# The Waldron Shale: An Important Silurian Fossil Deposit

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## Introduction

If you think of famous Silurian formations, chances are the first one that comes to mind is either the Waldron or the Rochester Shales. The latter was named by James Hall in 1839 and is noted for spectacular fossil trilobites and echinoderms as well as diverse brachiopods, bryozoans, and mollusks (see Chinnici, P., and Smith, K. (eds.), 2015. The Silurian Experience, 2nd Ed. Primitive Worlds Press, Rochester, NY, p. 36-68.)

The Waldron was named by N. M. Elrod in 1883 using nomenclature of Waldron beds or Waldron fossil beds. The earliest faunal studies were by James Hall (1879). Unlike the exquisite Crawfordsville, Indiana, crinoid beds, the Waldron Shale is not a conservation lagerstätte in the strict use of the term. However, the well-preserved fossils make it one of the best to reveal the diversity of life in Indiana, Tennessee and to a lesser extent, Kentucky, about 428 million years ago.

Geographically, the area of deposition (across what is now Indiana, Kentucky and Tennessee) was located in a shallow tropical/sub-tropical ocean at a paleolatitude of 25 degrees south of the equator.

## Stratigraphy & Correlation

The Waldron Shale is named for a locality in Waldron, Shelby Co., Indiana, today known as the abandoned Standard Materials Co., Quarry (IGWS, 2022). The formation is typically 12 to 14 feet thick (3.6 – 4.3 M), dominated by medium dark gray to greenish gray clay, in places dolomitic or glauconitic. There are lenses of fine-grained limestone, especially in the lower and upper layers. Spectacular fossils may be found throughout the formation, but it is notoriously variable in fossil distribution and preservation.

By comparison, the Rochester Shale (named by James Hall in 1839) is younger and found east of Waldron exposures. In the north, the Rochester Shale is exposed from Hamilton, Ontario to near Utica, New York, where is grades laterally in Herkimer Sandstone. It covers a bit over 400 km. The formation also occurs in the central Appalachian in many different folds of the Valley and Ridge extending south westward to Cosners Gap, West Virginia about 550 km from western New York.

The fauna is similar to that of the Waldron with a large number of shared genera. Species are usually different, as their age is several million years apart. The Rochester does contain true Lagerstätten with spectacular trilobites and stalked echinoderms, somewhat more completely preserved than those known in the Waldron Shale (Figure 1).

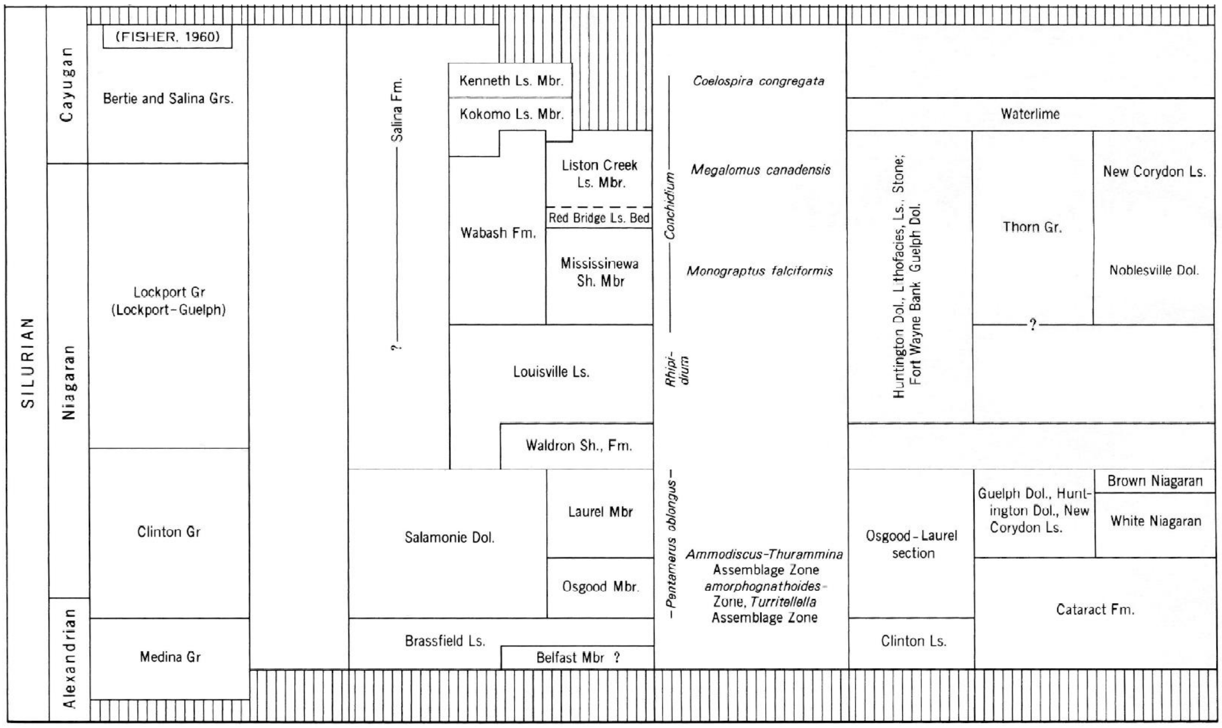


**Figure 1.** Correlation chart of Wenlockian formations.

Within Indiana, the Waldron Shale is exposed the eastern half of the state, with most outcrops occurring in quarries. The Hartsville location below Anderson Falls in Bartholomew Co. is within a state nature preserve and is one of the few natural exposures. There are road cuts with Waldron exposed but very few locations are accessible to collectors. The exposure in Tunnel Mill at the Tunnel Mill Boy Scout Reservation near Charlestown is one of the few accessible today.

The most complete exposures are in limestone quarries that mine the overlaying Louisville Limestone and underlying Laurel Formation. Unfortunately, these quarries are largely closed to collectors. Figure 2 is the Waldron stratigraphy at the Atkin's Quarry (Conkin, 2002).

Indiana quarries include:

Clark Co., Indiana: Aggrock Quarry inside the Speed Quarry, Atkins Quarry, Cooper Lane Quarry, Mulzer Quarry, and Sellersburg Stone (Photo 1).

Ripley Co.: Napoleon Quarry

Scott Co.: Scott County Stone

Shelby Co.: Cave Stone Quarry and St. Paul Quarry

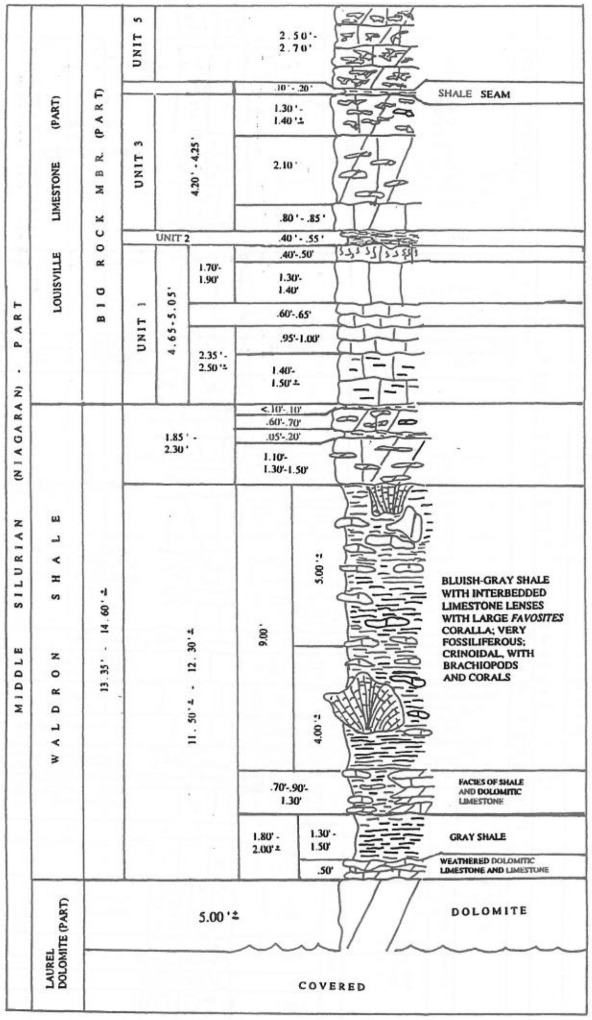


**Figure 2.** Waldron Shale Stratigraphic Chart (Atkin's Quarry).

**Photo 1.** Dr. Carl Brett and (now retired) IMI geologist Rick Lucas in the Waldron level at the Sellersburg Quarry, Dec. 29, 2014. (Alan Goldstein photo.)


**Photo 2.** Sellersburg Quarry highwall with the formations identified. (Alan Goldstein photo.)

Sellersburg Quarry exposes the Silurian Laurel Formation, Waldron Shale, Louisville Limestone, Wabash Formation, and the Devonian Jeffersonville Limestone, Speed Limestone, North Vernon Limestone, with a cap of the New Albany Shale (Photo 2).

The Falls of the Ohio State Park has provided collecting piles of Waldron Shale since 1995, first from the Atkin's Quarry and in the past decade, the Sellersburg Quarry.

In Kentucky, the Waldron is absent on the eastern flank of the Cincinnati Arch, a result of the depositional geometry around the Arch which would have already been present in the Silurian. Any sediment deposited in this region would have been eroded during the Devonian from episodes of widespread tectonic uplift during the Acadian Orogeny. The Waldron can be found within a Silurian outcrop belt on the western margin of the Cincinnati Arch. The unit in Kentucky does not exceed thicknesses of 3-4m in total. The Waldron Shale does bear fossils here, but they are typically not well preserved (Ettensohn, 2013). In a few localities where fossils are seen they are highly dolomitized, and all calcite has been dissolved away leaving very poor steinkerns.

In contrast, the Tennessee Waldron Shale is fossil rich. It is considered to include shale and limestone horizons that are found stratigraphically between the Laurel Limestone and the Lego Formation (Danielson, et al., 2019). Here, three different Waldron subunits, called A, B, and C, are recognized.

Based on the placement of a specific carbon isotopic excursion (CIE) known as the Mulde CIE, it appears as though Waldron units in Tennessee, Kentucky, and southern Indiana are generally correlative. However, stratigraphy in northern Indiana (specifically from quarries in Bluffton and Huntington, Indiana) previously attributed to the Waldron Shale, do not correlate. The Mulde CIE in those locations occurs stratigraphically lower than what has been heretofore called the "Waldron Member" of the Pleasant Mills Formation. The so called "Waldron Formation" of northern Indiana, mainly a nodular fine grained shaly limestone may thus be miscorrelated to the Waldron in southern Indiana. Further study is needed to reconcile the use of the name Waldron Shale within Indiana (Danielson, et al, 2019).

## Depositional Environment: Indiana's Waldron

The Waldron Shale was deposited during the Homerian stage of the Wenlock series of the Silurian period, dating to approximately 428mya following a global minor extinction event in which an estimated 95% of graptolites went extinct. This event is known as the Mulde Extinction which is marked by the aforementioned shift in carbon isotopes in rocks found around the world (Cramer, et al, 2006). This event is also associated with a global change in sea level, and the Waldron Shale represents a phase of sea level rise (Danielson et al., 2019).

In Indiana, Feldman (1989), and Peters and Bork (1999), published the most comprehensive studies of the taphonomy and paleoecology of the Shale. Much of what is discussed below is a summary of their research (Figure 3).

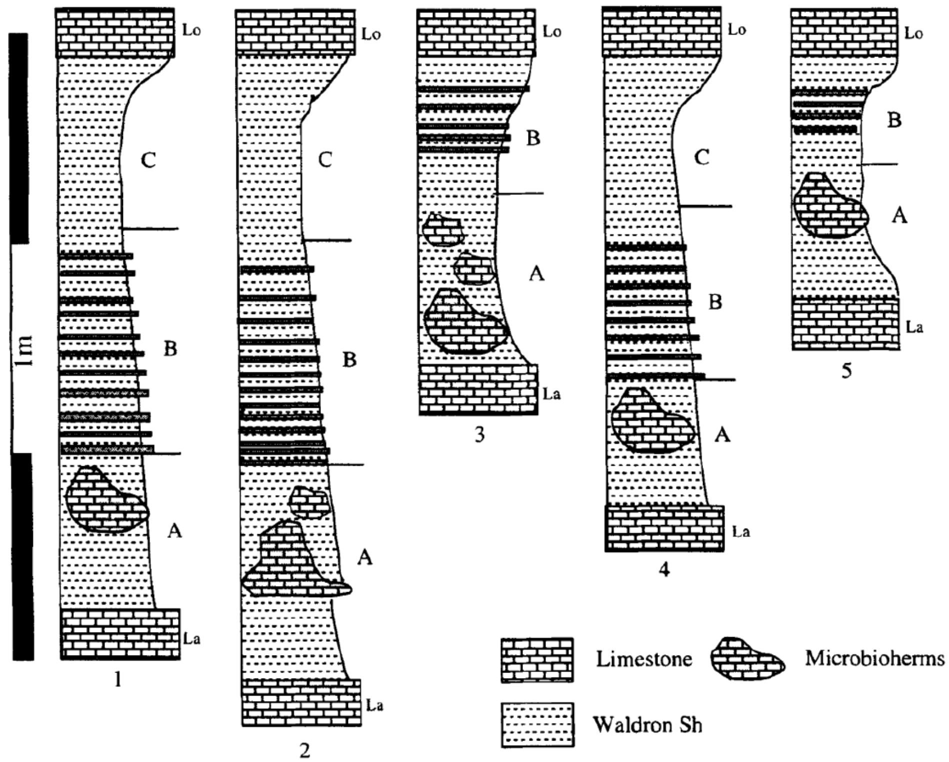


**FIGURE 3**—Sections showing thickness of Waldron Shale and approximate boundaries between paleocommunities; A = Facies A—Biohermal Community; B = Facies B—Inter-reef Community, C = Facies C—Deeper Platform Community; Lo = Louisville Limestone; La = Laurel Dolomite.

Stratigraphically complete sections of the Waldron exhibit four distinct facies that indicate changes in water depth, turbulence, and other parameters. Facies A, the lowest, is characterized by concentrated layers of fossils within shale horizons that exhibits patchy lateral distribution. These concentrations of fossils are interpreted to be the result of storm-influenced deposition with winnowing of finer sediment and some reworking of shell material. This suggests that the water depth of this horizon would be considered between normal to storm wave base. Micrite (lime mud) formed by algae indicated that this facies was within the photic zone. Small, mounded areas of fossil growth known as bioherms are known from Facies A, and fossils are most concentrated around these mounds.

Facies B contains fewer fossils and the small patchy mounds known from Facies A do not occur in this horizon. This facies is interpreted to have accumulated in somewhat deeper water, below normal-wave base though still in the photic zone. The bed is composed of thinly bedded mudstone with some more resistant dolomitic shale. At the base of some mudstone layers, beautifully preserved fossils can be found. These are thought to have been caused by episodic storm deposits, known as tempestites. The preservation of these thin layers also is indicative of a low amount of bioturbation within this unit. The thinly layered sediment indicate episodic pulses of mud may have come from coastal sources and/or were from resuspension of sediment by storms (Brett, et al, 2018).

Facies C contains fewer fossils, many of which are dolomitized and therefore poorly preserved. Some fossil preservation occurs with pyritization, which occurred after burial. The lower diversity assemblage may have been a result of high turbidity (i.e., water cloudiness) and/or lower levels of oxygenation. It is thought that this horizon represents deeper water, below storm wave base. Feldman also names a fourth Facies "D" as distinctive from Facies C because of lithologic changes (e.g., more clay-rich dolomite) however the change in lithology may be attributed to preservational processes and not depositional. In any case, this facies is not often recognized in studies of the Waldron. Feldman noted that the locations near the northern extent of the Waldron Shale in his study area exhibited a greater proportion of Facies C and D as compared to locations to the south.

According to Feldman, 1989, the pyritization of fossils after burial can be indicative of certain environmental conditions in which organic material experiences anaerobic decay which produced hydrogen sulfide that could be further oxidized to sulfur and/or combined with iron to form pyrite, during times when sedimentation rates were low, and when temperatures were warm and relatively stable year-round.

## Depositional Environment: Clark County, Indiana's Waldron

Feldman and Peters and Bork did not investigate the quarry localities in Clark County, Indiana. They became accessible and were studied by Goldstein from 1994 to 2009. The Sellersburg location is now used by the authors for educational programs (described later).

It is curious that exposures only a few miles away across the Ohio River in Louisville, Kentucky, the Waldron is poorly fossiliferous and the shale is heavily dolomitized. Exposures of this dolomitic shale in Oldham and Bullitt Counties, Kentucky, show poorly preserved macrofossils indicating that the fauna occurs, but that diagenetic processes during dolomitization have dissolved the calcite skeletal remains leaving poorly preserved steinkerns or nothing at all. In contrast, in Clark County, Indiana, all quarries contain varying densities of fossils some which are beautifully preserved and contain an unusual rich diversity of species noted below.

The lower section of the Waldron in Clark County is glauconitic, with a rich assemblage of fauna often with a distinctive greenish hue. Brachiopods are often found complete, while trilobite molts dominate and crinoidal remains are often fragmented. Cystoid thecae are complete and rarely crushed.

The middle section is dominated by dark gray shale. Fossils are sparser, but better preserved. The best *Calymene breviceps*, *Eucalyptocrinites crassus*, and large brachiopods like *Eospirifer*, *Meristella*, *Uncinulus*, and *Whitfieldella* are found in these layers. Calcite crystal vuggy interiors are common for the brachiopods. Mass mortalities of the gastropod, *Platyceras* (*Platystoma*) *niagarense* occur sporadically, often associated with *Calymene* molts.

A widespread bioherm layer contains Fistuliporid bryozoans in undulating masses as thick as 30 cm. This is traceable across the quarries in Clark County.

The upper Waldron is again glauconitic with a typically diverse fauna similar to the lower section. In Clark County, this layer contains additional fauna normally associated with the overlying

Louisville Limestone. Genera include the tabulate corals *Coenites*, *Heliolites*, and *Thecia* and the rugosans, *Asthenophyllum*, *Dokophyllum, Plasmophyllum*, and *Tryplasma*. No colonial rugosans like *Arachnophyllum* and *Entelophyllum*, abundant in the Louisville Limestone are known. The pentamerid brachiopod *Sieberella* is relatively common here, while other (larger) pentamerids like *Conchidium, Pentamerus* and *Rhipidium* are only found in the Louisville Limestone.

The contact between the Waldron and Louisville Limestone undulates but is relatively sharp in the quarries. The basal Louisville Limestone is orangish and is widely observed in shot rock because the quarries use this stratum as a bench for supporting heavy equipment. When the rock is blasted to remove Waldron, this limestone in always associated.

Two minerals are common in this shale. Brachiopods, gastropods and cystoids may be filled with calcite, either completely filled or as free modified scalenohedral crystals. Early diagenesis of this calcite kept the remains from being crushed as sediment compacted and lithified.

Euhedral pyrite is abundant in free crystals and partial to complete encrustation of skeletal remains. Cubes are most common, followed by octahedrons. Most crystals are under 5 mm though 3 cm complex cubes are known. The pyrite is golden when fresh and oxidizes to reddish. Pyrite trace fossil associations are well-documented. See Feldman (1989) for additional information about diagenetic processes involving mineralization.

## Fauna: Indiana

The fauna of Feldman's Facies A includes brachiopods, gastropods, bryozoans, crinoids and corals as well as some microfossils. Ostracods, juvenile gastropods and other fragmental elements are known to occur here. The fossils in this horizon are typically not in life position, though some bryozoans and corals are preserved in-situ.  Micritic algae are also noted here.

The fauna of Facies B is similar to that of Facies A though the preservation of the fossils is different. Some horizons within Facies B exhibit fragmented preservation. However, at the bases of some mudstone horizons complete, articulated and beautifully preserved specimens can be found. Complete crinoids, trilobites, and colonies of bryozoans are known from this portion of the Waldron. James Hall collected a completely articulated specimen of *Eucalyptocrinites crassus* from a location near Waldron Indiana, complete with holdfast, stem, cup, and crown (Feldman, 1989: Photo 3).

Facies C and D are less fossiliferous. They often exhibit dolomitized or pyritized fossils.

## Fauna: Clark County, Indiana

As mentioned above, certain genera and species are found in the Clark County outcrops that are not observed elsewhere or have some unique attributes.

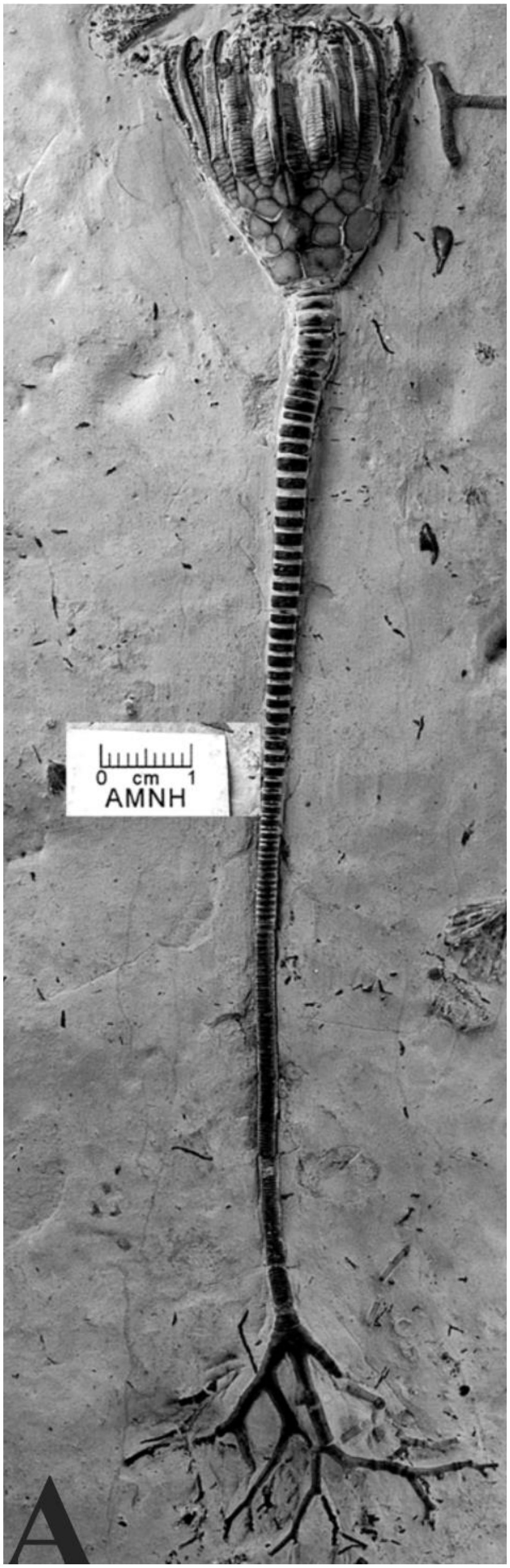


**Photo 3.** James Hall's complete *Eucalytocrinites crassus* specimen. (Roy Plotnick photo.)

If the Waldron Shale had a "flagship fossil," it would certainly be *Eucalyptocrinites crassus* (Photo 3). This crinoid is common throughout the shale, especially in smooth cone to bowl-shaped cups. This genus is unique with ridge strut-like plates separating pairs of biserial arms. Though the cups often are preserved in one piece, it's not unusual to find disarticulated body plates and partial arms. Complete calices of juveniles - under 2 cm tall - are not rare in Clark Co. deposits. Calices are often found in weathered shale where the column is not attached. Evidently, unlike most crinoid calices, these robust cups could persist on the seafloor for extended periods of time (up to several years) as indicated by the establishment of communities of bryozoans, worm tubes and other encrusters on evidently dead and inverted (from life position) calices (see Liddell and Brett, 1982). Slabs with relatively complete specimens are found, but not often. The "classic" tree root-like holdfasts are common in all Waldron locales (Photo 4). The most spectacular exceed 15 cm in diameter.

Rhombiferan cystoids are found almost exclusively in the glauconitic deposits, whether it is shale or a thin slab of limestone. They vary from five millimeters to 6 cm, but the extreme sizes are rare. *Caryocrinites perculptis* has very ornate plates, first described from the Waldron Shale west of Nashville, Tennessee, by Frank Springer (Photo 5). When collecting at the Atkin's Quarry from 1994 to 2009, one could find a cystoid about every two hours, though once, 12 in four hours were found. The blastoid *Decachisma pentalobus* is very rare. The authors are aware of only two or three found since 1994. The coronoid *Cupulocorona gemmiformis* is locally common, reaching a half-centimeter, though most are somewhat less.

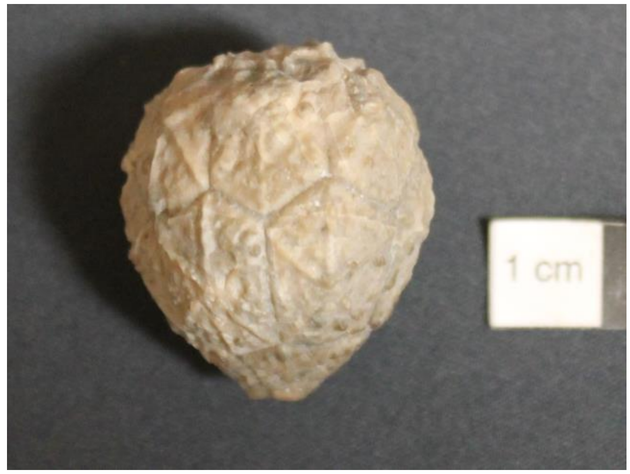


**Photo 4.** *Eucalyptocrinites crassus* holdfast. (John A. Catalani photo.)

**Photo 5.** *Caryocrinites perculptis*. (Goldstein collection and photo.)

The unusual crinoid *Myelodactylus convolutus* is common in the Waldron Shale. Most specimens consist of a flattened column shaped like a 9, 6 or C, missing the calyx and cirri. Well-preserved specimens with the tiny calyx visible are uncommon. The crowns are usually hidden within cirri (Photo 6).

*Lyriocrinus melissa* is uncommon and has a low bowl-shaped cup but often found with arms – partial or complete (Photo 7). In contrast *Periechocrinus christyi* (Photo 8) has a large very tall calyx with large plates. Other genera are found include the ornate *Melocrinus obconicis* Hall (common), *Botryocrinus polyxo* (uncommon), and *Dimerocrinus inornatus* (Hall) (uncommon). Other genera from Hall (1879, 1881), like *Calceocrinus*, *Ichthyocrinus*, *Macrostylocrinus*, and *Saginocrinus* have not been observed by the authors.


**Photo 6.** *Myelodactylus convolutus*. (Goldstein collection; Mark Schneider photo.)

**Photo 7.** *Lyriocrinus melissa*. (Falls of the Ohio State Park collection and photo.)


**Photo 8.** *Periechocrinus christyi* is not rare in Clark Co. and is easily recognizable by the elongated cup.

*Calymene breviceps* is large by the standards of other Waldron locations with specimens 5 cm (2-inch) length not uncommon (Photo 9). Partial *Trimurus delphinocephalus* are common. Complete specimens are rare but well documented (Photo 10). A complete enrolled *Ceratocephala* was found in the shale collecting piles at the Falls of the Ohio State Park and is now in their collections. *Harpidella christyi* is extremely rare. The authors are aware of one partial specimen found since 1994. Partial *Arctinurus* and *Litotix* with thoracic segments have been collected. In some cases, they are only partial because of the way the rock broke in the quarry shot.



**Photo 9.** *Calymene breviceps* (Goldstein collection).

**Photo 10.** *Trimurus delphinocephalus* (FOTO collection).

Brachiopods are dominated by typical Waldron genera. However, the pentamerid *Sieberella* is common. It resembles Nettleroth's *Sieberella knotti*, described from the Louisville Limestone (Photo 11). No research has been done to confirm this. It bears similarity with *S. roemeri* from Tennessee's Brownsport Group. *Dicocoelsia* is reported in the Waldron but not seen in Clark County.

Brachiopod expert, Paul Copper, identified specimens of the abundant atrypid as *Gotatrypa muldae* (Goldstein, personal comm. at NAPC, 2009.). This species is ubiquitous, often found with silver-white shells.


**Photo 11.** Except for *Sieberella knotti*, the brachiopod fauna consists of typical Waldron species. (FOTO collection).

Bryozoans are dominant fauna in the Waldron Shale. Because they are difficult to identify, they are usually ignored except for unusually well-preserved specimens. Fistuliporids form persistent beds in the shale. *Lichenalia* (formerly *Fistulipora*) *concentrica* is appropriately named for the concentric growth rings observed on the underside of colonies. Large, somewhat three-dimensional fenestrate bryozoans are found in thin limestone slabs. Only two species of fenestrate were described by Hall, *Fenestella acmea* has smaller fenestrules than *F. parvulipora.* There are, no doubt, more accurate means for identification with a microscope or thin sectioning.

The dominant tabulate in the Waldron is *Favosites forbes* var. *occidentalis*, which is likely a separate species (*Favosites occidentalis* Hall). It is often found grown on a crinoid column and the growth is often symmetrical indicating growth on an upright column of a live host. This allowed the colony to live above periodical mud incursions that corals didn't like. A common coral in the Waldron in Clark Co. is *Favosites discoideus* (Roemer). It lived on the seafloor apparently nearly immune to siltation. Colonies of 10 to 25 cm are found, especially in the upper layers. This is one of several tabulate corals that occur in the Waldron before it transitioned into the lime-mud-based Louisville Limestone.

Other less common tabulate species include *Thecia major* and *Thecia minor*, and the small but thick-branching *Favosites cristatus*. *Thecia* grew in thin, expansive colonies with somewhat star-shaped corallites. *Coenites* is uncommon but readily recognized by its anastomosing growth. Three species found include *C. reticulata* (smooth with round corallites the size of bryozoan zooecia; *C. aculeata* with a similar form and size but corallites have a protruding lip; rarest is *C. ordinata*, a larger diameter species.

Curiously, other common tabulate corals of Louisville Limestone like the halysitids and heliolitids are very rare to non-existent. Were they more susceptible to suffocation by clay particles than lime mud?

A similar situation is noted with rugose corals. *Duncanella* and *Streptelasma*, common in Waldron localities, are mixed with unfamiliar species. Two abundant species are *Asthenophyllum davisi*, a small trochoid to almost patelloid horn coral and *Plasmophyllum niagarense* (*Blothrophyllum niargarese* in Stumm, 1965), cylindrical form. The small trochoid genus *Tryplasma* is known from two species, *T. prava* and *T. mitella* in the Louisville Limestone, but are more difficult to identify as mud-filled calyx doesn't easily show septal structure. *Dokophyllum intertrium* (*Kodonphyllum* in Stumm, 1965) has distinctive support struts (like mangrove roots in form), only known in short stubs attached to the coral's epitheca.

Consult Erwin Stumm's Silurian and Devonian Corals at the Falls of the Ohio for photos of species of both coral types.

With some flat-based colonial organisms like *Fistulipora* and *Thecia*, one might expect other types of corals and stromatoporoids, abundant in the Louisville Limestone, to occur, but they are absent. Perhaps clay particles were deleterious keeping similar growth-form species, like *Arachnophyllum*, away?

Sponges of all types are virtually unknown in the Clark Co. Waldron. Uncommon, thin layered structures observed superficially resemble stromatoporoids need investigation and are likely algal mats. The abundance of herbivorous snails in the Waldron would support the hypothesis of abundant algae.

The benthic graptolite possibly *Desmograptus micronematodes* is found in carbonized colonies of various sizes (Photo 12).

Trace fossils are associated with pyrite, either in euhedral crystals or in iridescent microcrystals. Thin pyritized traces of various colors are abundant in the middle facies. They superficially resemble graptolites, but a magnifying lens will prove otherwise. Traces with pyrite spots have been found, possibly biogenetic in origin (Photo 13). Rare arthropod tracks have been found in limestone that filled the underlying shale. Brett (2015) describes detailed discussion of the paleoecology/modes of life of many of the genera common to the Waldron and Rochester Shale.

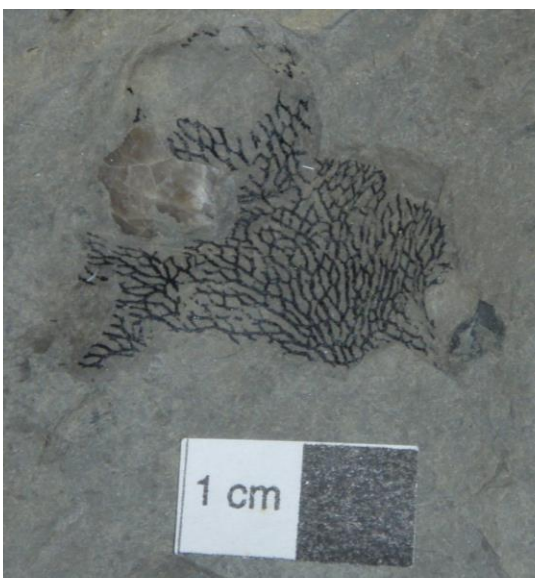


**Photo 12.** *Desmograptus micronematodes* found in the middle zone of the Waldron Shale. (Goldstein collection).

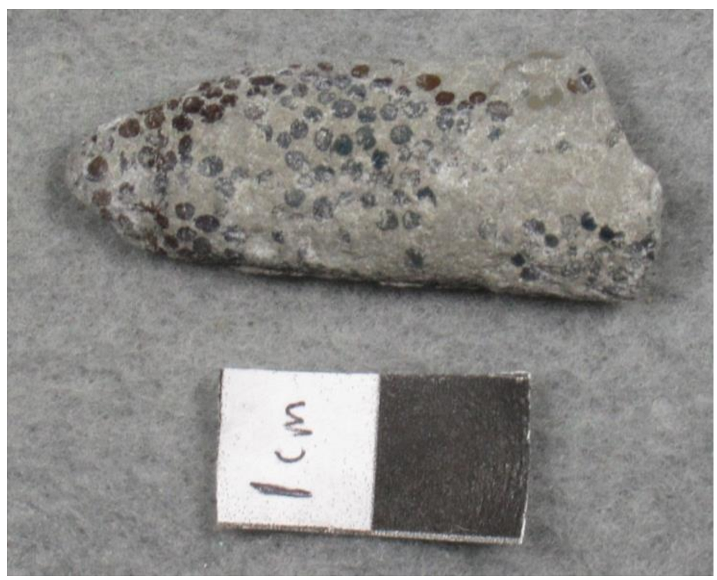


**Photo 13.** Trace fossil with spots composed of multiple-colored pyrite (FOTO collection).

## Waldron Shale Project

In 2015, authors Bulinski and Goldstein developed an educational outreach program for K-12 teachers called the Waldron Shale Project. Participating teachers receive a full day professional development workshop where they receive content-based instruction on geologic time and paleontology and then a 3-gallon bucket of fossiliferous Waldron Shale material from the Sellersburg Quarry (Irving Materials, Incorporated) of Clark County, Indiana. The teachers learn how to process the shale, so that fossils can be removed, cleaned, and identified. They then bring the materials back to their own classroom so that their students can experience a taste of paleontology research first-hand.

In 2019, we received a grant from the Kentucky Academy of Sciences to expand this effort. This allowed us to purchase supplies including brushes, magnifiers, fossil storage boxes and a digital microscope for each teacher. More recently the Sam Shine Foundation has extended this funding so that we can continue to offer these supplies for future workshops. The Waldron Shale project has an official website hosted at Bellarmine University which can be found here:
https://www.bellarmine.edu/arts-and-sciences/department-of-environmental-studies/the-waldron-shale-project/

Since 2015, over 100 teachers from across Indiana and Kentucky have participated, bringing paleontology to their students, year after year. We estimate that thousands of school children in the region have now had the opportunity to discover their own fossils as a result of this project. Teachers interested in participating in future workshops should consult the website above for information about how to apply.

This hands-on approach to science has been used as an introduction to how science "works" and in earth science lessons. Teachers tell us it is one of the students' favorite activities of the year. Many of the teachers incorporate a visit to the Falls of the Ohio State Park to the further connect the lesson to the real world (Photo 14**).**

**Photo 14.** Educators practice sorting fossils in a professional development at Bellarmine University. They apply this activity with their students in the classroom. (Kate Bulinski).

## Conclusion

The Waldron Shale is one of the best-known fossil deposits in Indiana. While accessibility to collecting localities is variable, it seems that there are ample localities that specimens seem to be available for collectors and scientists. The Indiana State Museum has a nice display of Waldron Shale fossils. Specimens may be seen in the National Museum of Natural History, Field Museum of Natural History and other museums.

While much is known about the formation and its fauna, there are plenty of areas for additional research by paleontologists – professional and amateur.

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