size of concretions?

A four-fold approach is conceived to continue research into the mechanisms of ironstone concretion formation at Mazon Creek. Such an approach would consist of:

1) Statistical analyses to discern trends in concretion abundance types, and thus the inferred concretion formation conditions;
2) Detailed measurements of concretions and the enclosing strata;
3) Laboratory analysis of specimens/strata; and
4) Experimental concretion growth in the lab

To augment the limited census data on concretion variance shown in Section V, the first leg in this approach, statistics-based analysis, will be applied by the pooling of concretion data from active collectors, using a tally-form of concretion variables similar to that outlined below in Table 4. Data obtained will be analyzed using ANOVA (analysis of variance), logistic regression and frequency table tests to better understand the interaction of different observed variables on concretion abundance and variation within and across sites. Analyses will be compared to the values expected from statistical null models of concretion formation.

Stratum/Location:
Specimen: complete partial (part of larger concretion/structure)
Size Length (max.): < 5 cm 5 – 15 cm. > 15 cm.
Edge encapsulation: full partial none
Shape spherical ovoid cylindrical lenticular pancake irregular
Bedding planes/Laminations: yes no
Shape - orientation to bedding plane: parallel oblique perpendicular
Matrix color: tan gray black
Matrix particle size: clay -- silt -- sand/micaceous
Matrix cementation: poor -- -- -- well
Matrix cement: compression (none) clay siderite pyrite calcite
Fossil presence: none micro (< 5 mm.) -- macro (>1 cm)
Fossils: distinct (specimen) (layer) (layers) diffused
Fossil specimen: single individual 2+ individuals mash
Fossil location(concretion): edge center off-center
Fossil orientation to concretion shape: aligned no relation
Fossil type: plant animal plant mash

Table 4 Concretion Variables Tally Sheet

The second method would entail collecting concretions *in situ* and mapping their orientation across the strata section to help plot the mineral and geochemical gradients through the concretions and into the surrounding matrix. Access to *in situ* concretions is still possible in a few, private access sites along the Mazon River. This data could be used to understand small-scale environmental variations pertinent to concretion formation and to understand which particular mechanisms were operating locally.

Third, detailed mineral/chemical analysis would be done using established laboratory methods, updating with modern geochemical techniques the previous analysis work (e.g. Woodland & Stenstrom, 1979). Isotopic ratios of oxygen, sulfur, and carbon species may be useful to tease out sources of water, and organic inputs to concretion formation. For example, seawater is enriched in the O^{18}/O^{16} ratio and organic sourced carbon is enriched in the C^{12}/C^{13} isotopic ratio vs. inorganic carbon.

Finally, after establishing a clearer understanding of the localized depositional environments, similar sediment conditions can be set up in the lab, complete with decaying organisms, to get a better picture of the timing of chemical processes as they occur while concretions form. To date, previous studies that have examined concretion formation in a laboratory (Berner, 1968) or through *in situ* sediment observation, (Al-AGHA et al., 1995) do not fully describe concretion analogues to geologic concretions. This could suggest that concretion formation confronts limits at the laboratory scale due to factors such as reactions times, depths, area limits, or some as yet unknown criteria.

It is hoped that data gained from this approach can contribute to the ongoing understanding of the “Concretion Conundrum.

VIII. Additional information for Figures:

Figure 7. Concretion sizes and shapes; Pits 1, 4, 11, and Coopers Pit.
Figure 8. Twinned growth concretion: concretions grew together after nucleating around distinct proximate sources; Pit 1.
Figure 9. Concretion cement/matrix: black (pyrite-rich) and tan matrix; Coopers Pit
Figure 10. Cross section of concretion: note the un-compacted mold of a plant stem, infilled with sphalerite and kaolin; Coopers Pit.
Figure 11. Concretion filled with plant mash throughout; Pit 1.
Figure 12. Ironstone concretions with sandstone matrix; Coopers Pit.
Figure 13. Concretions cemented by calcite; Coopers Pit.
Figure 14. Concretions that dried and cracked before final hardening: infilled with calcite and kaolin; Pit 4.
Figure 15. *Calamites* stem fossils that extend outside of the concretion boundary; Pit 1.
Figure 16. Pyrite halos and kaolin infill around fossil concretions; Coopers Pit.
Figure 17. Ball growths in mudstone not mineralized as concretions; Pit 11.
Figure 18. Irregular concretions showing upward growth through sediment; MZ River.

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The Monster from Illinois

John A. Catalani

Most of us fossil collectors have a favorite geologic time period that dominates our collections. If you have a fascination, say, with the Lower Carboniferous (Mississippian Subsystem), your collection is undoubtedly chockablock with blastoid specimens, especially the amazingly abundant species of the genus *Pentremites*. For me, the Ordovician Period dominates my collection because these rocks were exposed in every quarry and roadcut surrounding my hometown of Rockford, Illinois. And since nautiloids are particularly abundant in these rocks, they became the focus of my research. Although the components of this fauna give us a fairly thorough picture of the ecosystem that was active in the shallow seas that covered what is now northern Illinois and southern Wisconsin during the Late Ordovician, the carbonate rocks present in these exposures preserve, for the most part, only those animals that secreted hard shells suitable for normal fossilization.

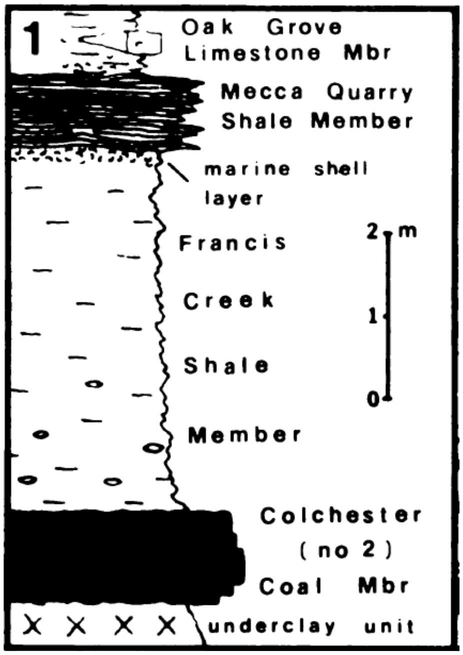

Fig. 1 Diagrammatic section of the Middle Pennsylvanian near Lowell, Illinois, west of the Mazon Creek area. The Colchester (No. 2) Coal Member is the basal unit of the Carbondale Formation. The concretion-bearing Francis Creek Shale Member, here somewhat thin, lies above the Colchester Coal. (Modified from Baird *et al*., 1985, Figure 2.)

However, in Illinois there was one special fossil deposit that preserved all types of animals and plants, even soft-bodied forms, including the future state fossil of Illinois. The rock unit containing these fossils was exposed in a series of localities in the Mazon Creek area and specimens from these sites dominated the collections of many of the amateurs that lived in the Chicago area. Specifically, for all you stratigraphy geeks out there, the fossils are found in the lower 2-4 meters of the Francis Creek Shale Member of the Carbondale Formation of the Desmoinesian Series (Westphalian D Stage) of the Middle Pennsylvanian Epoch of the Carboniferous System (see **Fig. 1**). Such sites are referred to as Lagerstätten (sing. Lagerstätte). Lagerstätten are fossil accumulations that either preserve organisms in exceptional detail often revealing soft tissues (**Konservat-Lagerstätten**), or preserve specimens in great abundance (**Konzentrat-Lagerstätten**) or, in rare cases such as Mazon Creek, both.

Certain physical and biological conditions were required to ensure such superb preservation. Obviously the organisms must have been buried quickly, often by a massive burial event such as a mudslide or turbidity current, to have escaped not only the ravages of scavengers but also physical effects such as shell-abrasion or disintegration. Also, to increase the likelihood that soft tissues would be preserved, anoxic conditions were needed to eliminate or at least curtail bacterial decomposition. Such deposits, with soft-bodied organisms preserved that normally do not fossilize, allow paleontologists to more completely analyze and evaluate the biodiversity and paleoecology of these ancient communities—a window, if you will, through which we can view a specific instant in time in the evolution of life on Earth.

The Mazon Creek Lagerstätte is one of those windows and gives us a view of the flora and fauna of a Pennsylvanian coal-swamp assemblage. By ascertaining both the types of environments in which the animals and plants lived as well as the process of their fossilization we can put our state fossil into some sort of context. At that time (approximately 300 million years ago), what is now the Mazon Creek area pretty much straddled the Paleoequator with best-guess estimates placing it at about 4° south latitude. As one might expect, the climate was mostly humid tropical. The fluctuating environments (transgression-regression cycles) of the Midcontinent were caused by changes in sea-levels that have been attributed to glacioeustasy (Gondwana glaciations) driven by orbital-parameter forced periodicity (Milankovitch Cycles) and that correspond to specific depositional time scales as classified by principles of sequence stratigraphy. The sedimentary environments alternated between terrestrial, deltaic/swamp, marginal marine (estuarine), and deeper-water marine resulting sedimentary rock sequences referred to as cyclothems. The lush vegetation growing on the floodplains died, accumulated in place, and was subsequently buried forming peat that would eventually be converted to coal. As the sea began to rise, marine habitats dominated and shales began to be deposited. The source of these clastic sediments was the Appalachians that, at this time, were growing higher in response to the Alleghenian Orogeny. The sediments were transported, as were many terrestrial plants and animals, by large river systems flowing from northeast to southwest that resulted in an enormous delta system that prograded (grew out) seaward resulting in the deposition of thick shale layers, such as the Francis Creek. In addition, the Illinois Basin was subsiding gradually allowing Pennsylvanian sediments to accumulate in excess of one kilometer thick. In the Mazon Creek area, the fossiliferous Francis Creek Shale Member directly overlies the Colchester (No. 2) Coal Member, the basal member of the Carbondale Formation mentioned above, which, as we shall see, was an important factor in the recovery, analysis, and evaluation of the Mazon Creek Biota.

Mazon Creek fossils are preserved in siderite concretions (also referred to as nodules) that range in shape from round to elongate. The fossils are often, but not always, found in the middle of the nodules, parallel to the long axis. The concretions formed around organic matter in an environment rich in iron and carbonates. Initial bacteria action removed sulphate and released carbon dioxide allowing for the formation of the siderite (iron carbonate) concretions that protected the future fossil material from further decay. Limited postmortem transport and rapid burial in a somewhat restricted basin of low oxygen and sulphate concentration, along with the formation of the entombing concretions, ensured the exceptional preservation of the plants and animals. Soft tissues are often preserved as lighter-colored impressions or “halos” visible against the darker background of the siderite concretions. The concretions presented the collectors with a challenge—how to open them without destroying the fossil. Early on, many collectors simply hit the nodules along the long axis with a hammer to attempt to open them often shattering both concretion and fossil. It was found that the most parsimonious way to open concretions was by subjecting them to repeated freeze/thaw cycles by first soaking them in buckets of water and then placing them outdoors during winter months.

The Mazon Creek Biota is subdivided into three environment/taxon groups: the terrestrial Braidwood Flora, the terrestrial/freshwater Braidwood Fauna, and the marginal-marine (estuarine) Essex Fauna. It is the presence of plant material, over 250 species, that makes the Mazon Creek Lagerstätte unique among such deposits. Braidwood animals include insects (150+ species), centipedes, millipedes, spiders, horseshoe crabs, and amphibians. The Essex fauna is made up of jellyfish, worms, shrimp, cycloids, and fish. Because the animals lived at or very near their eventual burial sites, studies of the areal distribution of the animals revealed a fairly sharp boundary between Braidwood and Essex faunas. This is additional evidence that these animals were buried quickly by virtual torrents of sediments carried by the myriad of delta distributaries during flood stages. The only mixing of the Braidwood and Essex organisms occurred as the terrestrial plants and animals and freshwater animals were transported seaward by the river systems. The periodic influx of freshwater by these flooding episodes into the marine environment killed the marine organisms allowing them to be buried in the sediments carried by the floodwaters. An estuarine environment was proposed as the habitat of the Essex Fauna based on the absence of deeper-water marine taxa such as corals, bryozoans, trilobites, and articulated brachiopods. The fact that many of the Essex animals preserved are of small size provides further evidence of an estuarine environment. It has been suggested that these small individuals represent juvenile populations and that the estuaries served as "ecological nurseries" as they do today. Alternatively, the small size of the animals may reflect their inability to escape the influx of sediments while the larger animals were able to flee to safety.

It is in this marginal-marine environment that we finally encounter the enigmatic *Tullimonstrum gregarium*—the "Tully Monster" and, since 1989, the state fossil of Illinois.

The history of fossil collecting in the Mazon Creek area began almost 200 years ago when fossils were collected from natural exposures along, what else, Mazon Creek (or River). However, it was activities related to the extraction of the Colchester coal that propelled concretion collecting to another level. Although both shaft and strip (surface) mines were employed, it was the 15-or-so strip-mine pits, arranged in an arc from Morris through Braidwood to Essex that provided the greatest access to the Francis Creek Shale and its fossiliferous concretions (see **Fig. 2**). In a strip mine, the overburden that covers the coal (or whatever is mined) is removed in linear, parallel "strips" of land. This process is repeated continuously back and forth until the land surface is overturned with the lowest layers, in this case the Francis Creek, exposed in "spoil piles" at the surface. As the Francis Creek Shale was subjected to weathering activities, the shale broke down exposing the concretions and making them available to collectors. And, I might add, this was one fossil deposit in which amateurs played a major role by amassing systematic, well-documented collections of the Mazon Creek plants and animals. Many of these dedicated amateurs donated specimens to professionals notably the late Eugene (Gene) Richardson, then Curator of Fossil Invertebrates at Chicago's Field Museum, who knew the value of these "amateur" collections. Unfortunately, most of the Mazon Creek sites are now overgrown or otherwise unavailable for collecting.

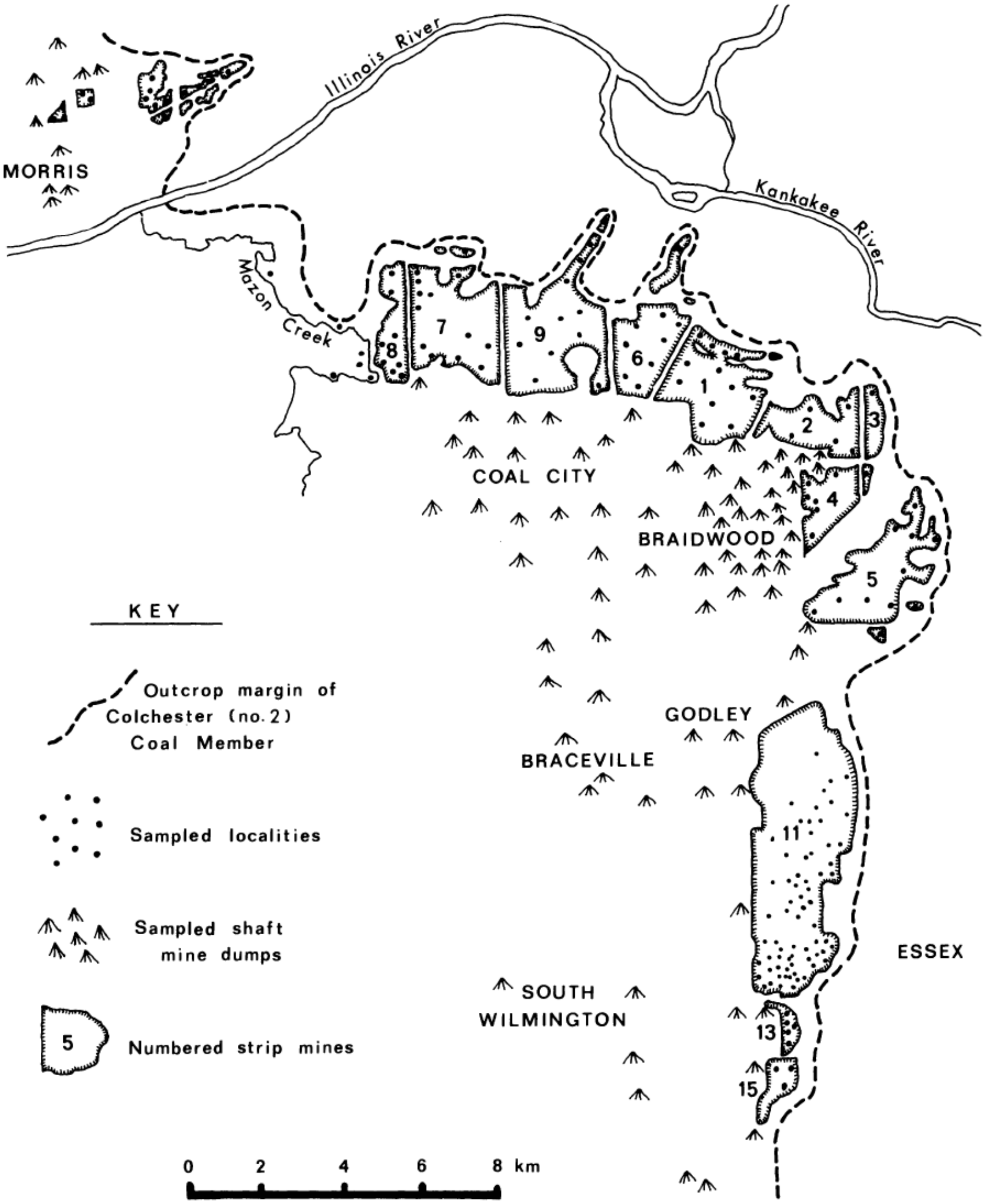

Fig. 2 Map of the Mazon Creek area showing locations of towns, shaft-mine dumps, and numbered surface coal mines. Mine tailings and spoil piles provided access to the fossiliferous concretions. (Modified from Baird *et al.*, 1985, Figure 3.)

In 1955, Francis Tully of Lockport, Illinois, found a strange, worm-like organism in one of the Mazon Creek concretions he had collected. He eventually brought the fossil to Gene Richardson who, after much study and soul-searching as to what this creature could possibly be, formally described the animal in 1966 naming it *Tullimonstrum gregarium* (Tully's common monster) and, because of its unique nature, refused to assign the Tully Monster to a phylum. Even in later papers, after many additional specimens were collected and studied, Richardson chose not to assign the creature to a specific phylum.

So, what is it about this enigmatic animal that presents scientists with such conceptual difficulties and defies taxonomic assignment? Part of the problem is that *Tullimonstrum* was a soft-bodied organism with no hard parts and thus is preserved essentially as a lighter impression against the darker background of the concretion. Also, the morphology of the animal was unique making any attempt at comparisons to known animals somewhat futile. It is not even possible to determine which side of the worm-like body was ventral and which dorsal.

Fig. 3 Holotype specimen of *Tullimonstrum gregarium* displaying the proboscis (twisted over the body at left), the bar and spherical organs, segmented body, and folded tail at right. (Photo by Jack Wittry, used with permission.) Bar scale = 1 cm.

The animal, which ranged between 10-30 centimeters in length and was probably an active swimmer, can be divided into three body parts (see fossil photo **Fig. 3** and reconstruction **Fig. 4**): an anterior flexible proboscis, a wider and slightly depressed trunk, and a tail equipped with two flexible fins. The body is segmented but it is not clear if these bands represent true segmentation or an internal feature. Although no internal organs are usually identifiable, some well-preserved specimens display a medial impression that runs the length of the animal and has been interpreted as a digestive tract. The elongate proboscis is equipped with an anterior “toothed” structure variously termed “jaw” or “claw”. However, it has been suggested that the “claw” is simply an artefact of body compression during burial and that the anterior end of the proboscis was actually a “globular buccal mass” possibly equipped with a radula-like structure. The most bizarre feature of the animal was a more-or-less rigid bar positioned horizontally across the anterior part of the trunk. At each end of the bar was a spherical organ. Interpretations of these spherical structures range from eyes to equilibrium or stabilizing organs to copulatory organs to support structures *if* the animal was benthic and *if* the bar was located ventrally (which, of course, cannot be determine).

As mentioned above, the tail is equipped with two flexible and, most importantly, asymmetric fins. Now, if the fins were located horizontally (as they are traditionally pictured) and if they were used for locomotion (no other purpose comes to mind), it would have been virtually impossible for the animal to swim in a straight line—very inefficient. However, there is evidence, besides the asymmetry, that the tail fins were actually arranged dorsoventrally (vertically). In well-preserved specimens there is a diagonal fold or crease preserved at the base of the tail that would be correctly positioned if the vertical fins had been twisted to the horizontal position due to compression from the weight of sediments during burial.

Thus, *Tullimonstrum* is a unique animal and it is understandable that it was originally thought to be a member of some unknown phylum now extinct. Although the animal still defies classification, best-guess cladistics place its closest relationship with either some type of shell-less gastropod-like mollusc or the conodont animal that, until very recently, was considered a primitive vertebrate. It is appropriate that such a wonderful animal was chosen to be the state fossil of Illinois.

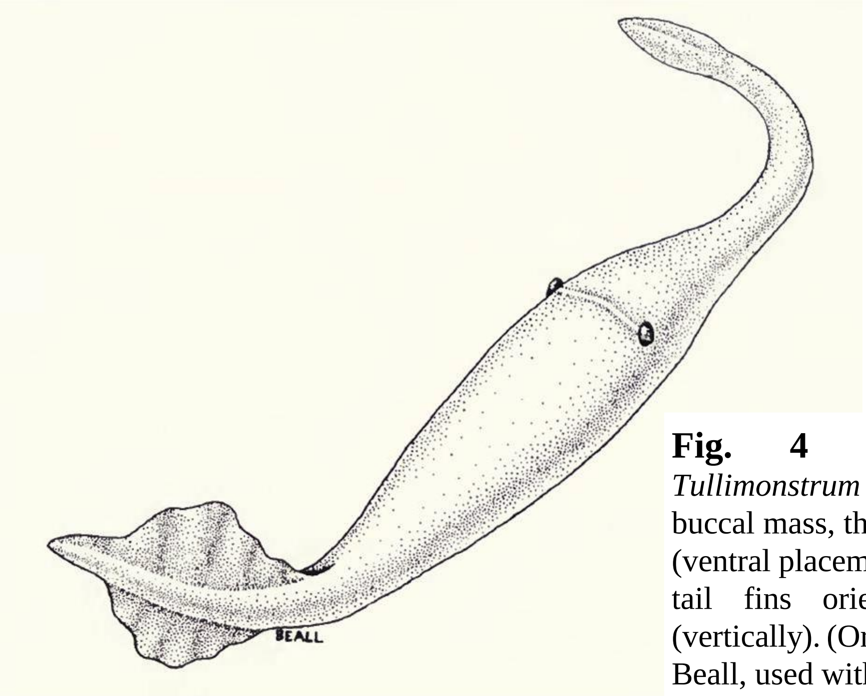

Fig. 4 Reconstruction of *Tullimonstrum* with an anterior buccal mass, the bar located dorsally (ventral placement as likely), and the tail fins oriented dorsoventrally (vertically). (Original artwork by Bret Beall, used with permission.)

Acknowledgements

I would like to thank Paula Mikkelsen and PRI for permission to include this paper, a modified version of which appeared in the Summer 2011 issue of *American Paleontologist* magazine, in this year's EXPO Edition. I would also like to thank Jack Wittry for permission to use his photograph of the holotype specimen of *Tullimonstrum* and Bret Beall for permission to include his reconstruction of *Tullimonstrum* in this paper.

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Horseshoe Crabs and their Relatives in the Pennsylvanian of the Midcontinent

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The most common horseshoe crab fossil in collections worldwide is the familiar *Euproops*, primarily from locations in America and Europe. Of the 400 or so fossil horseshoe crabs in my study collection, 85% of the Pennsylvanian ones are Euproops. Euproops is a kind of horseshoe crab known as a Xiphosuran; this means it is probably related to the modern horseshoe crabs. Xiphosurans have been around since the Ordovician (Rudkin 2008) and have a **solid** opithosoma or abdominal plate (the back part of the body). Other horseshoe crab relatives are the lesser known "Synziphosurians", featuring a **segmented** abdominal plate. I have put the name in quote marks as these arthropods seem to be a group of similar looking fossils that may not be closely related to each other. These are the two main forms commonly called horseshoe crabs.

Segmented bodies are usually interpreted as a primitive character. Humans for example are not considered segmented, are they? But take a close look at our vertebrate skeleton; the ribs and vertebral column look hauntingly similar to relict segmentation. Muscles in vertebrates also can look segmented. If you have "six pack abs" as I do…. not, they also look segmented. Modern horseshoe crabs show a number of features on their abdominal plate (opisthosoma) that show signs of an earlier segmented state.

The solid opithosomal types (xiphosurans) in the Pennsylvanian include forms found in the Essex and Braidwood assemblages in Illinois and other states. How many types there are is debatable! **First** is our old friend ***Euproops*** **(Fig.1)** which has been divided up into several "species" that are all preservational views of the same animal: *Euproops danae*. There are other Euproops species, just not from the US midcontinent. Euproops is usually pronounced Eyou-pro'-ops but some say Eu-proop-s, with the double o's as in oops! I suppose that as long as the person you are speaking with understands what you mean, either pronunciation is A-OK!

Like modern horseshoe crabs, *Euproops* appears to exhibit sexual dimorphism with the females tending to grow larger than the males. There is a cast of a truly giant *Euproops* in Dr. Richardson's cast collection at the Field Museum in Chicago. I did not get to measure it but it looked to be baseball sized! Others of this size undoubtedly exist or remain to be found.

In 1979, Dr. Daniel Fisher published an illustration of Euproops "hiding" on a lycopod plant stem. The article suggested that this was evidence for the arthropod moving about on land on a regular basis. This argument and the associated illustration can be found in the Nitecki Mazon book as well as in a recent volume on Paleobotany (Taylor & Taylor, 2009, P. 1022). Scottish Paleontologist Lyall Anderson has demolished this argument. Modern (and probably extinct) horseshoe crabs can live out of water for days as long as their spider- like book lungs are moist. This does not mean they were or are adapted to live on land.

Some of the Illinois and Missouri fossils preserve legs which are often seen as impressions beneath the front shield or prosoma. The Richardson Mazon book shows a drawing of a Euproops with the lateral eyes very far forward. I have never seen any xiphosuran with eyes in this position! Horseshoe crabs and many of their relatives have many eyes and can detect light even with their telsons! Euproops danae is also found in the Knob Noster lagerstätte in Missouri (Hannibal *et al* 2003). In the past every new looking *Euproops* specimen was given a separate species name but again, all the Essex and Braidwood Euproops specimens are *E. danae*! (At least as of today.)

The second xiphosuran found in the Essex and Braidwood areas is **"*Paleolimulus*" (Fig. 2)** which is in need of reexamination. There is a good chance that the Essex and Braidwood forms are in need of a new name. They are much less common than Euproops and show the same sexual dimorphism with the females much larger than the males. The largest "*Paleolimulus*" specimen I have is just over 6 cm wide and thus probably a female. It was found years ago by the intrepid collectors Wesley and Loretta Holm. It was so large that Wesley told me he thought it was a big leaf at first!

***Liomesapis laevis* (Fig. 3) is the third kind of xiphosuran** found in the Braidwood assemblage. I am not certain it is found in the Essex. It was called "*Pringlia*" in the past. *Liomesapis* tends to be smaller and looks like two slightly shriveled peas side by side. Sometimes the needle like tail spike (telson) can be seen. The telson is very long but seldom exposed. This uncommon form is also found in the Knob Noster area. Like Euproops, it could roll up. It is probably more common than it seems because it is often misidentified as a seed. I blush to tell you that I had one in my fossil seed drawer for two years! MAPS member Jerry Mennemeier has been instrumental at recognizing these rare beasts and he will probably find more unusual types in the future!

A fourth kind of Xiphosuran has been recognized from the Pennsylvanian Knob Noster area: *Valloisella* (Hannibal et al 2003). This was the first time this genus had been found in the Americas. Others have now been found; the highly domed smooth prosoma and tear drop shaped body form is a clue to recognizing *Valloisella*. I sure would like to hear of other specimens! Super collector Tom Testa has found one fossil possibly of this or a related form in the incognetum at the Field Museum Pit 11 collection! Is this kind found rarely at Mazon Creek?

There are other names kicking around that may represent additional genera like "*Streptocyclus*", but it looks like a squashed *Euproops* so that name is probably invalid. At a MAPS expo in the 1980's I bought a fossil labeled as a horseshoe crab that turned out to be a larval cockroach. This shows the two could be confused and yes, the larval roach is rarer.

Now for the other type of horseshoe crab relative: the synxiphosurans. Up until a few years ago, most authorities said these primitive arthropods became extinct in the Devonian. In 2007 Rachel Moore and I with Bruce Lieberman described a new Mississippian synxiphosuran from Bear Gulch in Montana (Moore *et al*, 2007). I had run across three specimens of this new synxiphosuran **(Fig 4)**. I also went to the Carnegie Museum and traveled to the University of Montana, Missoula to see if they had any further specimens, but they did not. Incidentally, Euproops may be in the Bear Gulch as well. While we were working on the article, we became aware of several Pennsylvanian synxiphosurans just found in Poland. One was sold by an on-line site as an insect larva! As of this time, that form is undescribed. This is a call to action for all collectors active in the Mazon Creek and similar areas to be on the lookout for new material! Probably the synxiphusura became extinct in the end Permian extinction event rather than the Devonian (McKenzie, 2009).

Have you found horseshoe crabs that show odd details or are from unfamiliar localities of any age? Even pieces and parts are of interest. I would like to hear from you! smckenzie@mercyhurst.edu

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Fig. 1. *Euproops danae*, Braidwood Fauna, near Terre Haute, Indiana. Specimen is 4.5 cm wide.

Fig. 2. "*Paleolimulus*" from Pit #1 area. Specimen is 6 cm wide.

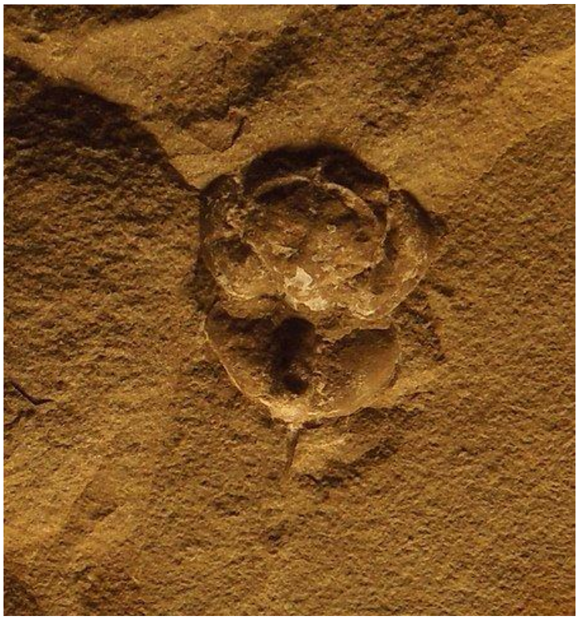

Fig. 3. *Liomesaphis laevis* Braidwood area near Mazon Creek. Specimen is 1.1 cm wide.

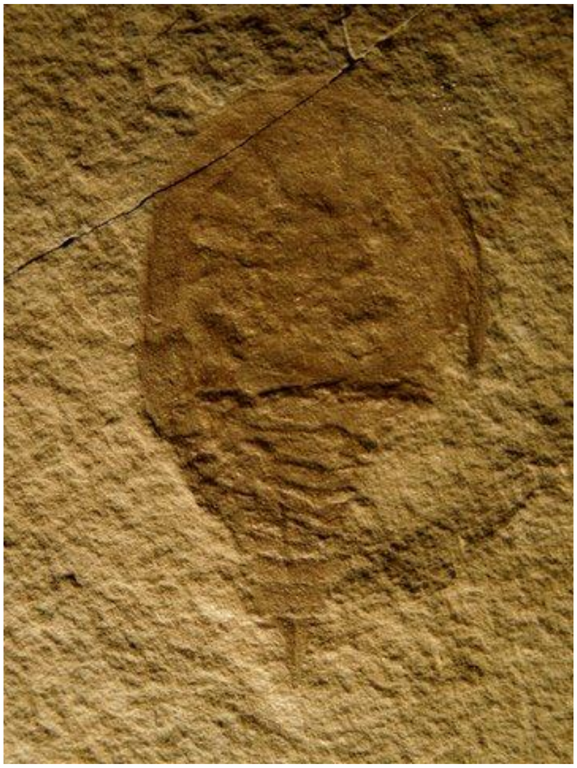

Fig. 4. (right) *Anderella parva*, Mississippian, Bear Gulch, Montana, (counterpart of Holotype). Specimen is 3.6 cm long. The telsons are very long on these specimens, but are usually not preserved.

An Early Pennsylvanian Mystery

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Forty years ago I found some unusually looking foliage from an Early Pennsylvanian plant. To date I have been unable to have it identified, I'm writing this article in the hopes that someone will recognize the fossil I'm talking about and shed some light to its identity.

In the 1970s my father learned of a plant fossil site near our home and he took me there. It was my first chance to collect plant fossils and we found a variety of specimens. The site is on city property near where Lizard Creek empties into the Des Moines River in western Fort Dodge. Soon after, the city began excavating the site: using the material for fill and in the process uncovered many fossils.

At the time the strata was identified as undifferentiated Mid Pennsylvanian Cherokee Group. The Cherokee Group since has been split into formations in Iowa and the strata exposed here is part of the Early Pennsylvanian Kalo Formation (RL Ravn 1984).

The Kalo Formation at the Kalo type section overlies the Early Pennsylvanian Kilbourn Formation and is overlain by sandstones of the Mid Pennsylvanian Floris Formation (RL Ravn 1984). At the Lizard Creek site, about six miles northwest of Kalo, the Kalo is in contact with brachiopod bearing shale of the Upper Mississippian Pella Formation.

Over the years I have had several experts offer opinions on the specimens, none of which agreed. The identifications include: a seed pod; an early cycadale; and a relative of *Sigillaria*.

In 1974 I sent a specimen to the Smithsonian Institute. In 2002 I received a reply from Raymond Rye museum specialist with the Smithsonian's Department of Paleobiology. He apologized for the long delay and even included my return postage: $1 in 10 cent stamps.

"In the scientific opinion of our staff it is neither a cycad nor a neuropterid. Each pinna seems to be very narrow and long, with no point of attachment to a rachis being visible. And those pinna that appear to be divided into a series of pinnules, we think instead these are examples of a single pinna that has been shredded, perhaps by a windstorm. In every case, we could detect only a midvein and rachial veins in each pinna – no other pattern was apparent to us."

"The features are consistent with *Taeniopteris* and that is our best guess of what your specimen is," Rye wrote. However he pointed out *Taeniopteris* is a form genus with a wide geological range.

I myself have noticed the pinna tips of some specimens are *Neuropteris*-like and the strong midvein also reminds me of *Neuropteris*. That is why I believe the specimens are related to *Neuropteris*.

Rye also suggested the specimen originated in a glacial erratic and was not native to this area. He is not the only one to have suggested this. However I believe the specimens are from the Kalo Formation because I have found them within the bedrock and alongside other Pennsylvanian plants including *Neuropteris*, *Lepidostrobus*, and *Sphenopteris*.

The Lizard Creek site consists primarily of various sandstones and varies considerably from the coal, shale, sandstone and thin limestone beds at Kalo. However strata resembling that at Kalo does occur higher up the bank of Lizard Creek overlooking the plant fossil site. There are many exposures of the Kalo in Webster County however the Lizard Creek site appears different from the others. Many Kalo exposures in the area include at least one discontinuous dark limestone. At one site the limestone is two feet thick and continues for a fair distance along the Des Moines River and has the most varied marine fauna I have ever collected in, surpassing even the Upper Devonian Cerro Gordo fauna at Rockford, Iowa. Years ago I made a population count of the fauna and found the brachiopod *Cancrinella* comprised 49 percent of the count. The next numerous specimens were crinoid columns at 7 percent (Wolf 2006).

All of the bivalves are disarticulated and many of the larger nautiloid shells are broken indicating the specimens were transported before burial. Absent is the common Desmoinesian brachiopod genus *Mesolobus* which places these beds earlier in the Pennsylvanian. There is no such limestone at the Lizard Creek site. Kalo strata in Webster County also offers wonderful cone-on-cone, marcasite, pyrite, concretions, and at least one locality has columnar celestite.

The Fort Dodge Kalo exposures correlate with the Kalo exposures at Pella, Iowa where many plant fossils occur. The strata at Kalo has been studied by Iowa State University geologists who identified a variety of environments including: shallow marine; flood basin; delta front; distributary channel; swamp; and prodelta (J Lemish 1981).

Even though the Lizard Creek site is now poorly exposed some fossils can still be found. In recent years I have been unable to find more of the unusual fossils.

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The author diligently searches for more of the unusual fossils.

Plant fossils can still be found at the Lizard Creek site.

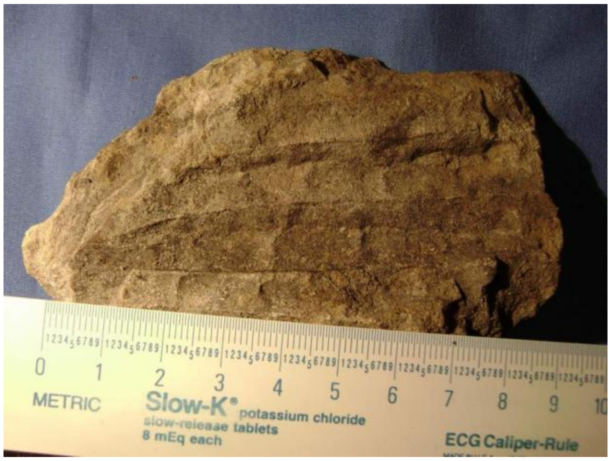
Kalo Formation limestone in place along the Des Moines River south edge of Fort Dodge.

A typical specimen.

A single specimen.

Specimen displaying the tip of a pinna.

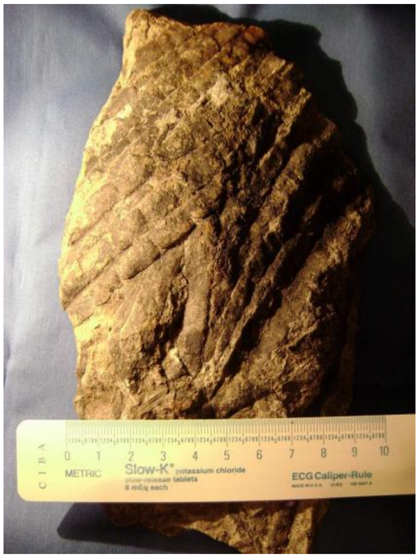
Several specimens branching.



Specimen preserved in a rock with *Lepidostrobus* (not visible).

Several specimens next to *Neuropteris*.

A specimen next to *Sphenopteris*.



Sketch of a specimen from *Fossils of Iowa*.

This specimen was examined by the Smithsonian Institute.