Algae

Both red and green calcareous algae are found in the Trenton and Black River Groups. These grains are much less common than the other skeletal grains observed in the formations.

Red Algae

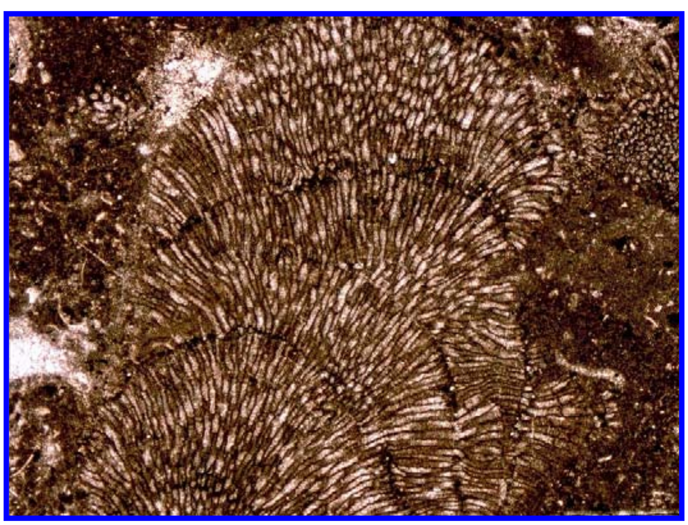
Red algae (Rhodophyta) belonging to the Family Solenoporaceae are observed in the Trenton-Black River. The red algae are composed of high-Mg calcite and the grains are generally cm-sized. The original internal and external structures of the red algae are often preserved because of their high-Mg calcite composition (Scholle and Ulmer-Scholle, 2003, p.22).

The red algae are identified by their very fine-scale reticulate, cellular or latticework internal structure. Solenoporoids are characterized by radiating tubular or filamentous structures and are often found as encrusting, rounded, or nodular masses (Scholle and Ulmer-Scholle, 2003, p.22).

Green Algae

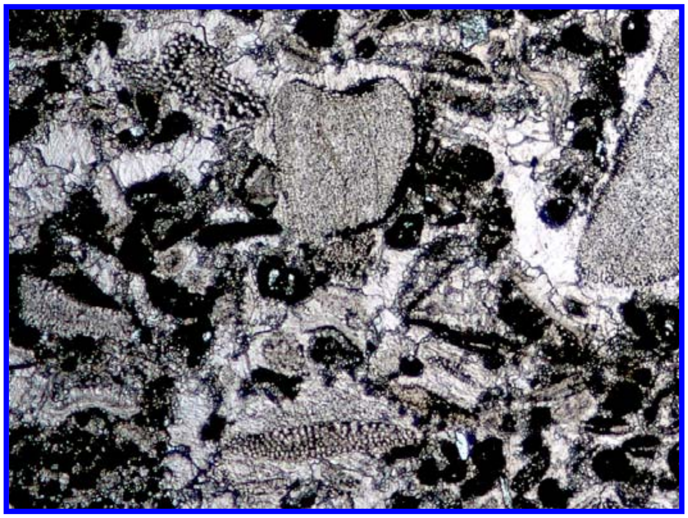
Green algae (Chlorophyta) also contribute to the sediment comprising the rocks of the Trenton and Black River Groups. The abundance of green algae is much less than that of other skeletal grains present, but is similar to the abundance of red algae.

The two important green algae groups important in the Middle Ordovician are the Codiaceae and the Dasycladaceae. We have identified Codiacian variety green algae in the Trenton and Black River rocks. The codiacean algae include *Halimeda* and *Penicillus,* which are common contributors to reefs and lagoons in modern carbonate environments. In thin section *Halimeda* occurs as rounded, sand-sized grains with a swiss cheese texture; Penicillus disintegrates to lime mud or micrite and is not discernible in thin section (Tucker, 1991).

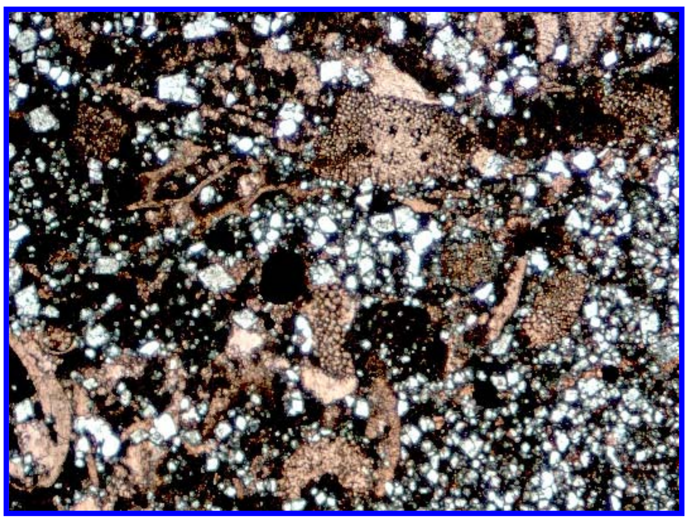


Red Algae, Example #1
West Virginia, Wood County, Trenton Formation, 9838 ft

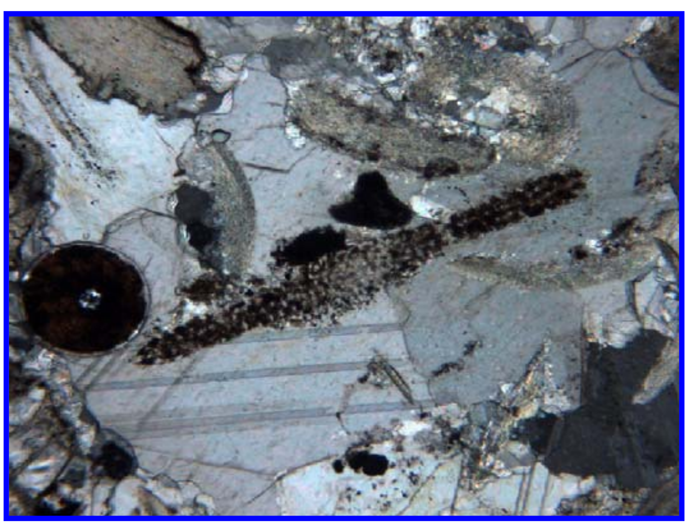
This large red algae grain shows the characteristic simple elongate cellular or tubular fabric of the Solenopora sp. This fragment occurs in a poorly sorted skeletal wackestone near the base of the Trenton Formation.



Green Algae, Example #2
West Virginia, Wood County, Trenton Formation, 10100 ft
There a few elongate codiacian green algae present in this skeletal grainstone of the Trenton Formation.



Green Algae, Example #3
West Virginia, Wood County, Trenton Formation, 10423 ft
There are numerous irregularly shaped codiacian green algae present in this dolomitized skeletal wackestone.



Green Algae, Example #4
Pennsylvania
This example of calcareous green algae is from the Trenton-Black River of Pennsylvania. The elongate grain is like the codiacian variety of green algae.

Brachiopods

Brachiopods were common in shallow Paleozoic seas and are common constituents of the faunal assemblages observed in the Trenton and Black River rocks of the study area. Brachiopods are bilaterally symmetrical with two valves or shells of unequal size. The shells range from smooth to corrugated or spiny. Brachiopods cannot be distinguished from bivalves in thin section without paying careful attention to the defining features of the shell microstructure (Scholle and Ulmer-Scholle, 2003).

The low-Mg calcite composition of most brachiopods shells often result in preservation of the shell microstructure. The common structure of a brachiopod shell consists of two layers. The thin outer or primary layer is comprised of fine calcite fibers oriented perpendicular to the brachiopod shell. The thin outer layer is not always preserved. The inner or secondary layer is thicker with calcite fibers inclined obliquely to the surface of the shell. The microstructure of the shell is most commonly fibrous, but can also be prismatic (Scholle and Ulmer-Scholle, 2003).

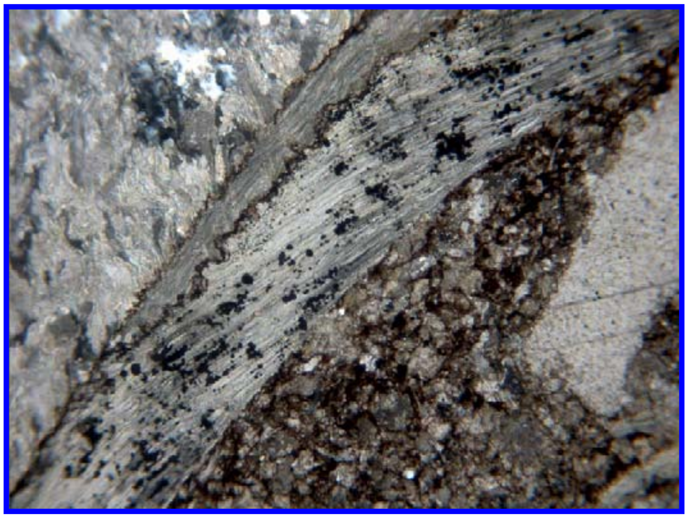
Modifications to the microstructure of the brachiopod result in distinct structures that can aid in brachiopod identification (Scholle and Ulmer-Scholle, 2003). These microstructures are:

- **Laminated –** interlaminated sheets of phosphate and chitin, not common in limestones
- **Impunctate –** primary and secondary layers lack perforations
- **Punctate –** shells have small holes that perforate the shell wall and are oriented perpendicular ot the shell surface, punctate are often filled with micrite
- **Pseudopunctate –** stacked, conical plications giving the shell a wavy appearance, unique to brachiopods, but found in only a few groups

Most of the features listed above are recognized in the brachiopods identified in thin sections of the Trenton and Black River Formations of the study area. Examples of these structures are shown below.

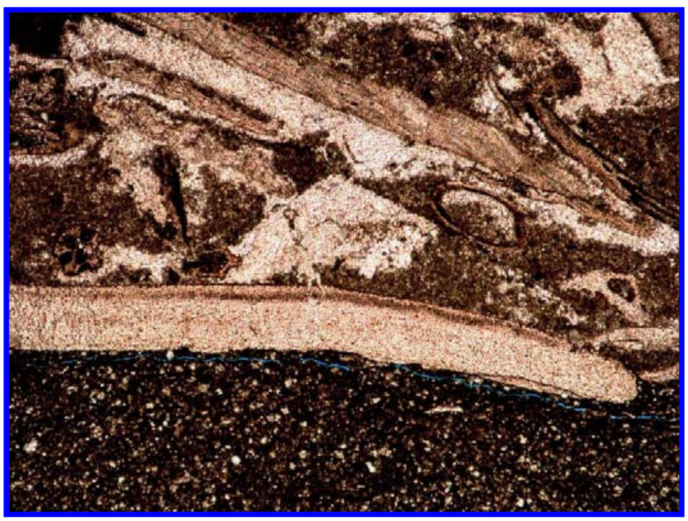
Brachiopod Example #1, Laminated
Pennsylvania, Union Furnace Outcrop, Trenton Group, Coburn Formation

This laminated brachiopod shell occurs in a dolostone and is the only original skeletal material preserved. The grain is phosphatic which is typical of laminated brachiopod shells composed of alternating sheets of phosphate and chitin. These grains are not very common in limestones.



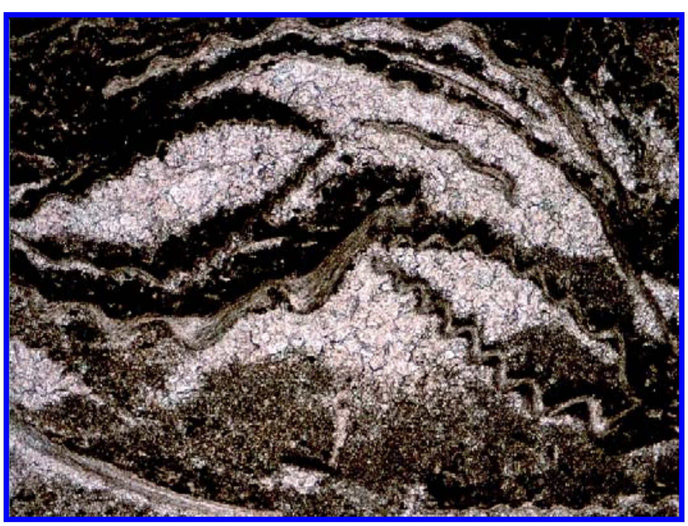
Brachiopod Example #2, Impunctate
Pennsylvania

This example of an impunctate shell also illustrates a 2 layer fibrous microstructure. The outer has been altered or micritized and the perpendicular orientation of the calcite fibers is no longer obvious. The oblique angle of the calcite fibers comprising the inner, secondary layer is very obvious in this photo. This grain has been partially pyritized.



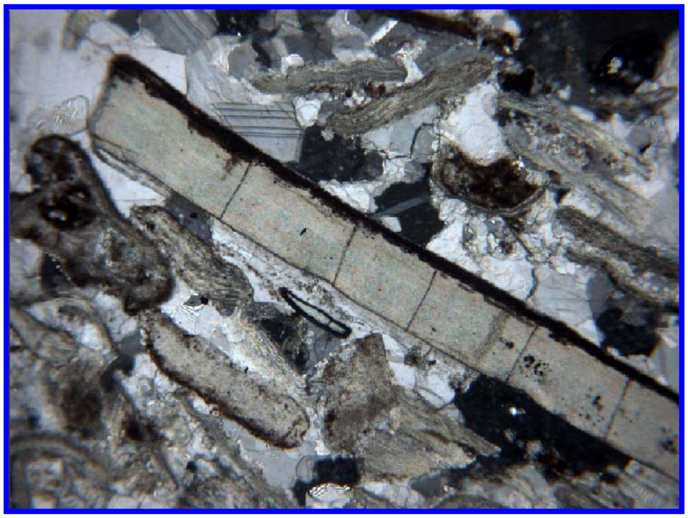
Brachiopod Example #3, Impunctate
West Virginia, Wood County, Trenton Formation, 9636 ft

There are three brachiopod fragments present in this photograph of a skeletal wackestone of the Trenton Formation. The two larger fragments are impunctate. The upper grain is a good example of the fibrous microstructure. The lower grain shows two distinct layers in the brachiopod grain. A cross-sectional view of a brachiopod spine is also present.



Brachiopod Example #4, Impunctate
West Virginia, Wood County, Sandhill Well, Trenton Formation, 9834 ft

The elongate brachiopod grains in this skeletal wackestone have a very distinct crenulated structure. Crenulations are common in the brachiopod grains observed in the Trenton and Black River.

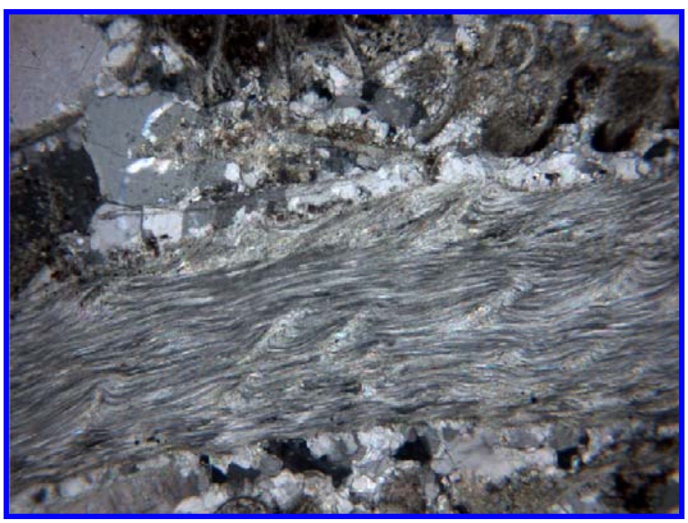


Brachiopod Example #5, Punctate
Pennsylvania, Union Furnace Outcrop

This large brachiopod grain does not have a distinct fibrous structure like that observed above, but punctate are present in this grain. The punctate are perpendicular to the surface of the shell and are dark in color because they are filled with micrite. There is also a micritic coating on the top edge of the grain.

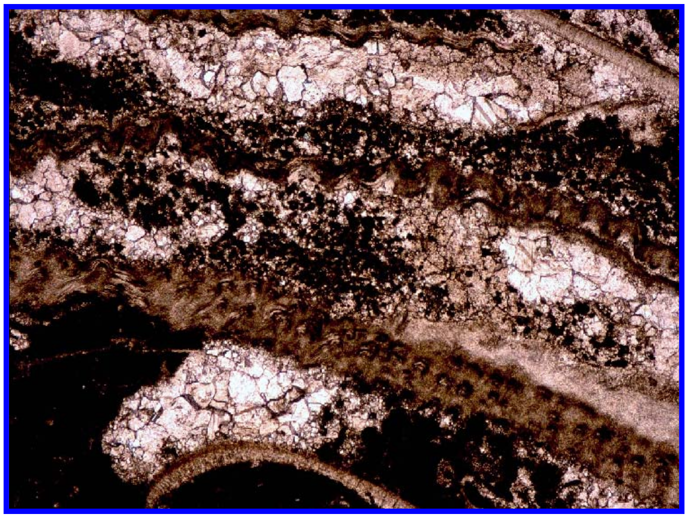
Brachiopod Example #6, Punctate
West Virginia, Wood County, Sandhill Well, Trenton Formation, 9602 ft

Micrite filled punctate are very obvious in this large brachopod grain from the Trenton Formation. The fibrous microstructure is maintained where it has not been penetrated by the punctate.



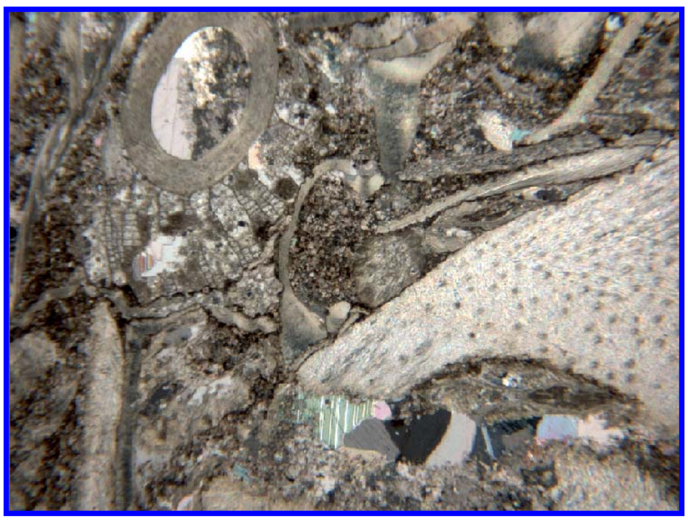
Brachiopod Example #7, Pseudopunctate
Pennsylvania, Union Furnace Outcrop

This detailed view of a brachiopod shell shows the fibrous microstructure and preserved pseudopunctate. The wavy appearance of the grain in this thin section is typical of brachiopod shell fragments throughout the Trenton and Black River.



Brachiopod Example #8, Pseudopunctate
West Virginia, Wood County, Sandhill Well, Black River Formation, 9912 ft

These brachiopod fragments occur in a skeletal packstone/grainstone of the Black River Formation. There are two different microstructures illustrated in this photograph. The upper brachiopod fragment has a fibrous crenulated shell. The lower fragment also has a fibrous microstructure, but the small round structures on the shell are pseudopunctate. This rounded or elliptical appearance results from an oblique, nearly transverse cut through the brachiopod shell. Note that the microstructure of the fragments has been preserved, but the surrounding skeletal grains have been replaced with sparry calcite.



Brachiopod Example #9, Spine
Pennsylvania

The brachiopod spine in this photograph has a concentric, parallel, fibrous inner layer. The central canal of the spine has been filled with sparry calcite cement.

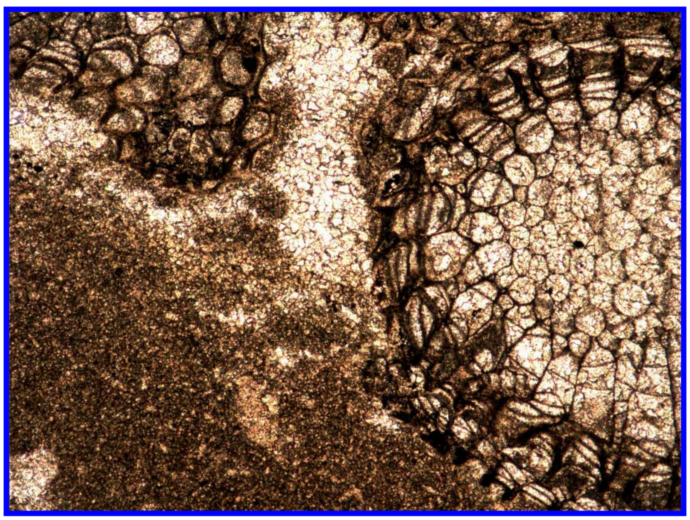
Brachiopod Example #10, Spine
West Virginia, Wood County, Sandhill Well, Black River Formation, 10146 ft

Most of the long spines present on certain groups of brachiopods are broken off during transport and deposition of the shells. In this example from the Black River Formation the spine has not been detached. The fibrous microstructure of this grain is evident.

Bryozoans

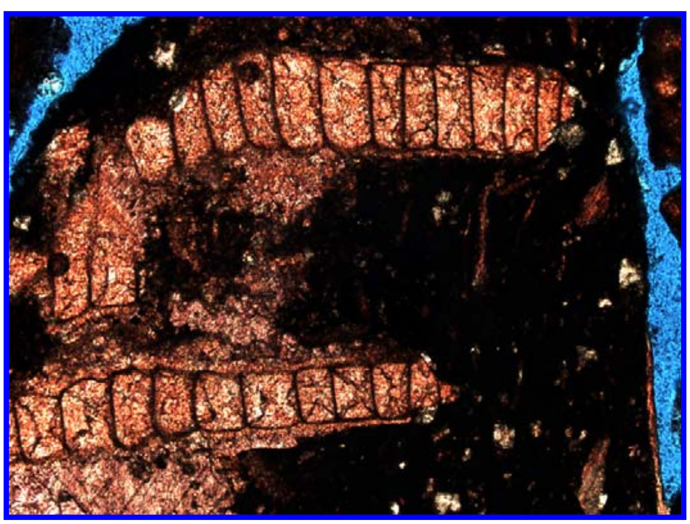
Bryozoans are colonial organisms with skeletons composed of both aragonite and calcite (Tucker, 1991). Bryozoans are very common in the Trenton and Black River rocks and often occur as large fragments in thin section. The morphology of the bryozoan fragments depends on the orientation of the grains in thin section and the species of bryozoan observed (Scholle and Ulmer-Scholle, 2003, p.124). Bryozoan skeletons consist of foliated calcite with round holes (zooecia) filled with sparite. The most common bryozoans of the Paleozoic are of the fenestrate variety (Tucker, 1991).

Bryozoans of the Trenton and Black River occur in all rock types ranging form mudstones to grainstones. The bryozoan fragments are typically large, but some smaller fragments are also present. The zooecia of the bryozan colonies are commonly filled with sparry calcite cement and in some cases fine micritic cement (Scholle and Ulmer-Scholle, 2003, p.124). The three most common orders of byrozoans observed in the Trenton and Black River are the Trepostomida, Fenestrida, and Cryptostomida. Examples of the three orders are shown below.



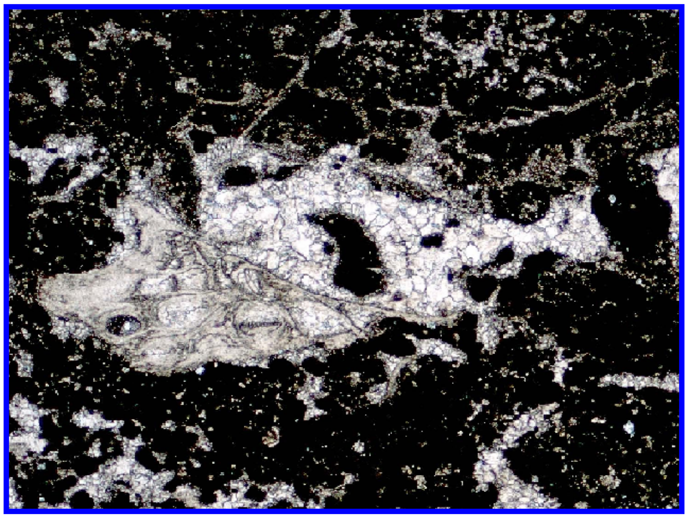
Bryozoan, Example #1, Trepostome
West Virginia, Wood County,
Trenton Formation, 9560 ft

This is an example of a transverse section of a trepostome bryozoan colony. The numerous diaphrams (partions) within in the zooecia are characteristic of treptosomes. The zooecia are well preserved because they have been filled with sparry calcite cement.



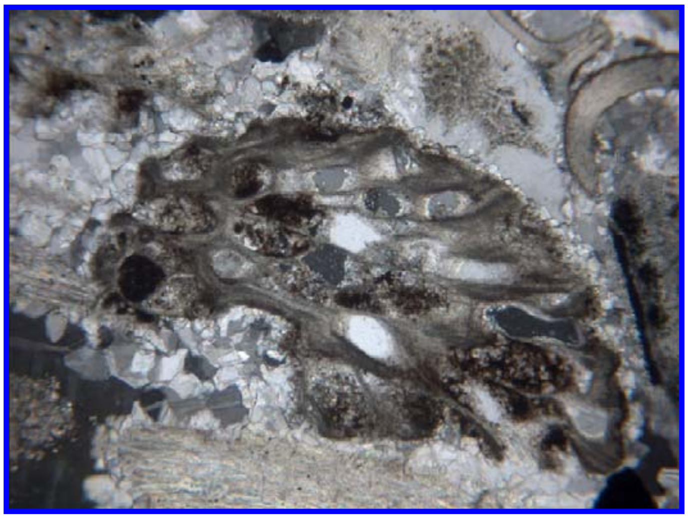
Bryozoan, Example #2, Treptosome
Pennsylvania, Bradford County
Bayles #1 Well, 12350 ft

The majority of this thin section is occupied by a Fistuliporoid bryozoan grain. The majority of the intergranular material surrounding the bryozoan is dark micritic matrix, but there is a small amount of calcite cement adjacent to the bryozoan.



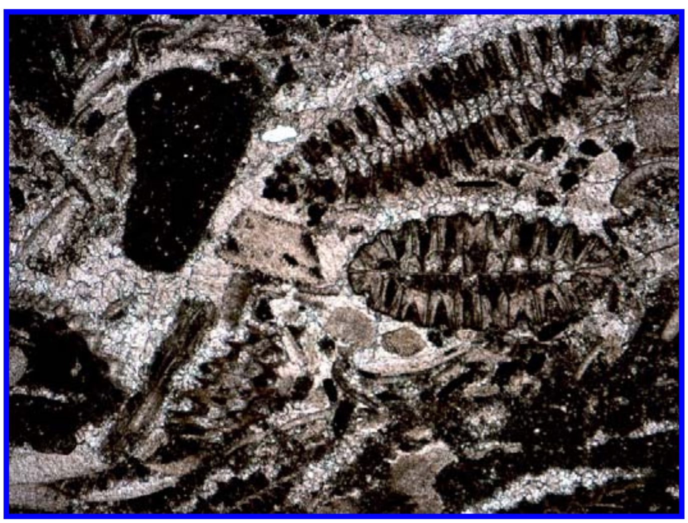
Bryozoan, Example #3, Fenestrate
West Virginia, Wood County,
Trenton Formation, 9884 ft

Fenestrate bryozoan colonies, such as the one in this thin section, are frequently observed in Paleozoic limestones. The zooecia wall structure is preserved in this structure and has a fibrous microstructure. The zooecia have been filled with sparry calcite cement.



Bryozoan, Example #4, Fenestrate
Pennsylvania

The fibrous microstructure of the zooecia walls of this fenestrate brozoan colony is preserved. The zooecia have been filled with both sparry calcite cement and fine-grained dark micritic cement.



Bryozoan, Example #5,
Cryptostomida, Ptilodictyina,
Stictopora fenestrata
Pennsylvania

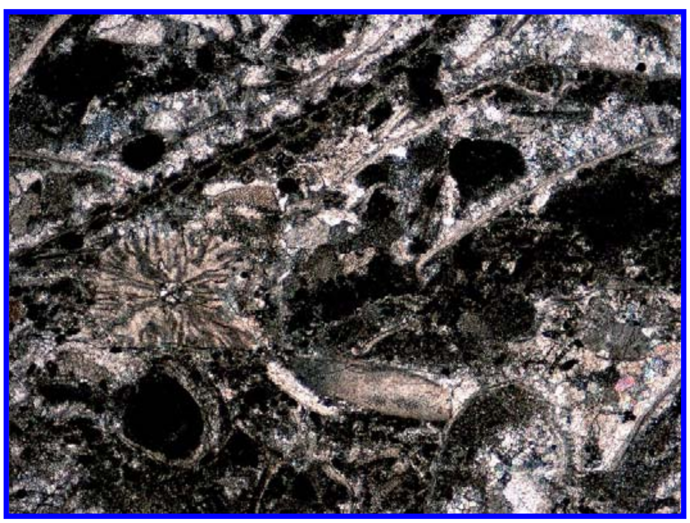
This is a transverse section through the bryozan, *Stictopora fenestrata*. These bryozoans have a bilateral symmetry and are often called bifoliates. The zooecial walls are laminated and flatten outward. These bryozoans typically occur as flattened branches.

Corals

Corals also contribute to the skeletal material observed in Trenton-Black River. In thin section corals are not as commonly observed as other skeletal grains, but they are common in the Pennsylvania, Union Furnace outcrop. The corals observed in the Trenton-Black River belong to the Order Tabulata and the Order Rugosa. Species determination of individual corals is dependent on the morphology of the coral skeleton. An outer wall and a series of internal vertical plates (septa), horizontal plates (tabula), and curved plates (dissepiments) characterized the coral skeleton. The original mineralogy of nearly all tabulate corals is calcite, but very few, including *Tetradium* corals may have been aragonitic (Scholle and Ulmer-Scholle, 2003, p.102).

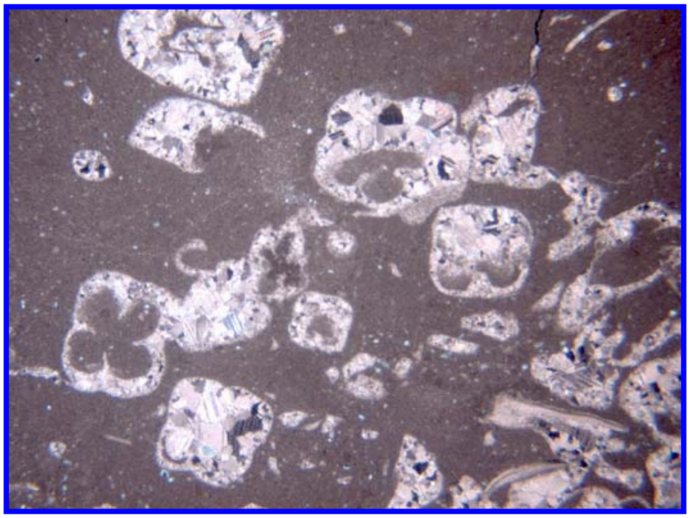
In thin section corals tabulate corals are recognized by the presence of individual corallites arranged in colonies. Corallites can be round, oval, or polygonal in shape. Horizontal tabulae are prominent and the septa are often not well preserved. Tabulate corals are distinguished from bryozoans because they generally form large colonies and have larger individual chambers (Scholle and Ulmer-Scholle, 2003, p.102).

Rugose corals are solitary or colonial. Solitary forms have distinct horn shapes in longitudinal sections. The septa are better developed than tabulate coral septa and the rugose corals are bilaterally symmetrical. In thin section the wall structure of the rugose corals have a fuzzy appearance and are often filled with clear calcite crystals (Scholle and Ulmer-Scholle, 2003, p.105).



Coral, Example #1, Rugose
West Virginia, Wood County, Trenton Formation, 9828 ft

This is a transverse section through a solitary rugose coral. The grain is round in shape with a central columella and the individual septa are preserved. The internal area between the brownish septa has been filled with sparry calcite.



Coral, Example #2, Tetradium
Pennsylvania, Union Furnace Outcrop, UF8,

The *Tetradium* corals in this thin section dominate this skeletal wackestone. Notice the distinct polygonal shape of these Tetradium. This cloverleaf like morphology is observed in thin section and outcrop. The corallites have been completely replaced with sparry calcite and no internal structure is preserved indicating that they were originally aragonitic in composition.

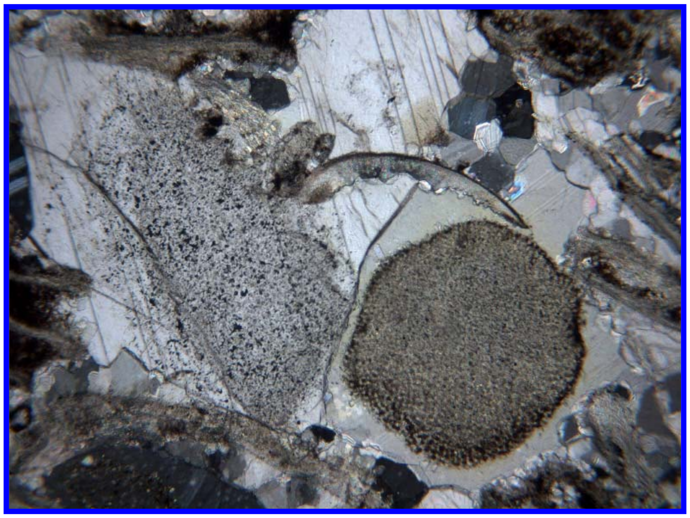
Coral, Example #3, Tetradium
Pennsylvania, Union Furnace Outcrop

Tetradium corallites are common in this skeletal wackestone. The grains have been replaced with calcite and no internal structure is preserved.

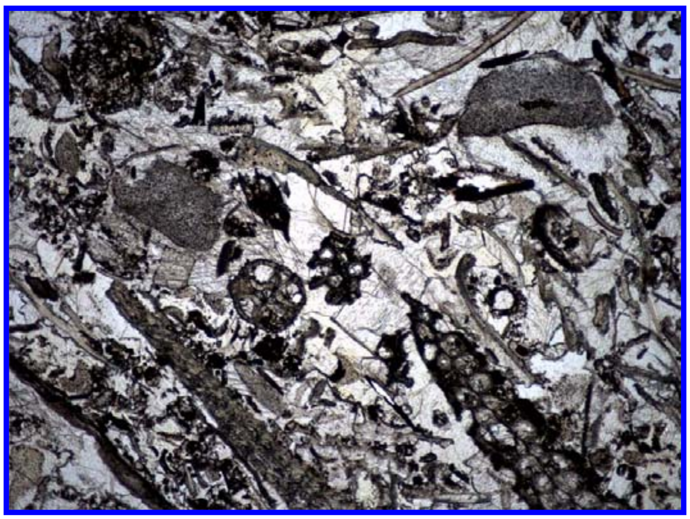
Echinoderms

Crinoids (Class Crinoidea) are the echinoderms present in the Trenton-Black River rocks. They are very abundant in all of the subtidal environments observed in these rocks. Crinoids are composed of high-Mg calcite and have distinct pentameral symmetry. Although whole crinoids reached greater than 1 meter in size they normally disaggregate into mm or cm sized plates or ossicles (Scholle and Ulmer-Scolle, 2003, p. 184).

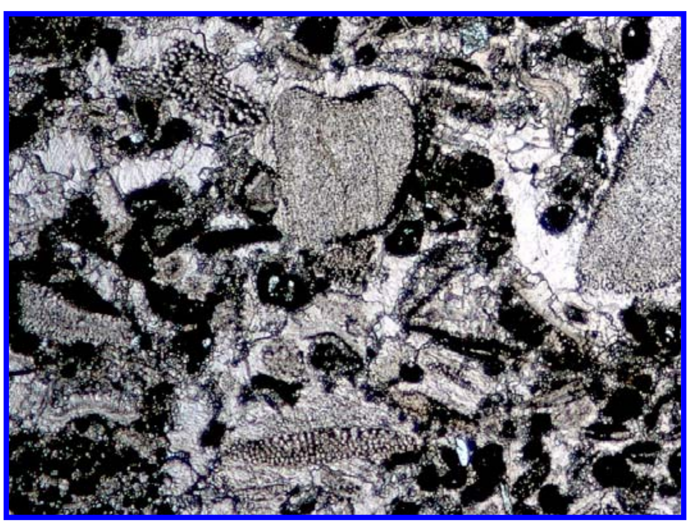
In thin section individual plates or columnals have circular, ovoid or pentagonal shapes and often have a central canal that is also circular or pentagonal. The single unit extinction of echinoderm fragments under crossed polars is the most distinct petrographic characteristic of these grains (Scholle and Ulmer-Scholle, 2003, p.184). This extinction pattern occurs because each individual skeletal component acts as a single crystal of calcite. The single crystal plates commonly have syntaxial overgrowths, which can form overgrowth cements (Tucker, 1991). Crinoid plates are often perforated with small pores that are visible in thin section if they have been filled with some contrasting material (commonly micrite or organic material). These filled pores result in a distinctive dusty appearance of crinoid fragments in thin section (Scholle and Ulmer-Scholle, 2003, 1991).



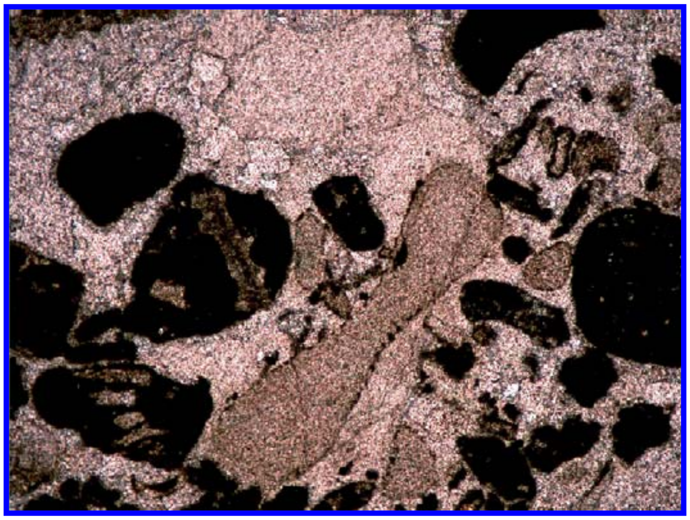
Echinoderm, Crinoid, Example #1
Pennsylvania
The crinoid present in this skeletal grainstone thin section is surrounded by clear calcite syntaxial overgrowth cement. The dusty appearance of the crinoid grain results from the filling of pores with micrite.



Echinoderm, Example #2
Pennsylvania, Mercer County, McKnight Well
There are several irregularly shaped crinoid fragments in this skeletal grainstone. The grains have a dusty appearance from the filling of pores with micritic carbonate material. Syntaxial overgrowth cements are not immediately obvious in this thin section, but are likely present.

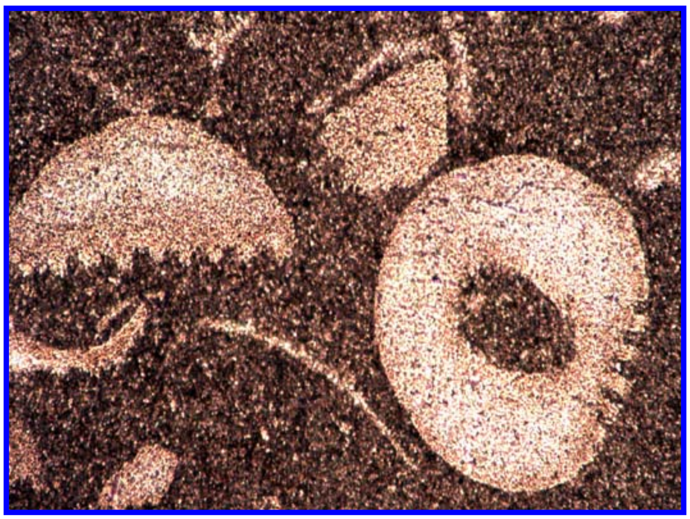


Echinoderm, Example #3
West Virginia, Wood County Well, Black River Formation, 10100 ft
The crinoids in this thin section are similar to those observed in the above photograph. The grains have pores filled with micritic carbonate giving them a dusty appearance. The grains are irregularly shaped.



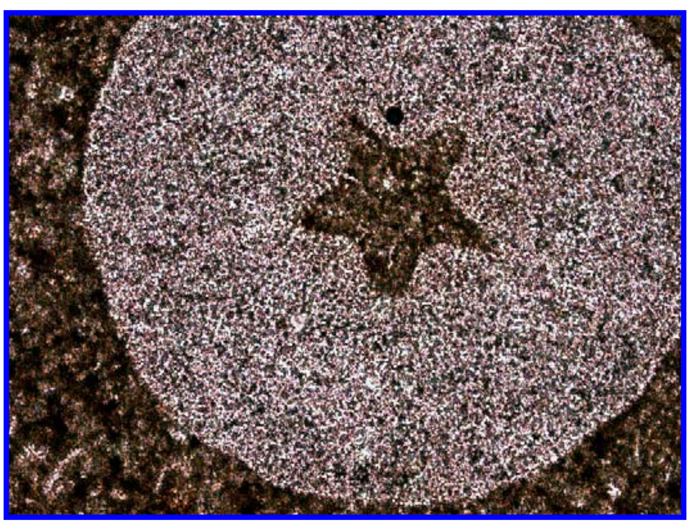
Echinoderm, Example #4
West Virginia, Wood County, Trenton Formation, 9798 ft

This thin section of a skeletal/intraclastic grainstone contains a distinct "dumbbell" shaped crinoid grain. This discoidal crinoid plate is thickest at its margins and thinner in the interior. There are some small borings filled with micrite at the edges of the grain.



Echinoderm, Example #5
West Virginia, Wood County, Trenton Formation, 9554 ft

There are several rounded crinoid grains in this skeletal wackestone. The central canal or columnella is present in the round grain on the right side of the section.



Echinoderm, Example #6
West Virginia, Wood County, Trenton Formation, 9532 ft

This star shaped canal in the center of this large rounded crinoid grain results from the pentameral symmetry of these skeletal grains.

Mollusks

Bivalves, gastropods, and cephalopods occur in the Middle Ordovician Trenton and Black River rocks. Bivalves and gastropods are the most common mollusks observed in thin section and examples are included in this discussion of the petrography of the Trenton-Black River in the Appalachian Basin.

Bivalves (pelecypods)

Bivalve species are found in marine, brackish, and freshwater environments (Tucker, 1991). Bivalves consist of two equal shells or valves whereas brachiopods valves are different shapes and sizes. The shell fragments observed in thin section are elongate, retangular to curved grains and are commonly disarticulated (Sholle and Ulmer-Scholle, 2003, p. 160).

Bivalves are aragonitic and consist of several layers of internal microstructure. The most common structure observed in bivalves is an inner layer composed of sheets of aragonite tablets and an outer layer of aragonite (or calcite) prisms. The aragonitic composition of bivalves often results in dissolution of the grains and repalcement by drusy calcite spar. Aragonitic shells may also be calcitized resulting in faint relics of the original microstructure. Bivalves with an original calcite mineralogy maintain their original microstructure and are often foliated and prismatic (Tucker, 1991).

Gastropods

Gastropods are abundant and diverse in normal marine conditions, but diversity decreases in hypersaline and brackish waters. Gastropod shells are primarily aragonitic with microstructure similar to the bivalve structure described above. This internal microstructure is not usually preserved and is typically replaced with drusy calcite spar. Gastropods are recognized in thin section by shell morphology which consist of distinctly curved shapes spiraled around a central axis (Tucker, 1991).

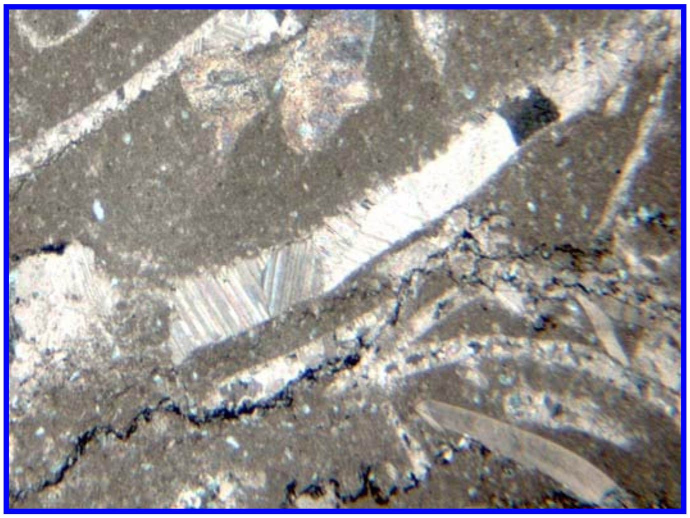
Mollusk micrsostructures *(Scholle and Ulmer-Scholle, 2003, p. 154)*:

Homogeneous—microstructure with no distinguishing characteristics; Wavy extinction-under crossed polars

Prismatic – certain layers of mollusk shells are composed of prismatic crystal shapes; Under crossed polars these prisms go to extinction at different times.

Granular – certain layers of mollusks are made up of small individual grains

Cross-lamellar – microstructure is composed of groups of little wedges, these wedges go to extinction at different times under crossed polars, mollusks are the only phylum to exhibit this type of microstructure.



Mollusk, Example #1 Bivalve

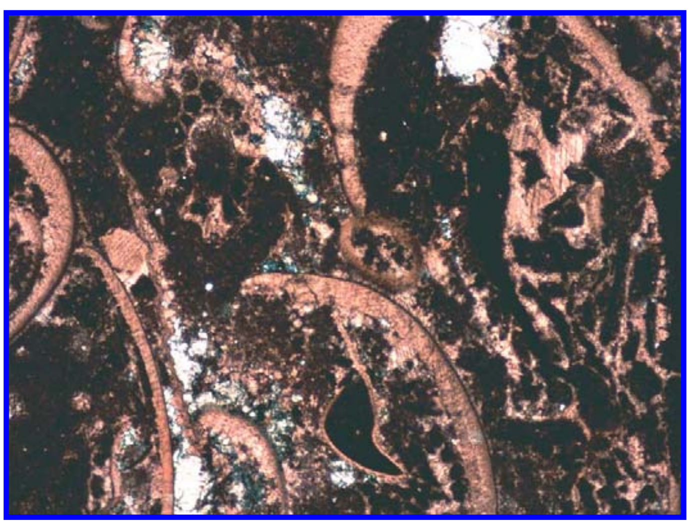
Pennsylvania, Union Furnace Outcrop, Nealmont Formation

There are several bivalve shells present in this skeletal wackestone. The majority of the smaller elongage grains have been replaced with drusy calcite cement. This replacement is a common diagenetic process observed in mollusk grains. The large bivalve fragement in the center of the thin section has a coarse prismatic microstructure that is a distinctive petrographic characteristic of mollusks. The coarse nature of the prisms suggests that they may have been diagenetically altered.

Mollusk, Example #1 Bivalve

West Virginia, Wood County, Trenton Formation, 9636 ft

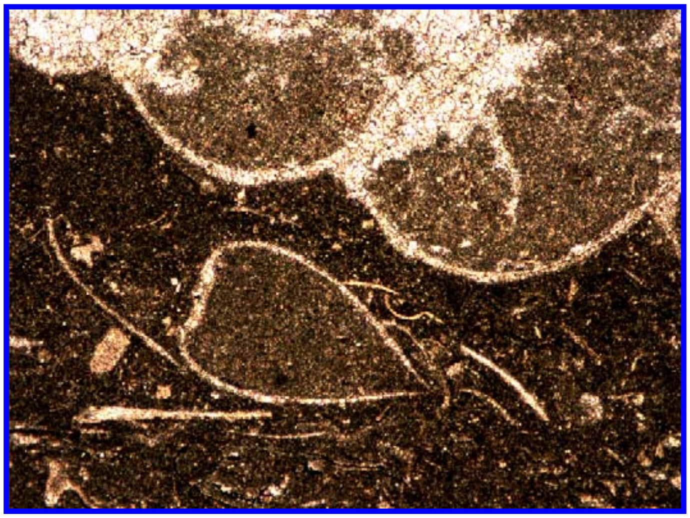
The bivalves in this thin setion are multilayered consisting of one fine, horizontally foliated layers, and coarser prismatic layers. This photograph was taken under crossed polars and the sweeping extinction pattern common in mollusks is evident.



Mollusk, Example #2 Bivalve

Pennsylvania, Black River Group

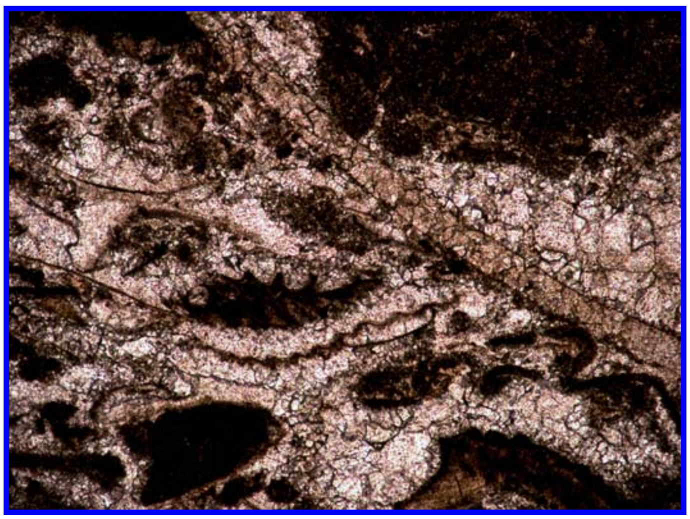
Mollusk fragments, primarily bivalves, are the most common skeletal grains in this packstone. The bivalves have micritized rims and the inner portion has been replaced with sparry calcite



Mollusk, Example #1 Bivalve and Gastropod

West Virginia, Wood County, Trenton Formation, 9538 ft

This skeletal wackestone contains both a gastropod fragment (top) and a bivalve fragment (center). No original shell material is preserved in either of the grains. The outer shell of the gastropod has been replaced with sparry calcite and paritally filled with micrite and partially filled with sparry calcite intragranular cement. The outer shell of the bivalve has been replaced with fine sparry calcite and the central portion has been filled with micrite.



Mollusk, Example #1 Bivalve

West Virginia, Wood County, Trenton Formation, 9570 ft

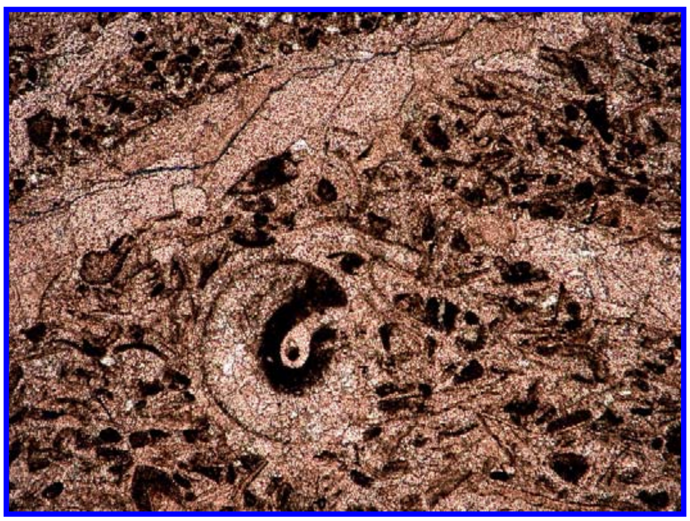
There is no original microstructure maintained in the large bivalve fragment in this skeletal grainstone. The grain is identified by its shape. The shell has been completely replaced with sparry calcite cement.

Mollusk, Example #1 Gastropod

West Virginia, Wood County, Trenton Formation, 10431 ft

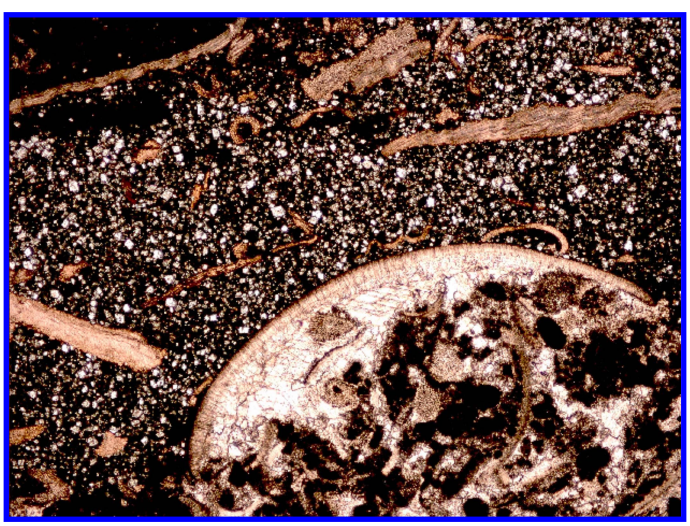
The gastropod in this thin section has a geometric shape that is often observed in gastropods of the Trenton-Black River. The outer shell of the gastropod has been replaced with fine calcite cement and the central portion has been replaced with coarser drusy calcite cement. There is a thin micritic rim surrounding the inner and outer portions of the gastropod shell.

Mollusk, Example #1 Bivalve
West Virginia, Wood County, Trenton Formation, 10048 ft
A single valve of a bivalve shell is shown in this thin section. The shell has been replaced with fine calcite cement. The upper portion of the shell has been filled with coarser calcite cement. This calcite has been partially dolomitized.



Mollusk, Example #1 Gastropod
West Virginia, Wood County, Trenton Formation, 9649 ft

The gastropod in this skeletal/peloidal grainstone has been completely replaced with calcite cement. The shape of the gastropod has been preserved because the outer layer of the shell has been micritized.



Mollusk, Example #1 Gastropod
West Virginia, Wood County, Trenton Formation, 9912 ft

This bivalve fragment has an outer micritized rim and a thin portion of the shell has the prismatic microstructure preserved. The central portion of the bivalve has been filled with coarse calcite spar.

Arthropods

Trenton-Black River skeletal debris belonging to the Phylum Arthropoda include fragments from both the Class Trilobita and the Class Ostracoda. Trilobites are more common than ostracodes in the rocks from the study area.

Trilobites

Although some of the individual trilobite grains observed in thin section are quite large they are composed of individual pieces that are less than 1 m in length and these small fragments are also observed. The large trilobite grains have a distinct morphology and are easily recognized. Trilobites are composed of calcite crystals oriented perpendicular to the wall of the shell. The crystals comprising the shell are very small and in thin section the microstructure appears homogenous, but under crossed polars it exhibits an undulose extinction pattern. Although trilobites usually have a smooth appearance they may have fine lamellar layers or be multilayered with organic rich, dark, outer layers (Scholle and Ulmer-Scholle, 2003, p.194).

The trilobite skeleton is composed calcite and variable amounts of calcium phosphate. The body of the trilobite is segmented often resulting in individual fragments present in thin section. The fragments have a characteristic "hook" or "shepard's crook" shape that is unique to trilobite grains (Scholle and Ulmer-Scholle, 2003, p.194).

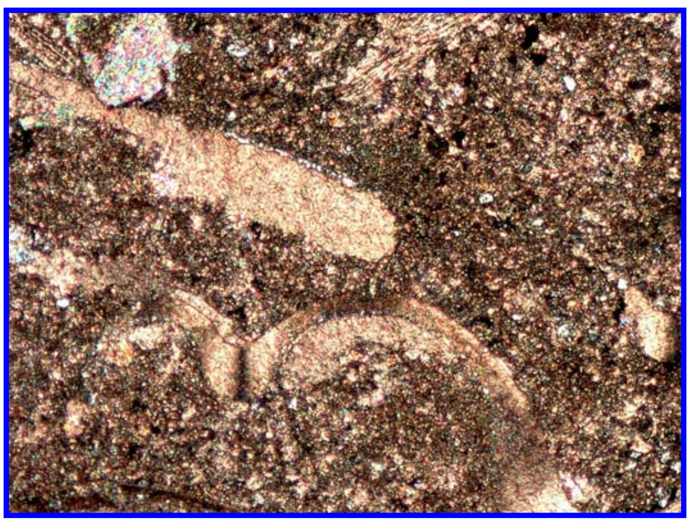
Ostracodes

Ostracodes are smaller than trilobites and are comprised of two valves usually less than 1 mm in diameter. These valves are jointed along a hinge and overlap slightly resulting in assymetrical valves in thin section. The ostracode shell is thin and composed of calcite and chitin. The valves are commonly disarticulated resulting in fragments in thin section (Scholle and Ulmer-Scholle, 2003, p. 198).

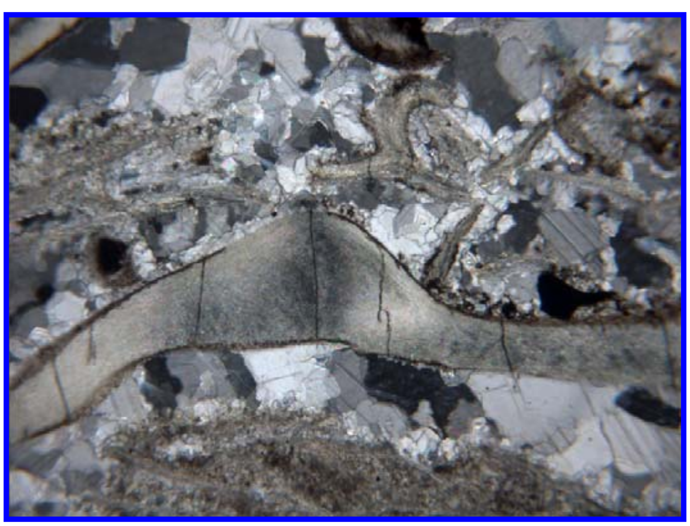
Ostracodes have homogeneous primatic and finely prismatic microstructures with crystals oriented perpedicular to the valves. The structures are usually well preserved. Under crossed polars ostracodes exhibit a sweeping extinction pattern, which differentiates them from most bivalves (Scholle and Ulmer-Scholle, 2003, p.198).

Trilobite, Example #1
West Virginia, Wood County, Trenton Formation, 9649 ft
The large trilobite grain in this skeletal grainstone has a distinct "shepard's crook" morphology that is characteristic of trilobites in thin section. The microstructure is homogeneous and there is slight micritization along the edges of the grain.

Trilobite, Example #2
West Virginia, Wood County, Trenton Formation, 9528 ft
There are several trilobite grains present in this skeletal packstone. They are easily distinguished from the other skeletal grains because of their “shepard’s crook” structure.



Trilobite, Example #3
West Virginia, Wood County, Trenton Formation, 9619 ft
The trilobite in this skeletal wackestone is a good example of the sweeping extinction pattern that is common in these skeletal grains. This photograph was taken under crossed polars and the extinction pattern is obvious by the alternating light and dark bands on the grain.

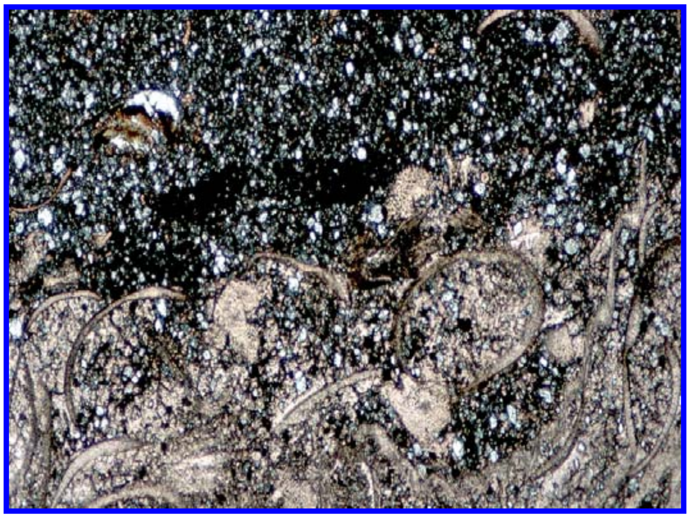


Trilobite, Example #4
Pennsylvania

This large trilobite has a convoluted shape that is common in these skeletal grains. The vertical lines on the grain are fine perforations (canaliculi) filled with micritic sediment.

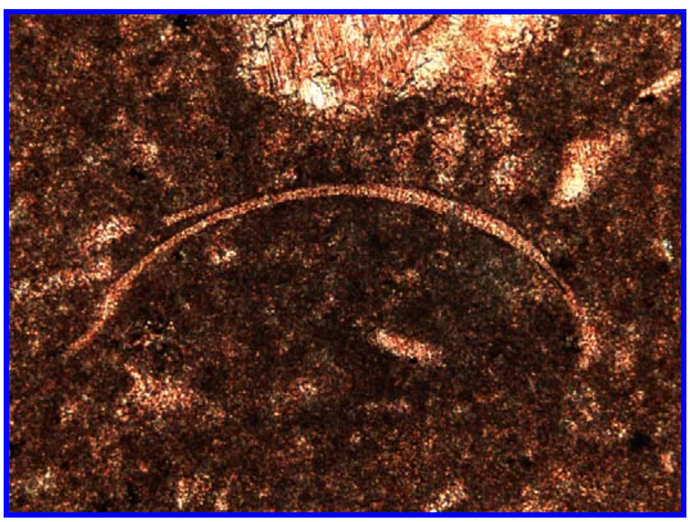
Trilobite, Example #5
West Virginia, Wood County, Trenton Formation, 9574 ft

This large convoluted trilobite grain is brownish in color due to the chitinous and organic constituents of the shell



Ostracodes, Example #6
West Virginia, Wood County, Black River Formation, 10131 ft

The small size of the ostracode grains at the bottom of this thin section is typical of these skeletal grain types. Note the curved, disarticulated valves that thicken toward one end.



Ostracode, Example #7
Pennsylvania

The rounded shape and thin shell shown in this photograph are typical features of ostracode grains.