Contributions
in Biology
and Geology

Number 35 September, 1980

Stratigraphy and Paleontology of the Maquoketa Group (Upper Ordovician) at Wequiock Creek, Eastern Wisconsin

Paul A. Sivon
Department of Geology
University of Illinois
Urbana, Illinois

MILWAUKEE
PUBLIC
MUSEUM

REVIEW COMMITTEE FOR THIS CONTRIBUTION:
T.N. Bayer, Winona State College University, Winona Minnesota
M.E. Ostrom, Wisconsin Geological Survey, Madison, Wisconsin
Peter Sheehan, Milwaukee Public Museum

ISBN:0-89326-016-4

Milwaukee Public Museum Press
Published by the Order of the Board of Trustees
Milwaukee Public Museum
Accepted for publication July, 1980

Stratigraphy and Paleontology of the Maquoketa Group (Upper Ordovician) at Wequiock Creek, Eastern Wisconsin

Paul A. Sivon
Department of Geology
University of Illinois
Urbana, Illinois

Abstract: The Maquoketa Group (Upper Ordovician) is poorly exposed in eastern Wisconsin. The most extensive exposure is found along Wequiock Creek, about 10 kilometers north of Green Bay. There the selection includes a small part of the upper Scales Shale and good exposures of the Fort Atkinson Limestone and Brainard Shale.

The exposed Scales Shale is 2.4 m of clay, uniform in appearance and containing no apparent fossils.

Limestone and dolomite dominate the 3.9 m thick Fort Atkinson Limestone. The carbonate beds alternate with layers of dolomitic shale that contain little to no fauna. The shales represent times of peak terrigenous clastic deposition in a quiet water environment. The carbonates are predominantly biogenic dolomite and biomicrite. Biotic succession within single carbonate beds includes replacement of a strophomenid-*Lepidocyclus* dominated bottom community by a trepostome bryozoan-*Plaesiomys-Lepidocyclus* dominated community. Transported echinoderm and cryptostome bryozoan biocalcarenites are common.

Bioclasts of the biocalcarenites were subjected to mechanical transport by moderate currents as evidenced by parallel and small-scale cross-laminations. The absence of mechanical wear on the larger allochems suggests deposition by moderate currents. Abundant corals in the upper 0.75 m of Fort Atkinson suggests increased agitation and shallowing.

The Brainard Shale is 23.0 m of shale and claystone with carbonate beds near the base and top of the formation. The presence of laterally-linked hemispheroidal algal stromatolites strongly suggests clastic deposition occurred in a protected marine mudflat environment.

The carbonate beds of the Brainard represent a less restricted, deeper

water environment than the shales. A normal marine fauna developed with the colonization of the argillaceous substrata by a *Thaerodonta-Diceromyonia*-trepostome bryozoan community. As shell debris accumulated, *Thaerodonta* and *Diceromyonia* declined and were succeeded by trepostome bryozoans. *Cornulites*, a fossil of uncertain affinity, is restricted to approximately 0.6 m of strata in the upper Brainard.

INTRODUCTION

The Maquoketa Group (Upper Ordovician) extends throughout large areas of Iowa, Illinois, Wisconsin, and Minnesota. The stratigraphy and paleontology of this group has been extensively studied in Iowa and Illinois. Comparatively little is known of the Maquoketa of eastern Wisconsin.

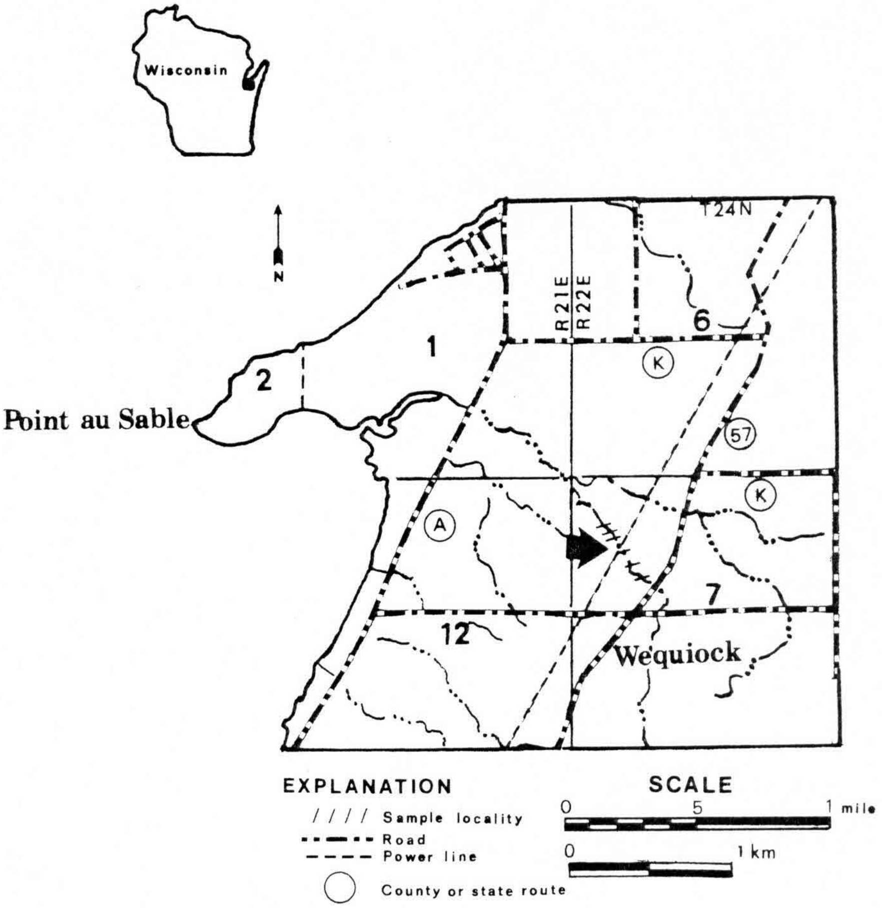

Fig. 1. Location of study.

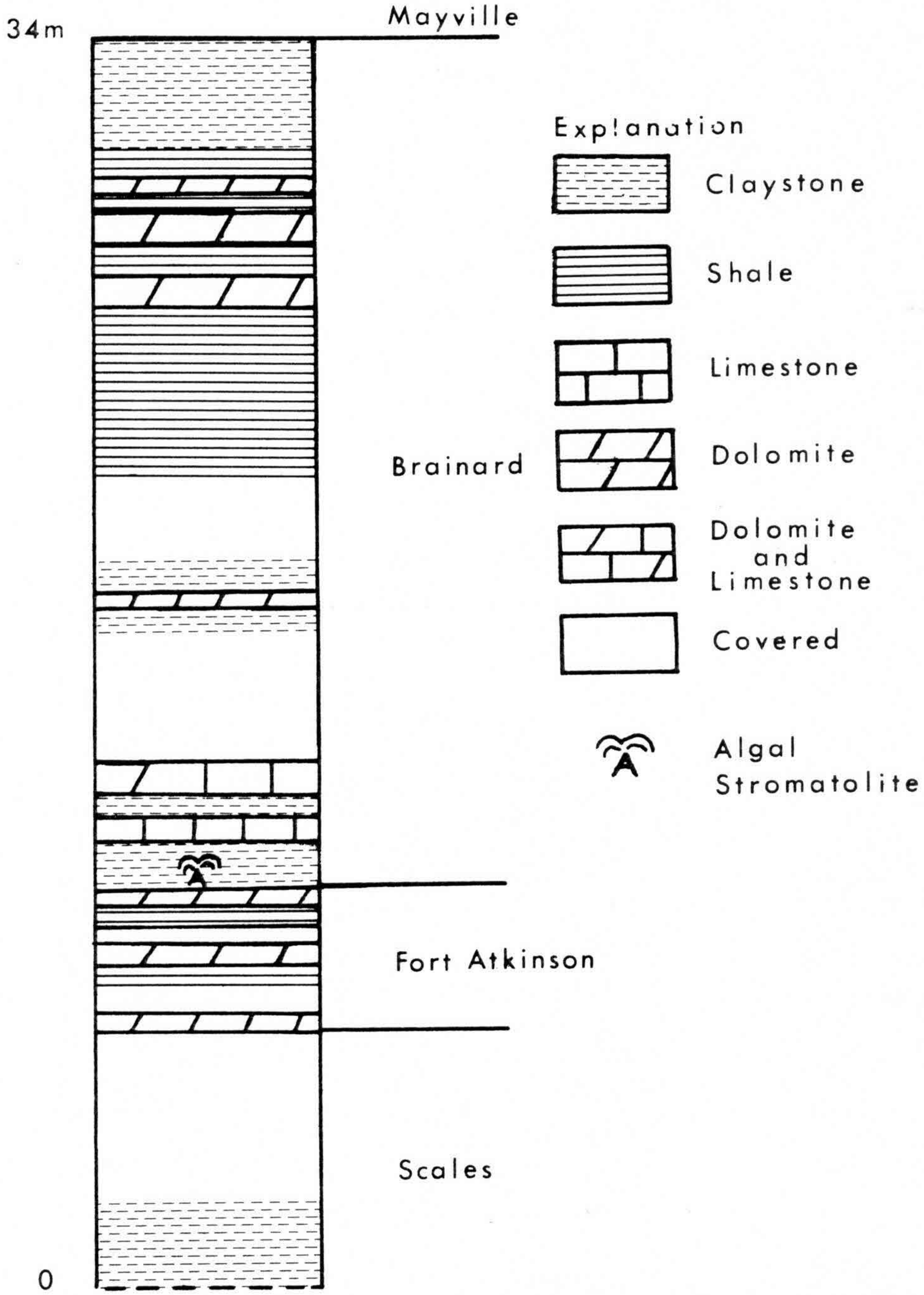

Fig. 2. Generalized columnar section of the Maquoketa Group at Wequiock Creek.

The Maquoketa is easily eroded and outcrops in eastern Wisconsin are rare and commonly very thin. The thickest outcrop in eastern Wisconsin is along Wequiock Creek, about 10 km north of Green Bay (Figure 1). This outcrop exposes the upper part of the Scales Formation, the Fort Atkinson and the Brainard Formations of the Maquoketa Group (Figure 2). This paper describes the lithology and the fossils and presents an interpretation of the paleoenvironment and paleoecology of the Maquoketa exposed along Wequiock Creek.

Geologic Setting

White (1870) first used the name Maquoketa Shales. The type locality is along the Little Maquoketa River, near Dubuque, Iowa. Calvin (1906) recognized four members of the Maquoketa in Iowa; from lowest to highest these are the Elgin, Clermont, Fort Atkinson, and Brainard. Templeton and Willman (1963) recognized, as had others (e.g., Savage, 1924), that four lithic units, similar lithologically to four members of the Iowa Maquoketa, were found in Illinois. Templeton and Willman (1963) modified the nomenclature in Illinois. They argued that the Fort Atkinson Limestone and Brainard Shale warrant formational rank because of their extent, thickness, and distinctive lithology and the Elgin and Clermont Shales, which are not easily separated in Illinois, should be included in a new formation, the Scales Shale. These changes required elevation of the Maquoketa to group status. The nomenclature of Templeton and Willman has been applied to the Wisconsin Maquoketa by Ostrom (1967).

The Maquoketa in eastern Wisconsin consists of a lower shaly formation, the Scales Shale, which rests unconformably on the Galena Dolomite (Moretti, 1971). The Scales is overlain by a dolomite and dolomitic limestone formation, the Fort Atkinson, and an upper shale formation, the Brainard Shale. Locally the Neda Formation, an oolitic hematite of uncertain age (Ostrom, 1967) overlies the Brainard. The Neda is absent along the Wequiock Creek section and the Brainard Shale is overlain by the massive Mayville Dolomite of the Niagaran Escarpment.

The Scales is named for Scales Mound, Jo Daviess County, Illinois (Templeton and Willman, 1963, p. 135). It is generally 25-35 m thick in Wisconsin (Ostrom, 1967). Two zones with distinctive pyritic and phosphatic beds are known as the depauperate zones and contain only small fossils, mostly molluscs. The Lower Depauperate Zone, at the base of the Scales Shale, is widely present while the Upper Depauperate Zone, near the top of the Scales Shale, is found only locally and is not found at Wequiock.

The Fort Atkinson Limestone is named for exposures at Fort Atkinson, Winneshick County, Iowa, where there are approximately 13 m of

"Massive, yellow, cherty, dolomite and associated beds of limestone" (Calvin, 1906). In Illinois the Fort Atkinson is commonly 5-13 m thick (Templeton and Willman, 1963) and in Wisconsin has a maximum thickness of approximately 13 m (Ostrom, 1967). The Fort Atkinson is fossiliferous with a large fauna of brachiopods and trepostome bryozoans.

The type section of the Brainard Shale, near Brainard, Fayette County, Iowa, is 40 m of blue and bluish-gray shale, with limestone near the top and base of the division. In Illinois the Brainard Shale is approximately 30 m thick where it is not deeply truncated by the sub-Silurian unconformity (Willman, et al., 1975). The Brainard in Wisconsin has a maximum thickness of about 30 m, is commonly fossiliferous and characterized by a zone of *Cornulites* in its upper part.

Templeton and Willman (1963) assign the Scales Formation to the Edenian and probably the Maysvillian Stages and the Fort Atkinson and the Brainard to the Richmond Stage of the Cincinnatian Series. Based on conodont studies of the Iowa Maquoketa, Glenister (1957) concluded that the basal strata, including the Lower Depauperate Zone, were clearly pre-Richmond in age and that the remaining upper Maquoketa is Richmond or older. Pulse and Sweet (1960), in a comparison with the North American conodont standard, placed the Elgin, Clermont, and the Fort Atkinson of Iowa as late Edenian and early Maysvillian. They found that the Brainard Shale contains long-ranging ubiquitous mid-continent species while the limestones of the upper Brainard yield *Phragmodus* and *Panderodus* suggesting an early Richmond age.

Late Ordovician graptolites found in the Maquoketa of eastern Missouri suggest correlation with graptolite zone 15 (*Dicellograptus companatus* var. *ornatus*) which includes the upper part of the Maysville and the Richmond (Berry and Marshall, 1971).

Location of Study

In eastern Wisconsin the Maquoketa is occasionally exposed in a narrow band trending northward and paralleling the eastern border of the state from Door County, Wisconsin to Illinois. The Maquoketa dips 1 to 2 degrees to the east on the eastern flank of the Wisconsin Arch. Exposures are commonly associated with waterfalls and cascades formed by streams flowing over the west wall of the Niagaran Escarpment. The Silurian dolomite of the Escarpment acts as a protective cap rock for the less resistant Maquoketa. Downstream from the Niagaran-Maquoketa contacts, resistant limestone and dolomite beds of the Fort Atkinson Formation may be exposed in a series of step-like cascades.

The upper part of the Maquoketa crops out along Wequiock Creek below a waterfall at a roadsize park about 10 km north of Green Bay, along Wisconsin 57; NW 1/4 sec. 7, T. 24 N., R. 22 E., of New Franken, WI. Quadrangle (Figure 1).

Previous Investigations

Ladd (1929) in a comprehensive study of the Maquoketa of Iowa, has summarized the pertinent literature through 1929. Differences which exist between the Maquoketa and the type Richmond have been attributed to an intervening land mass during deposition (Ladd, 1929). Gustadt (1958, p. 515) in a review of subsurface information concluded that "the type Cincinnatian Series and the Maquoketa Shale form a continuous rock unit with evidence of only local absence of Eden and Maysville equivalents and no evidence of intervening landmass at any time." Thus the Cincinnati Arch was not a positive feature during the Cincinnatian and was not an effective barrier to westward transport of clastics from the east.

Jones (1931) in one of the few studies dealing with the Maquoketa of eastern Wisconsin recognized lithologic equivalents in northeastern Illinois. Lists of fossils from the Lake Winnebago and Green Bay, Wisconsin regions formulated by Jones were meager and derived in part from debris.

Few paleoecologic studies of the Maquoketa faunas have been attempted. Bayer (1967) recognized a repetitive fossil benthonic community in the Elgin Member of the Maquoketa of Minnesota and believed lateral changes in community structure reflects proximity to shoreline.

Snyder and Bretsky (1971) believed the fauna of the depauperate zone of the basal Maquoketa was a paedomorphic community which had been selected for early maturity and high fecundity in a high stress environment.

Methods

The stratigraphic section along Wequiock Creek was measured with a Jacob's staff and ruler. Samples of 5 to 20 kilograms of rock were collected from carbonate beds and 1 to 3 kg from fine-grained clastic beds. All carbonate beds were sampled from carefully noted stratigraphic positions. Tops and bottoms of the beds were noted to allow description of faunal differences within individual beds. Shale and clay beds, which are commonly thick, homogenous, and poorly lithified in the Maquoketa, were sampled in bulk at irregular intervals.

Carbonate lithologies were examined with hand samples, polished slabs, and thin-sections. Alizarian red stain was used to distinguish between calcite and dolomite (Friedman, 1959). Selected samples of the fine-grained clastics were analyzed by x-ray diffraction techniques to identify common constituents.

This investigation focuses upon invertebrate fossils. The fossils are primarily dolomitic replacements. Preservation is poor in the largely unfossiliferous shales and clays. Some shales contain nodules and lenses of fossiliferous carbonate material; these shales were washed to obtain their fossils.

The fauna of the carbonate beds is more abundant and better preserved than that of the shales. Brachiopods, though dolomitized, are commonly identifiable to the generic level. Wang's (1949) study of the Maquoketa brachiopods of Iowa was a useful guide to identification. Due to the character of preservation, the separation of the genera *Tetraphalerella* and *Strophomena* was not feasible. These closely related forms are grouped as strophomenids. Corals and gastropods are identified to the generic level. Bryozoans are recrystallized and are identified only to the ordinal level.

The fauna of the carbonate beds and lenses in the shale is quantified to identify fossil assemblages and to aid in recognition of faunal changes both within individual beds and through the section. Each identifiable articulated brachiopod, isolated brachiopod valve, gastropod, solitary and colonial coral, and trepostome fragment greater than 1 centimenter in length, is counted as 1 unit. Trepostome bryozoan fragments greater than 1 centimeter in length are readily visible on a bedding surface and represent a major portion of a bryozoan colony. Pelmatozoans, cryptostome bryozoans, and *Cornulites* are classified as rare, common, and abundant. The result of the faunal count of each bed is given in Tables 1-4. The cumulative faunal abundance of each bed as well as abundance for the top and bottom of the bed, where possible, is calculated. This allows a description of components, diversity, and dominant elements of the assemblages (Tables 5-22).

Rarefaction is used to compare diversity of the shelly faunal constituents, excluding bryozoans, of the Brainard and Fort Atkinson. Rarefaction curves are generated following the procedures of Simberloff (1978). Rarefaction is restricted to comparing fauna of similar hierarchial levels (i.e., genera to genera; species to species) and the trepostome bryozoans, identified only to ordinal level were excluded.

Geologic Section

Approximately 34 meters (113 feet) of Maquoketa Group comprises the measured section along Wequiock Creek (Fig. 2). The section is bounded by soil cover at the base and by the Silurian Mayville Dolomite at the top.

Mayville Dolomite. Not measured; contact with Maquoketa Group conformable.

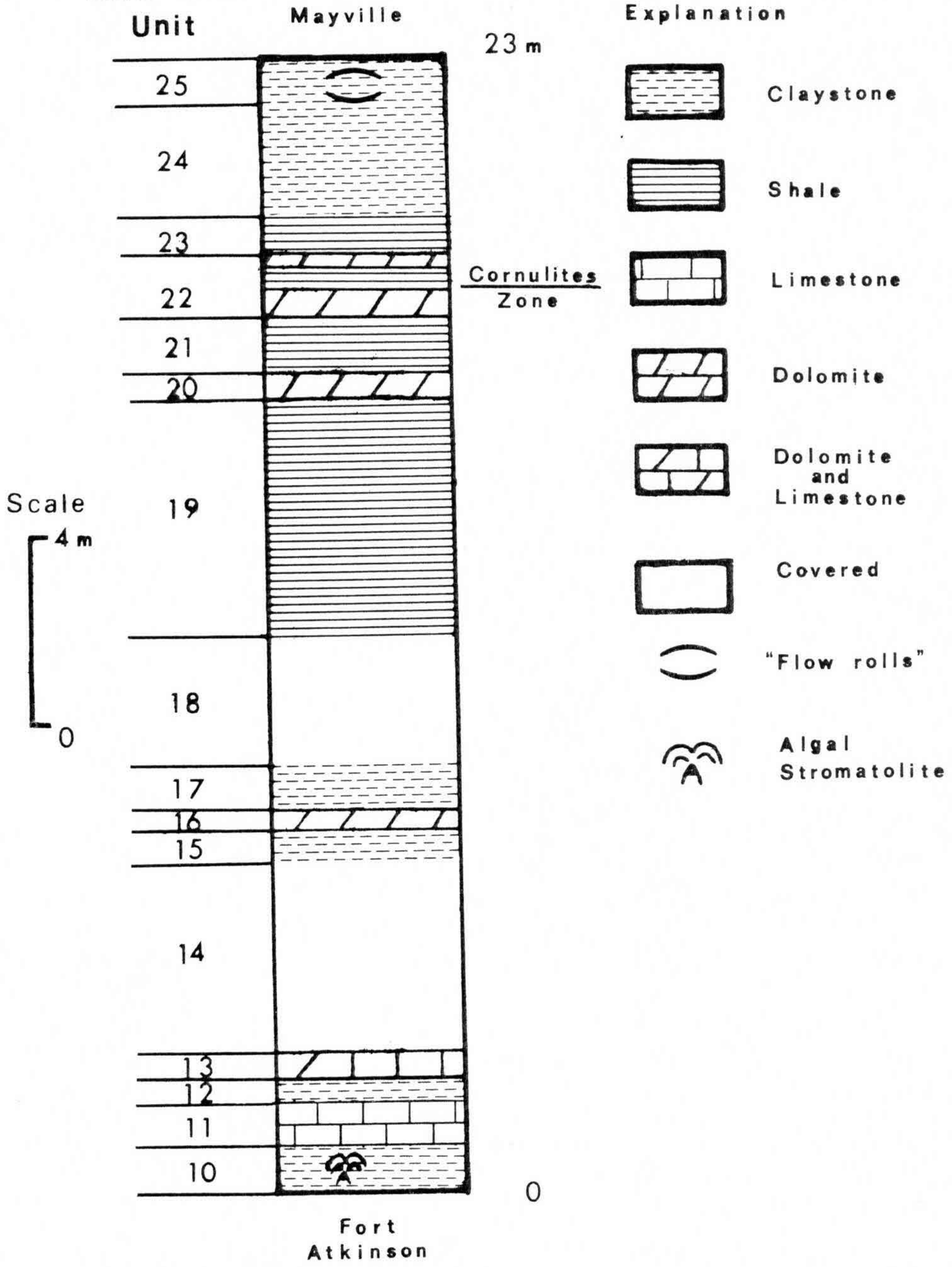

Fig. 3. Columnar section of the Brainard Shale.

Maquoketa Group:

Brainard Shale (Fig. 3).

Unit		Thickness (equivalents)	
		Meters	Feet
25.	Claystone, dolomitic, greenish-gray (5G 6/1); irregular beds, concretions and "flow rolls".	1.06	3.5
24.	Claystone, dolomitic, greenish-gray (5G 6/1); chert nodules; shale stringers at 15-30 cm intervals; burrowed; laterally continuous bands of chert.	3.02	9.0
23.	Shale, light-bluish-gray (5B 7/1); coarsely fissile; thin stringer of dolomite near base.	1.06	3.5
22.	Dolomite, biogenic, light-bluish-gray (5B 7/1), medium crystalline; upper and lower dolomite beds parted by a 16 cm shale; abundant cystoporate bryozoan *(Fistulipora annulifera?)*, brachiopods, trepostome bryozoans, Cornulites.	0.60	2.0
21.	Shale; same as unit 23.	0.18	0.6
20.	Dolomite, biogenic, light-bluish-gray (5B 7/1), medium crystalline, 2-4 cm beds; thin shale parting; abundant bryozoans, echinoderm fragments and brachiopods.	0.30	1.0
19.	Shale, medium-gray (N5); coarsely fissile; colony of *Paleophyllum?* having a minimum diameter of 45 cm and a minimum height of 15 cm.	4.87	16.0
18.	Covered.	2.74	9.0
17.	Claystone, light-bluish-gray (5B 7/1), blocky; *Lepidocyclus* and rare bryozoans.	0.91	3.0
16.	Dolomite, biogenic, light-gray to medium-light-gray (N7-N6); fine to medium crystalline; echinoderm fragments, bryozoans, and brachiopods.	0.09	0.3
15.	Claystone, same as unit 17.	0.54	1.8
14.	Covered.	4.11	13.5
13.	Limestone (biomicrite) and vuggy, medium crystalline, biogenic dolomite, light-olive-gray (5Y 6/1); abundant echinoderm fragments, common bryozoans and brachiopods.	0.24	0.8
12.	Shale, light-gray (N7); fossiliferous carbonate lenses.	0.60	2.0

Unit		Thickness (equivalents)	
		Meters	Feet
11.	Limestone (biomicrite-biosparite), light-gray (N7); 3-5 cm layers interbedded with 10-25 cm thick claystone beds; abundant echinoderm and bryozoan fragments, common brachiopod valves.	0.54	1.8
10.	Claystone; same as unit 14; algal stromatolite about 1 ft. above base.	1.03	3.4
	Total thickness of the Brainard Shale	23.00	75.6
	Fort Atkinson Limestone (Fig. 4); contact with Brainard Shale conformable.		
9.	Dolomite, biogenic, medium-light-gray (N6) to greenish-gray (5GY 6/7), medium crystalline; beds 4-6 cm thick; clay partings; solitary and colonial corals, brachiopods, bryozoans.	0.15	0.5
8.	Shales, light gray (N7); bedded with numerous carbonate lenses and nodules; solitary and colonial corals, brachiopods, bryozoans.	0.60	2.0
7.	Covered.	0.30	1.0
6.	Dolomite, biogenic and limestone (biomicrite), light-olive-gray (5Y 6/1) to greenish-gray (5GY 6/1); in 4-6 cm beds separated by thin (less than 1 cm) clay seams; in part mudstones with fine parallel and subparallel laminations and small scale cross-bedding; in part wackestones, vuggy; abundant echinoderm fragments, bryozoans, and brachiopods.	0.39	1.2
5.	Shale, light-gray (N7); coarsely fissile; dolomitic; fossiliferous carbonate lenses.	0.42	1.4
4.	Covered.	1.64	5.4
3.	Limestone (biomicrite) and medium crystalline dolomite, light-olive-gray (5Y 6/1) to greenish-gray (5GY 6/1); thin clay interbeds; echinoderm fragments, and bryozoans are common; brachiopods and trilobites are rare.	0.42	1.4
	Total thickness of the Fort Atkinson Limestone	3.90	13.0

Scales Shale; exact position of contact with Fort Atkinson Limestone uncertain.

2.	Covered.	4.93	16.2
1.	Clay, light-bluish-gray (5B 7/1); bedding obscured by weathering.	2.43	8.2
	Total thickness of Scales Shale	7.4	24.2
	Scales Shale below unit 1 is covered.		
	Thickness of Maquoketa Group along section	34.1	112.8

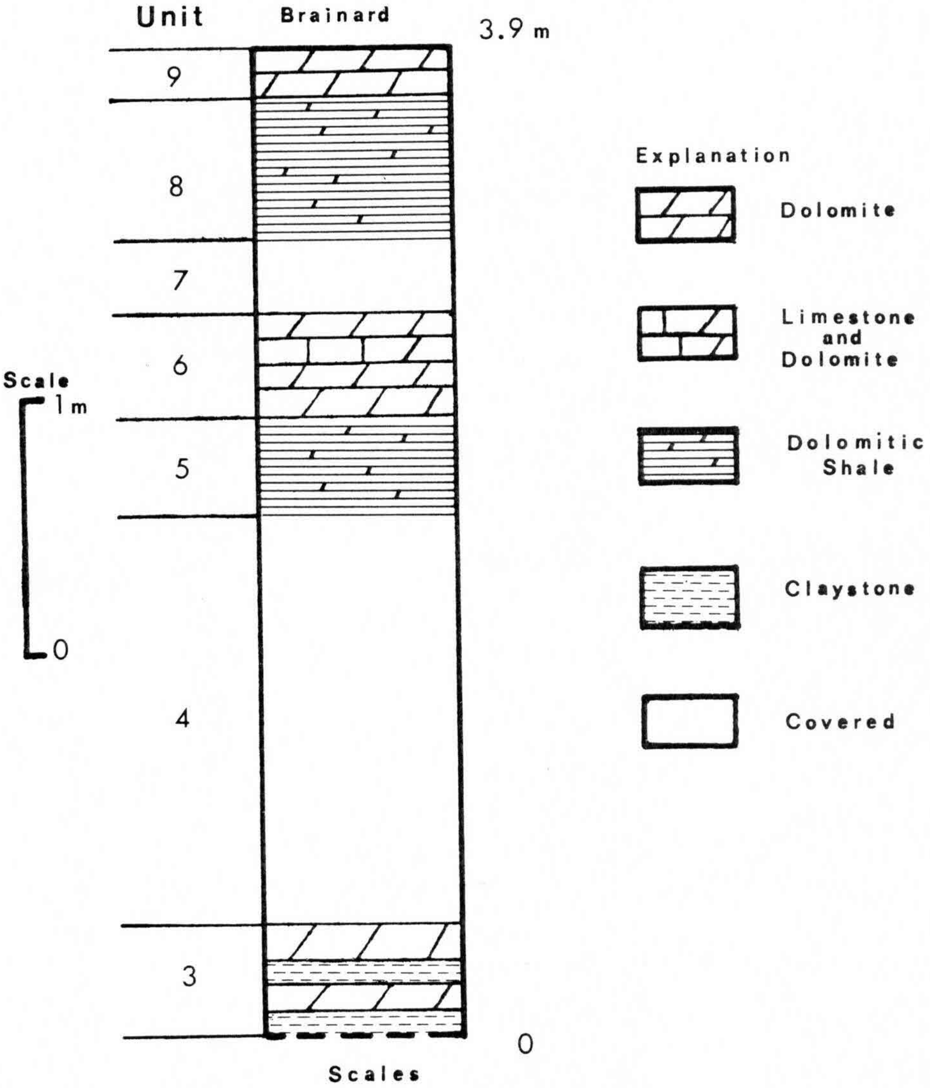

Fig. 4. Columnar section of the Fort Atkinson limestone.

Fig. 5. Cascade associated with the Fort Atkinson Limestone in Wequiock Creek.

FORT ATKINSON LIMESTONE

The 3.9 m (13.0 ft) of Fort Atkinson Limestone is associated with a series of three small cascades in Wequiock Creek (Figure 5). Common allochems are echinoderm fragments, cryptostome and trepostome bryozoan fragments. The allochems are commonly dolomitic replacements and the bryozoans and the echinoderm fragments may appear as dolomite ghosts. The brachiopod valves are complete and at times articulated showing little evidence of transportation.

Well formed dolomite rhombs are common to prevalent in the matrix. Original matrix material is micritic as remnant lime mud is visible between dolomite rhombs (Figure 6).

Mechanically deposited carbonate beds are present in the Fort Atkinson. These mechanically deposited beds tend to show the same textures and structures as do non-carbonate clastic sediments (Carozzi, 1952). The presence of small-scale cross-laminations in some mudstones (Figure 7) indicates that the mudstone is a detrital deposit and not a chemically formed precipitate (Harbaugh, 1959). Within the Fort Atkinson a single bed may be entirely a mudstone or entirely a wackestone. More commonly single beds are in part wackestone and in part mudstone (Figure 8).

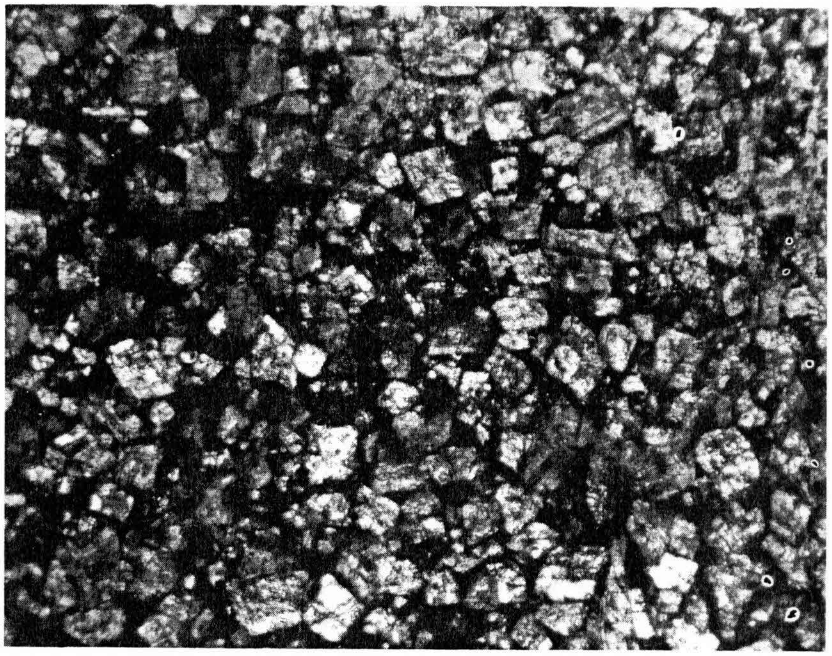

Fig. 6. Remnant lime mud between well formed dolomite rhombs in unit 3 of the Fort Atkinson Limestone. [X 320].

The cement of the Fort Atkinson beds is at times sparry but lime mud is present trapped in the zooecial cavities of some bryozoans. Much of the cement has apparently resulted from aggrading neomorphism of an original lime mud matrix.

The clay of the shale, as the clay of the entire Fort Atkinson, contains quartz, dolomite, chlorite, and illite.

Paleoenvironment

The alternation of carbonates and fine-grained clastics in the Fort Atkinson may have resulted from pulsations in the supply of clay and silt from the source area, from fluctuations of water depth, or by a combination of both parameters. The clays and shales were probably deposited below effective wave base in a sublittoral environment. A quiet water environment is required to have prevented winnowing of fine-grained clastics. Clastic sedimentation seems to have occurred at a rate which buried the bottom benthos before successful colonization.

The carbonate beds represent lime mud and bioclastic buildups at

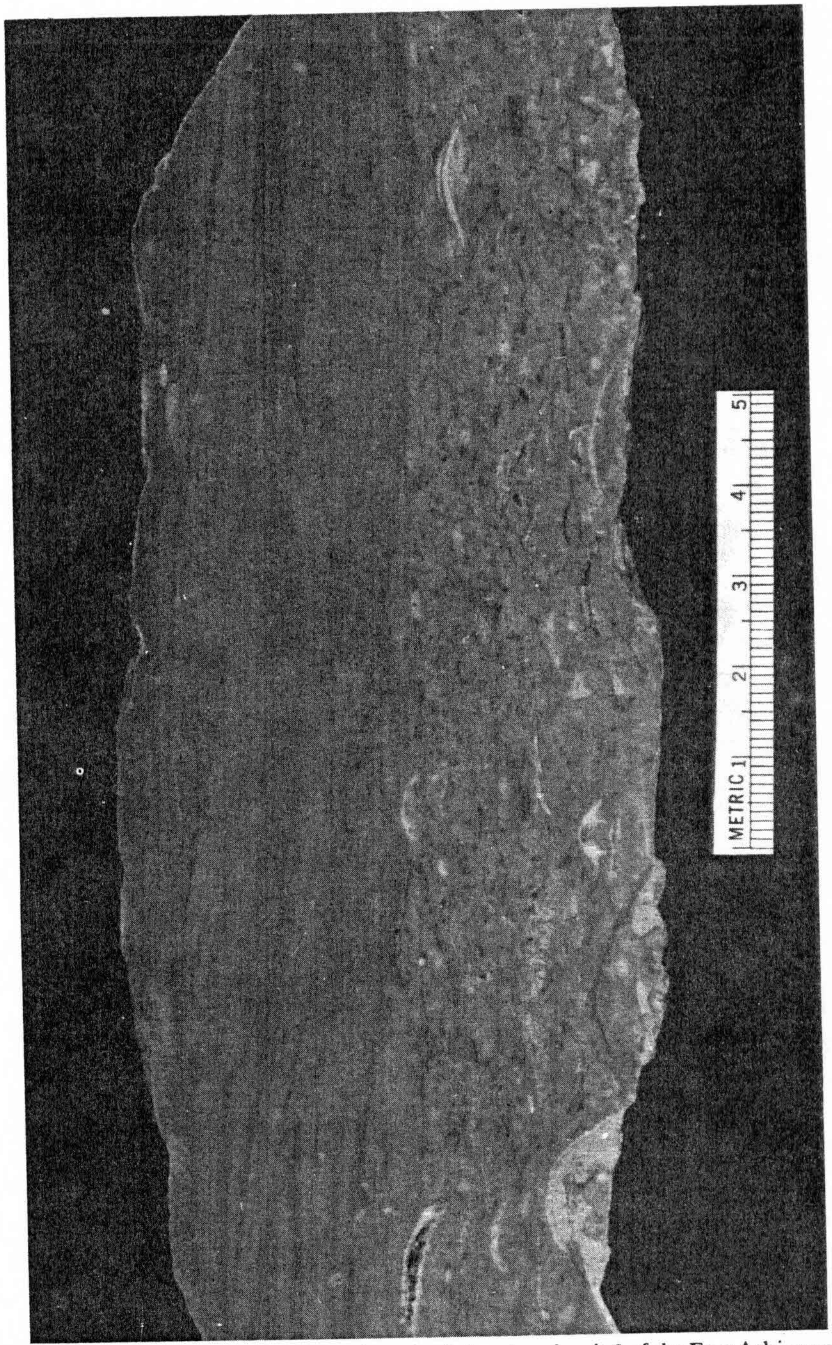

Fig. 7. Small scale cross-laminations in dolomite of unit 6 of the Fort Atkinson. [The scale is 5 cm.]

Fig. 8. Mudstone-wackestone from unit 6 of the Fort Atkinson. [The scale is 5 cm.]

and slightly below effective wave base in a shallow marine environment. Laminations and small-scale cross-laminations indicating mechanical transport of sediments and scour and fill structures suggest that the bottom was swept by moderate currents during extensions of wave base associated with periodic storms.

Fauna

Macroinvertebrates are the dominant fossil constituents of the Fort Atkinson. Of the invertebrates, 9 genera and 1 informal grouping, strophomenids, represent the Brachiopoda. Bryozoa are represented by the orders Trepostomata, Cystoporata, and Cryptostomata, and the coelenterata by the genera *Streptelasma* and *Foerstephyllum?* Echinoderm fragments are abundant.

Strophomenids, *Lepidocyclus,* trepostome bryozoans, and to a lesser extent, *Plaesiomys* dominate the Fort Atkinson assemblages (Table 1). The other genera of brachiopods are rare and play a minor role in the assemblages. Echinoderms and cryptostome bryozoans are normally associated and are a major component of the carbonates of the Fort Atkinson. Corals are abundant only in the upper 0.75 m of strata. Minute gastropods, which are rare in the lower Fort Atkinson, are an abundant clastic component of these uppermost dolomites.

Community Analysis

A community is defined as a recurrent association of species. The assemblages in the Fort Atkinson fulfill this definition. Succession is the process of community change that proceeds from the colonization of a newly opened or disturbed region by pioneer organisms through stages in which the original pioneers are replaced by different species (Valentine, 1973). The end result of succession is a climax stage, when a population is in equilibrium with local conditions.

Examples of within bed succession are found in the Fort Atkinson. The successional sequence is not complex and begins with the destruction of a previous community by a change to an unfavorable environment. The major faunal components of the Fort Atkinson, brachiopods and bryozoans, are lophophorates, dependent upon filtration as a feeding strategy. Though some filterers adapted to a moderate amount of clastic sedimentation, large amounts of fine-grained clastics clog the feeding structure or completely bury the benthos. The shales and clays of the Fort Atkinson represent an environment in which the fauna apparently could not survive. The carbonates represent reduced clastic deposition and an environment favorable to pioneering and succession. By observing faunal differences from the bottom of the carbonate beds to the surface of the beds, succession can be recognized (Table 2).

The shales and clay seams between the carbonate beds represent a mud substrate that was colonized by the fauna preserved on the bottom of the carbonate beds. This pioneer community was dominated by strophomenids and to a lesser extent, *Lepidocyclus.* The strophomenids with broad gently curved concavo-convex shells were apparently adapted for life on soft substrate (Rudwick, 1970; p. 90).

The substrate was changed by a buildup of the shelly fauna on the mud and in response, faunal components changed. In comparing the total number of specimens found on the bottom of carbonate beds with those found on the top of the beds, it is found that strophomenid abundance declined by 71.4 percent, suggesting restriction to the pioneering stage of the shelly fauna succession. *Lepidocyclus* was not substrate specific and increased in numbers. *Plaesiomys* replaced strophomenids in the later stage of succession as its abundance increases 375 percent from the bottom to top of the beds. Other shelly components as a whole increase approximately 100 percent from the bottom to top of the beds.

Bryozoan thickets were common within the carbonate beds of the Fort Atkinson. Bretsky (1967), in a study of episodic faunal changes in an Upper Ordovician flysh in Quebec, found that after colonization and development of substrate by shelly fauna, shell debris became available as suitable sites for bryozoan larval attachment and bryozoan thickets developed. The development of thickets in the Fort Atkinson is expressed by a dramatic increase (1400 percent) in the total abundance of bryozoans from the bottom to top of carbonate beds.

In the Ordovician Eden Shale, Anstey and Perry (1972) found that bryozoan abundance decreases when suitable substrate was less common and when terrigenous mud increased on the bottom. The rate of terrigenous sedimentation is also a major factor controlling the distribution of recent bryozoans in the sediments of the Rhone Delta (Laqaaiz and Gautier, 1965). By analogy it is suggested that the bryozoan thickets of the Fort Atkinson developed during periods of decreased or minimal terrigenous clastic sedimentation as a firm substrate became available.

Corals are abundant only in the upper 0.75 m of strata (unit 9). These corals indicate a current agitated environment. This higher energy environment is also indicated by associated abraided brachiopod shells. Minature gastropods that are abundant in this zone probably represent spat which did not survive in adverse current dominated conditions.

BRAINARD SHALE

The 23.0 m (75.6 ft) of the Brainard Shale lie conformably upon the Fort Atkinson Limestone. The clay of this unit, which is typical of the clay throughout this section, contains quartz, chlorite, dolomite, and illite.

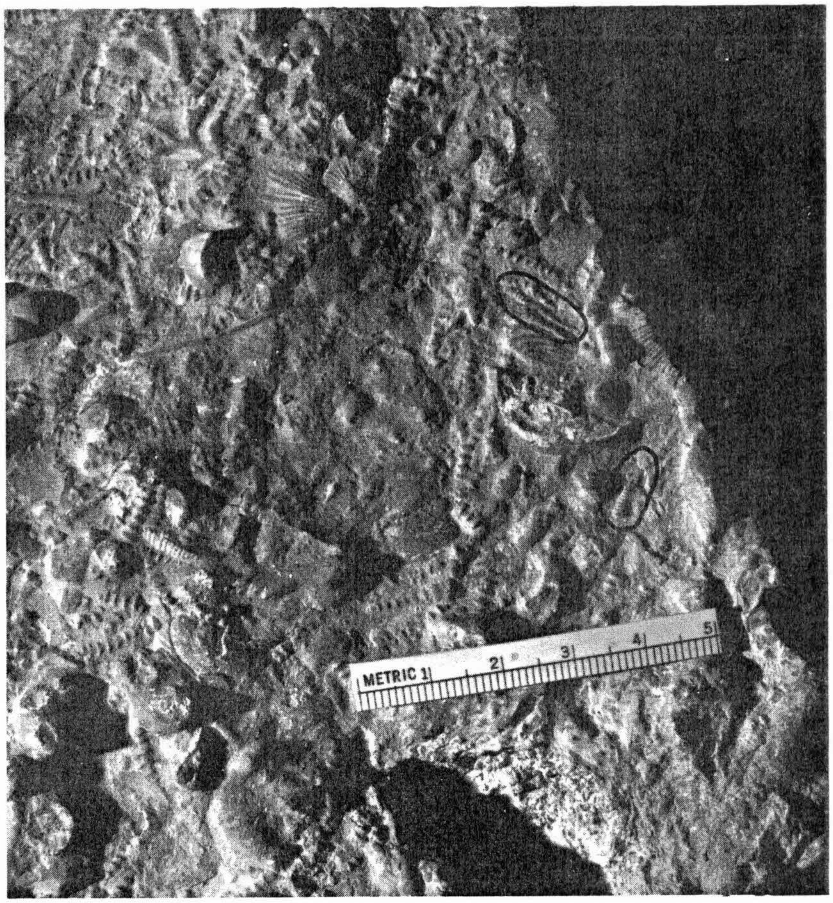

Fig. 9. Slab from the *Cornulites* zone of the upper Brainard, unit 22. [*Fistulipora annulifera* is very abundant; *Cornulites* are circled. The scale is 5 cm.]

The carbonate beds of the lower Brainard (Unit 11; Figure 3) are biomicrites and biosparites that contain 20-30 percent allochems. Echinoderm and bryozoan fragments are abundant and brachiopods are common. The upper carbonate beds are biogenic dolomite (Units 20 and 22) containing abundant brachiopods, trepostome and cryptostome bryozoans and *Cornulites* (Figure 9).

The uppermost 1.06 m of Brainard is a claystone (unit 25) which lacks shale stringers, is irregularly bedded, and contains structures similar in appearance to "flow rolls" (Sourauf, 1965). "Flow rolls" are not primary sedimentary structures but are the result of deformation by floundering which took place before the deposition of overlying strata. Field studies have supported this origin for these structures (Saurauf op cit.; Howard and Lohrengel, 1969).

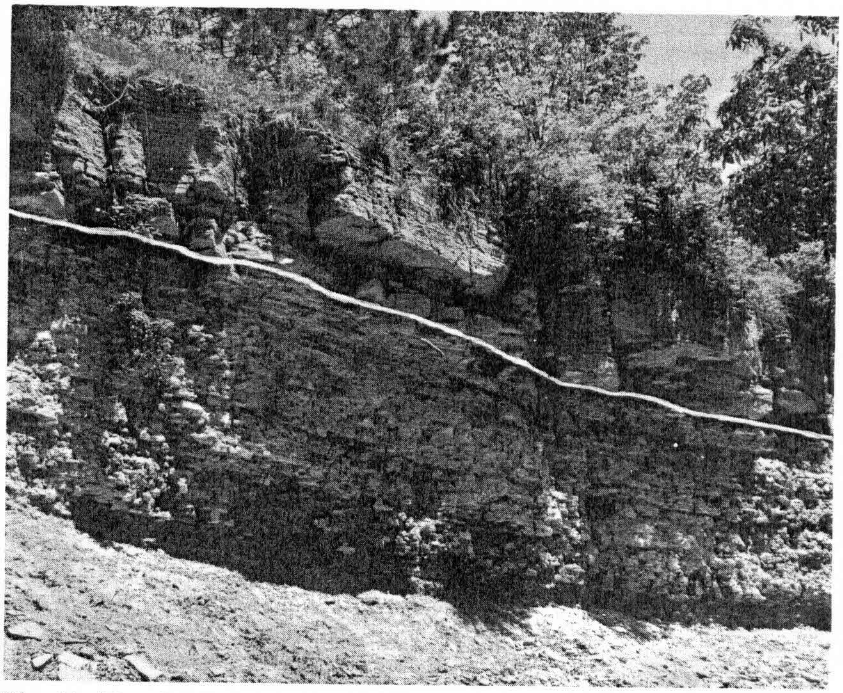

Fig. 10. Mayville Dolomite-Brainard Shale contact. [The contact is marked by the line.]

The contact of the uppermost claystone of the Brainard Shale with the massive dolomite of the Mayville Dolomite is conformable (Figure 10). Claystone beds do not appear to be truncated at the contact, and evidence of erosion, such as a basal conglomerate in the Mayville, is lacking. Some clay clasts of Maquoketa lithology are present in the lower 15-20 cm of Mayville.

Paleoenvironment

Shallowing as evidenced by the coral fauna and fragmental nature of the allochems in the upper Fort Atkinson, continued into the Brainard. The fine clastics were deposited in a shallow protected environment behind wave barriers where winnowing would be prevented. Laterally-linked hemispheroidal algal stromatolites of the lower Brainard (unit 10) supports this interpretation. This type of algal structure is characteristically developed in the marine, intertidal mud-flat environment in protected re-entrant bays and behind barrier islands (Logan, et al., 1964). Large coral heads in the shales of the upper Brainard suggests a shallow but perhaps less restricted environment.

The carbonate beds of the Brainard indicate a return to a less protected marine environment. The brachiopod-bryozoan-echinoderm fauna suggests normal marine conditions. The encrusting nature of the bryozoans indicate an environment of relatively high energy. This energy acted to winnow away a substantial portion of the muds whose remnants may be found trapped in the zooecial cavities of bryozoans.

Fauna

Macroinvertebrates dominate the Brainard fauna. The Brachiopoda are represented by 10 genera and the informal group strophomenids. Two of the genera, *Thaerodonta* and *Platystrophia*, are not in the Fort Atkinson. *Megamyonia*, which is rare in the Fort Atkinson, is absent in the Brainard. Bryozoa are represented by the orders Trepostomata and Cryptostomata, and the Coelenterata by *Streptelasma*, *Foerstephyllum?* and *Paleophyllum*. Pelmatozoan fragments are abundant. The *Cornulites* zone is present in the upper Brainard. The systematic position of cornulitids is uncertain. They have been presumed to be annelids (Morris and Rollins, 1971) but investigations of structure of the shell suggests that cornulitids are molluscs (Blind, 1972).

A summary of the percent abundance of the faunal constituents of the Brainard shows that trepostome bryozoans, *Lepidocyclus*, *Thaerodonta*, and *Diceromyonia* dominate the assemblages (Table 3). Strophomenids and *Plaesiomys* are commonly present but never dominant. The remaining genera of brachiopods and corals of the Brainard are minor constituents of the assemblanges. Cryptostome bryozoans and echinoderm fragments are rare to abundant.

The trepostome bryozoan colonies occur as ramose structures extending upward from broad sheets of basal zoaria. The basal zoaria are encrusted upon the valves of brachiopods.

Community Analysis

Within bed succession, though somewhat condensed (Fursich, 1978), was recognized in the Brainard by observing faunal changes from the bottom to the top of the carbonate beds (Table 4).

The bottom pioneering stage of the fauna is dominated by *Thaerodonta*, *Diceromyonia*, and fragments of trepostome bryozoans. *Lepidocyclus*, *Plaesiomys*, and strophomenids are also represented. As shell debris derived from these pioneers was strewn over the bottom, the substrate changed. The faunal components changed in response. By comparing the total number of each faunal element located on the bases of the samples of carbonate beds with the total found on the upper surface of the same samples, it is found that from bottom to top of the beds that the dominants of the pioneering community, *Thaerodonta* and *Diceromyonia,* decline by 52.6 and 20.5 percent respectively. Trepostome bryozoans increased by 131.1 percent to become the strong dominant of the upper community. *Lepidocyclus, Plaesiomys, strophomenids* and other faunal elements increase but remain numerically subordinate to *Diceromionia.*

The brachiopod fauna of the Brainard is similar to that of the Elgin Member of the Maquoketa in Minnesota (Bayer, 1967). The Elgin is the stratigraphically lowest member of the Maquoketa Group. In the fossil bearing limestone beds of Bayer's lithosome II a repetitive *Thaerodonta-Oniella* community was recognized. The major members of this community *(Thaerodonta* and *Oniella)* accounted for 20-70 percent of the samples. Other brachiopods of this community, in order of numerical abundance were strophomenids, *Plaesiomys* and *Lepidocyclus. Diceromyonia,* a dominant in the Brainard, is similar to *"Oniella"* of Bayer. Trepostome bryozoa which are very abundant in the Brainard at Wequiock are rare in the Elgin. Bayer considered the fauna in the Elgin to be environmentally controlled by periodic increases in the rate of terrigenous sedimentation. Influx of fine detritus was accompanied by shoaling and the destruction of the existing benthos. Periods of deeper water and firmer bottoms allowed reestablishment of the shell communities.

Community dominants differed markedly between the Fort Atkinson and Brainard. The pioneering fauna is dominated by *Thaerodonta, Diceromyonia,* and trepostome bryozoans in the Brainard and by strophomenids and *Lepidocyclus* in the Fort Atkinson.

Strophomenids were adapted for life on a soft muddy substrate not suitable for other epifaunal species. Richards (1972) recognized that the shells of strophomenids conditioned the substrate by stabilizing it and acting as attachment sites upon which diverse and mature epifaunal communities could develop. Strophomenids assumed this role in the Fort Atkinson.

In the Brainard, *Thaerodonta* and *Diceromyonia* were able to pioneer the substrate. The subordinate number of strophomenids suggests that the Brainard was not as soft as the Fort Atkinson at the time of colonization. Trepostome bryozoans quickly colonized the shell debris and their fragments became numerically dominant on the substrate. Larval attachment sites must have existed early in the colonization of the bottom. While the Fort Atkinson carbonates are dominantly lithified bioclastic sands, the Brainard carbonates, especially the upper Brainard, are more analogous to shell gravels composed of numerous brachiopod valves and trepostome bryozoans.

Rarefaction (Simberloff, 1978) allows comparison of the diversity of the Fort Atkinson and Brainard faunas. The rarefaction curves show that the shelly fauna, excepting bryozoans, from both formations have

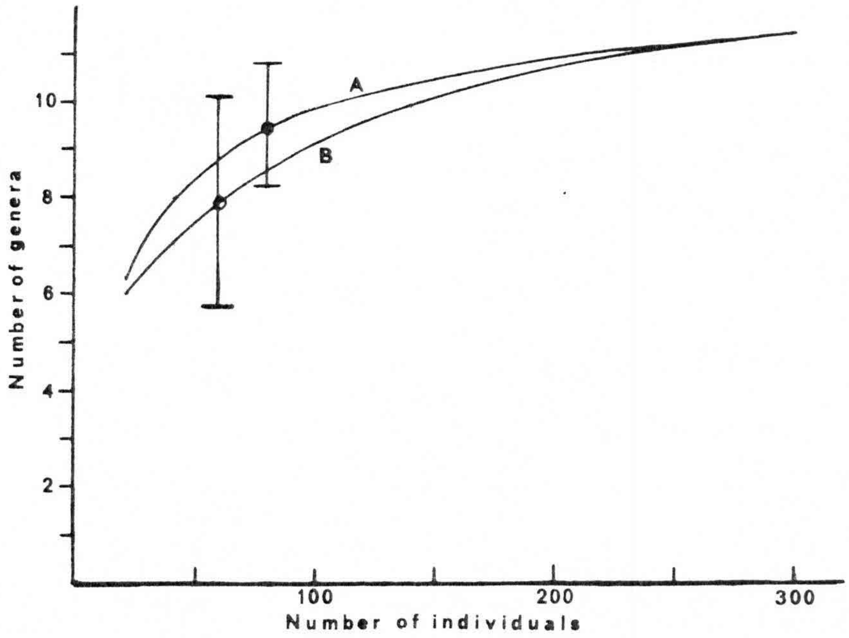

Fig. 11. Rarefaction curves of the Fort Atkinson A and Brainard B shelly faunal communities, excluding bryozoans.

very similar diversity and overlap in their 95 percentile confidence interval (Fig. 11). Though faunal components changed, diversity of the non-bryozoan elements of the communities attained about the same level in the Fort Atkinson and the Brainard. Inclusion of the bryozoans, especially the trepostomes, in the rarefaction curves would increase the relative diversity of the Brainard as they dominate collections from that formation.

Cornulites is restricted to a 0.6 m thick zone in the upper Brainard (unit 22), where it is abundant (Fig. 12). *Cornulites* occurs most commonly as epizoans on the exoskeleton of invertebrate hosts (Fisher, 1962; Morris and Rollins, 1971; Richards, 1974). They occur either singly or in clusters. Fisher suggests that dispersal in the marine environment was by means of a free-swimming larval stage. Usual hosts were brachiopods, gastropods, or bryozoans. Inorganic hosts are not selected.

Several cornulitid-host associations in the Waynesville fauna (Upper Ordovician; southwest Ohio) suggests that cornulitids positioned themselves to take advantage of feeding currents set up by a host (Morris and Rollins, 1971).

Though numerous possible examples of a host-cornulitid association

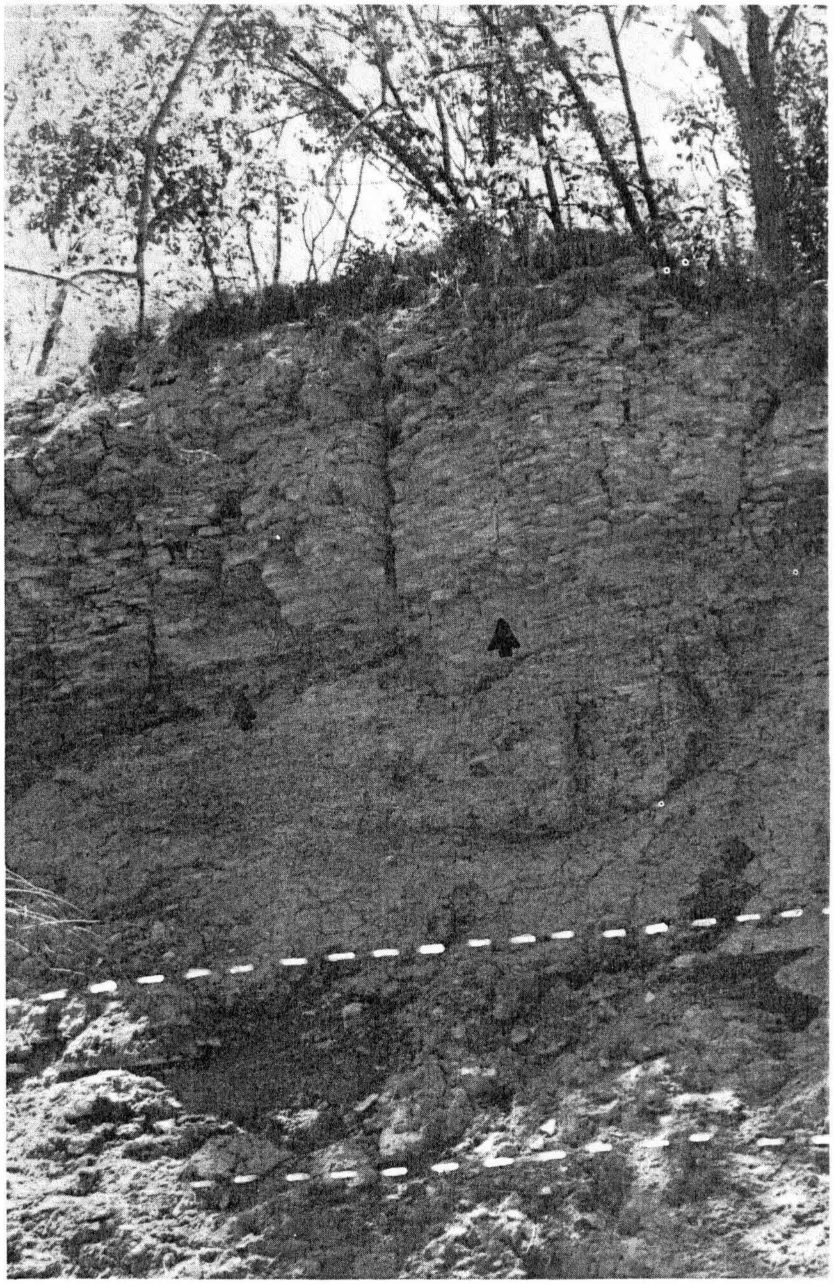

Fig. 12. Approximate position of the 0.6 m thick *Cornulites* zone. [The 0.6 m thick *Cornulites* zone is between the white dashed lines; the unit 23 - unit 24 contact is marked by the arrows.]

were found in the *Cornulites* zone of the Brainard, not one positive association was identified. The specimens appear to be positioned randomly in relationship to other invertebrates and each other. No clusters were observed. Most specimens are poorly preserved and the portion that would be attached to a host, the initial chamber, is commonly missing. Whole specimens are found isolated, not remotely associated with a possible host.

Two explanations of the sudden prolific appearance of *Cornulites* seem possible. The first is that the physical, chemical, and biologic parameters of the environment were such that optimum colonization and survival of *Cornulites* occurred. This suggests an autochthonous origin for the *Cornulties*. The second explanation is that a series of catastrophic events, such as storms, is responsible for the allochthonous deposition of *Cornulites* within the upper Brainard. *Cornulites,* torn from their hosts, would float, decay, then sink to the bottom to become an apparent component of the Brainard community. A refined systematic, morphologic, and ecologic understanding of *Cornulites* must evolve before an explanation can be accepted.

CONCLUSIONS

The Maquoketa shales contain little or no fauna and represent times of peak terrigenous clastic sedimentation. The clays and shales were deposited in a quiet water environment where they were protected from winnowing by current action. The alternation of the fine-grained clastics with carbonates may be explained by pulsations of clastic influx from the source area possibly associated with fluctuating water depth.

The carbonate beds of the Fort Atkinson, which represent times of reduced terrigenous clastic deposition, contain a normal marine fauna of brachiopods, bryozoans, and in the upper 0.75 m, abundant corals. Echinodermal bioclastic sands are common. Laminations and small scale cross-laminations in the bioclastic sands resulted from mechanical transport of the clasts by moderate currents. Escape burrows suggest rapid episodes of deposition for these sands. Abundant corals indicate shallowing and agitated waters at or slightly above wave base in the latest Fort Atkinson.

Within bed succession is found in the carbonate beds of the Fort Atkinson. As clastic sedimentation decreased a pioneer community, dominated by strophomenids and to a lesser degree *Lepidocyclus,* colonized the substrate. The substrate was changed as shelly material built up. Trepostome bryozoans, *Plaesiomys,* and *Lepidocyclus* became dominant.

The Brainard Shale is dominantly shale and claystone with associated carbonate beds near the base and top of the formation. Shallowing in the upper Fort Atkinson, as evidenced by the coral-rich zone and an increase in abraided bioclasts, continued into the Brainard and allowed the development of laterally-linked hemispheroidal algal stromatolites. The presence of these stromatolites suggest that the clay and shale were deposited in a protected intertidal to shallow subtidal mudflat environment. The carbonate beds of the Brainard were deposited in agitated slightly deeper water which allowed the winnowing of terrigenous clastics and the shallow water, normal marine, brachiopod-bryozoan-echinodermal communities to flourish. The bottom pioneering stage of the fauna was dominated by *Thaerodonta, Diceromyonia,* and trepostome bryozoans. From bottom to top of the carbonate beds *Thaerodonta* and *Diceromyonia* declined and trepostome bryozoans became the strong dominants of the community. *Cornulites* is restricted to approximately 0.6 m of strata in the upper Brainard. The *Cornulites* zone is also characterized by an abundance of cystoporate bryozoans.

Acknowledgments

I thank P. M. Sheehan for advice and critical review of the manuscript. The Milwaukee Public Museum made available laboratory space, photographic equipment and computer time and also defrayed the cost of photography and fieldwork. T. Cook aided in x-ray diffraction of samples. B. E. Winkleman assisted in thin-sectioning and rarefaction analysis. D. R. Schieflelbein assisted with photography.

LITERATURE CITED

Anstey, R. L., and Perry, T. G., 1973. Eden Shale bryozoans: a numerical study (Ordovician, Ohio Valley): Michigan State University Museum Publication. 2:1-80.

Bayer, T. N., 1967. Repetitive benthonic community in the Maquoketa Formation (Ordovician) of Minnesota: J. Paleontology. 41(2):417-422.

Berry, W. B. N. and Marshall, F. C., 1971. Late Ordovician graptolites from the Maquoketa Formation in eastern Missouri: J. Paleontology. 45(2):253-257.

Blind, W., 1972. The systematic position of *Cornulites* based on investigations of the structure of the shell, in Paleontology-Paleontologie section 7, 1972, Proceedings Int. Geol. Congr.-Congr. Geol. Int. Programme. 24:5-7.

Bretsky, P. W., 1967. Macroinvertebrate teilzones and episodic faunal changes from an Upper Ordovician flysch in Quebec: Can. J. Earth Sci. 14:1674-1686.

Calvin, S., 1906. Geology of Winneshiek County: Iowa Geol. Survey.

Carozzi, A., 1952. Tectonique, courants de turbidite et sedimentation: Revue Generale Sciences, Pures et Appliques. 59:229-245.

Fisher, D. W., 1962. Small conoidal shells of uncertain affinities, in Moore, R. C., ed., Treatise on Invertebrate Paleontology, Part W.: Geol. Soc. Amer. and Univ. Kansas Press, 259 p.

Friedman, G. M., 1959. Identification of carbonate minerals by staining methods: Jour. Sed. Pet. 29(1):87-92.

Fursich, F. T., 1978. The influence of faunal condensation and mixing on the preservation of fossil benthic communities: Lethaia. 11:243-250.

Glenister, A. T., 1957. The conodonts of the Ordovician Maquoketa Formation in Iowa: J. Paleontology. 31:715-736.

Gustadt, A. M., 1958. Upper Ordovician stratigraphy in eastern interior region: Amer. Assoc. Petr. Geol. Bulletin. 42:513-547.

Harbaugh, J. W., 1959. Small scale cross-lamination in limestones: Jour. Sed. Pet. 29(1):30-37.

Howard, J. D., and Lohrengel, C. F. II, 1969. Large nontectonic deformational structures from Upper Cretaceous rocks of Utah: Jour. Sed. Pet. 39:1032-1039.

Jones, J. A., 1931. Notes on the late Ordovician strata of the Green Bay-Lake Winnebago region: Wisconsin Acad. Sci. Trans. 26:121-126.

Ladd, M. S., 1929. The stratigraphy and paleontology of the Maquoketa Shale of Iowa, Part 1: Iowa Geol. Survey. 34:309-440.

Lagaaiz, R. and Gautier, Y. V., 1965. Bryozoan assemblages from marine sediments of the Rhone Delta, France: Micropaleontology. 11:39-58.

Logan, B. W., Rezak, R. and Ginsburg, R. N., 1964. Classification and environmental significance of algal stromatolites: J. Geol. 72:68-83.

Moretti, G., 1971. Reference section for Paleozoic rocks in eastern Wisconsin: Van Driest no. 1, Sheboygan County: Masters Thesis, University Wisconsin-Milwaukee.

Morris, R. W. and Rollins, H. B., 1971. The distribution and paleoecological interpretation of *Cornulites* in the Waynesville Formation (Upper Ordovician) of Southwestern Ohio: Ohio Jour. of Science. 7(3):153 p.

Ostrom, M. E., 1967. Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geol. and Natural History Survey Inform. Circular no. 8.

Pulse, R. R. and Sweet, W. C., 1960. The American Upper Ordovician, Standard III. Conodonts from the Fairview and McMillan Formations of Ohio, Kentucky, and Indiana: J. Paleontology. 34:237-264.

Richards, R. P., 1972. Autecology of Richmondian brachiopods (Late Ordovician of Indiana and Ohio): J. Paleontology. 46(3):386-405.

Richards, R.P., 1974. Ecology of the Cornulitidae: J. Paleontology. 48(3):514-523.

Rudwich, M. J. S., 1970. Living and Fossil Brachiopods: Hutchinson and Co., Ltd., London, 199 p.

Savage, T. E., 1925. Correlation of the Maquoketa and Richmond rocks of Iowa and Illinois: Ill. Acad. Sci. Trans. 17:233-247.

Simberloff, D., 1978. Use of rarefaction and related methods in ecology, Biological Data in Water Pollution Assessment: Quantitative and Statistical Analysis: ASTM STP 642, K.L.

Snyder, J. and Bretsky, P. W., 1971. Life habits of diminutive bivalve molluscs in the Maquoketa Form. (Upper Ord.): Am. J. Sci. 271(3):227-251.

Sorauf, J. E., 1965. Flow rolls of Upper Devonian rocks of southcentral New York State: Jour. Sed. Pet. 35:553-563.

Templeton, J. S., and Willman, H. B., 1963. Champlainian Series (Middle Ordovician) in Illinois: Ill. G. S. Bull. 89, 260 p.

Valentine, J. W., 1973. Evolutionary paleoecology of the marine biosphere: Prentice-Hall Inc., Englewood Cliffs, N. J., 511 p.

Wang, Y., 1949. Maquoketa Brachiopoda of Iowa: Geological Society of America, Memoir 42.

White, C. A., 1870. Geol. Survey of Iowa. 1:180-181.

Willman, H.B., Eldwood Atherton, T.C. Bushback, Charles Collison, J.C. Fry, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975. Handbook of Illinois stratigraphy: Illinois State Geol. Surv. Bull. 95, 261 p.

Table 1. Faunal constituents and their percent abundance (to nearest 1 percent) of the Fort Atkinson Limestone. [Cryptostome bryozoans and pelmatozoans are designated as abundant (A), common (C), and rare (R)].

	Unit								
Constituent	3a	3b	6a	6b	6c	6d	6e	8	9
strophomenid	21	43	10	6	41	29	23	42	62
Lepidocyclus	19	25	52	39	16	24	16	9	21
trepostome bryozoan	37	—	17	22	—	18	—	16	—
Plaesiomys	17	7	14	29	6	12	15	6	—
Hypsiptycha	2	—	3	—	8	—	4	5	7
Glyptorthis	—	11	—	1	6	6	—	—	—
Zygospira	6	4	—	1	18	—	—	—	—
Megamyonia	—	—	—	1	6	6	—	2	—
Diceromyonia	—	—	3	1	—	—	42	—	—
Austinella	—	7	—	1	—	6	—	—	—
Foerste-phyllum?	4	—	—	—	—	—	—	16	—
Streptelasma	—	—	—	—	—	—	—	2	7
Oepikina	—	—	—	—	—	—	—	3	—
cryptostome bryozoans	C	A	C	A	A	C	C	A	A
pelmatozoans	R	A	C	R	R	C	C	A	A

Table 2. Faunal constituents found on the bottom and top of carbonate beds of the Fort Atkinson and percent change from bottom to top.

	Number of Specimens		percent
Constituent	Bottom	Top	change
strophomenids	56	16	- 71.4
Lepidocyclus	33	53	+ 60.6
Plaesiomys	8	38	+ 375.0
trepostome bryozoans	3	45	+1400.0
others	17	34	+ 100.0

Table 3. Faunal constituents and their percent abundance (to nearest 1 percent) of the Brainard Shale. Cryptostome bryozoans and pelmatozoans are designated as abundant (A), common (C), and rare (R).

	Unit								
Constituent	11a	11b	11c	16	20a	20b	22a	22b	23
trepostome bryozoan	8	21	—	8	28	66	58	24	8
Lepidocyclus	71	64	44	42	—	10	6	4	8
strophomenid	6	7	11	8	15	—	5	3	8
Thaerodonta	2	—	—	25	—	7	8	29	31
Diceromyonia	—	—	33	8	49	—	8	32	27
Plaesiomys	6	7	11	—	—	—	7	9	—
Hypsiptcha	—	—	—	—	8	5	—	—	8
Glyptorthis	—	—	—	8	—	—	2	—	—
Austinella	—	—	—	—	—	7	3	—	—
Streptelasma	—	—	—	—	—	5	—	—	4
Zygospira	2	—	—	—	—	—	—	—	8
Platystrophia	—	—	—	—	—	—	4	—	—
Foerste-phyllum?	2	—	—	—	—	—	—	—	—
cryptostome bryozoans	R	R	A	C	A	A	A	A	A
pelmatozoans	A	A	A	A	A	R	C	A	C
Cornulites							A	C	A

Table 4. Faunal constituents found on the bottom and top of carbonate beds of the Brainard and percent change from bottom to top.

Constituent	Number of Specimens Bottom	 Top	percent change
Trepostome bryozoans	45	104	+131.1
Lepidocyclus	5	16	+220.0
Thaerodonta	38	18	- 52.6
Diceromyonia	34	27	- 20.5
Plaesiomys	8	18	+125.0
strophomenids	5	7	+ 40.0
others	4	14	+250.0

Appendix A

Faunal constituents of the Fort Atkinson Limestone.

Faunal constituents at stratigraphic unit 3, bed a. Lithologic description: coarsely crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Hypsiptycha	1	2.5	—	—	1	1.8
Lepidocyclus	5	12.8	5	35.7	10	18.8
Plaesiomys	7	17.9	2	14.2	9	16.9
strophomenids	5	12.8	6	42.8	11	20.7
Zygospira	2	5.1	1	7.1	3	5.6
trepostome bryozoans	19	48.7	—	—	19	37.2
totals	39		14		53	

cryptostome bryozoans: top — common; bottom — abundant

pelmatozoans: top — rare; bottom — rare

Faunal constituents at stratigraphic unit 3, bed b. Lithologic description: dolomitic biomicrite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Austinella	—	—	2	8.0	2	7.1
Glyptorthis	—	—	3	12.0	3	10.7
Lepidocyclus	1	33.3	6	24.0	7	25.0
Plaesiomys	2	66.6	—	—	2	7.1
strophomenids	—	—	12	48.0	12	42.8
Zygospira	—	—	1	4.0	1	3.5
Foerste-phyllum?	—	—	1	4.0	1	3.5
totals	3		25		28	

cryptostome bryozoans: top — rare; bottom — common

pelmatozoans: top — rare; bottom — common

Faunal constituents at stratigraphic unit 6, bed a. Lithologic description: medium crystalline crinoidal biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Diceromyonia	1	6.2	—	—	1	3.4
Hypsiptycha	1	6.2	—	—	1	3.4
Lepidocyclus	8	50.0	7	53.8	15	51.7
Plaesiomys	2	12.5	2	15.3	4	13.7
strophomenids	1	6.2	2	15.3	3	10.7
trepostome bryozoans	3	18.7	2	15.3	5	17.2
totals	16		13		29	

cryptostome bryozoans: top — common; bottom — common

pelmatozoans: top — common; bottom — common

Faunal constituents at stratigraphic unit 6, bed b. Lithologic description: dolomitic brachiopod biomicrudite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Austinella	—	—	1	10.0	1	1.1
Diceromyonia	1	1.2	—	—	1	1.1
Glyptorthis	—	—	1	10.0	1	1.1
Lepidocyclus	28	35.4	7	70.0	35	39.3
Megamyonia	1	1.2	—	—	1	1.1
Plaesiomys	26	32.9	—	—	26	29.2
strophomenids	2	2.5	3	30.0	5	5.6
Zygospira	1	1.2	—	—	1	1.1
trepostome bryozoans	20	25.3	—	—	20	22.4
totals	79		10		89	

cryptostome bryozoans: top — abundant; bottom — rare

pelmatozoans: top — rare; bottom — rare

Faunal constituents at stratigraphic unit 6, bed c. Lithologic description: medium crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Glyptorthis	3	9.0	—	—	3	5.8
Hypsiptycha	3	9.0	1	5.5	4	7.8
Lepidocyclus	8	24.2	—	—	8	15.6
Megamyonia	3	9.0	—	—	3	5.8
Plaesiomys	1	3.0	2	11.1	3	5.8
strophomenids	7	21.2	14	77.7	21	41.1
Zygospira	8	24.2	1	5.5	9	17.6
totals	33		18		51	

cryptostome bryozoans: top — abundant; bottom — rare

pelmatozoans: top — rare; bottom — rare

Faunal constituents at stratigraphic unit 6, bed d. Lithologic description: fine to medium crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Austinella	—	—	1	5.8	1	5.8
Glyptorthis	—	—	1	5.8	1	5.8
Lepidocyclus	—	—	4	23.5	4	23.5
Megamyonia	—	—	1	5.8	1	5.8
Plaesiomys	—	—	2	11.7	2	11.7
strophomenids	—	—	5	29.4	5	29.4
trepostome bryozoans	—	—	3	17.6	3	17.6
totals			17		17	

cryptostome bryozoans: top — rare; bottom — common

pelmatozoans: top — rare; bottom — common

Faunal constituents at stratigraphic unit 6, bed e. Lithologic description: dolomitic biosparite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Diceromyonia	9	52.9	2	22.2	11	42.3
Hypsiptycha	1	5.8	—	—	1	3.8
Lepidocyclus	3	17.6	1	11.1	4	15.3
strophomenids	1	5.8	5	55.5	6	23.0
trepostome bryozoans	3	17.6	1	11.1	4	15.3
totals	17		9		26	

cryptostome bryozoans: top — rare; bottom — common

pelmatozoans: top — rare; bottom — common

Faunal constituents at stratigraphic unit 8. Lithologic description: crinoidal-cryptostome bryozoan biomicrite.

Constituents	Cumulative number	cumulative percent
Hypsiptycha	3	4.6
Lepidocyclus	6	9.3
Megamyonia	1	1.5
Plaesiomys	4	6.2
strophomenids	27	42.1
trepostome bryozoans	10	15.6
Foerstephyllum?	10	15.6
Streptelasma	1	1.5
totals	64	

cryptostome bryozoans: abundant

pelmatozoans: abundant

Faunal constituents at stratigraphic unit 9. Lithologic description: medium crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Hypsiptycha	—	—	1	7.1	1	7.1
Lepidocyclus	—	—	3	21.4	3	21.4
strophomenids	—	—	9	64.2	9	64.2
Streptelasma	—	—	1	7.1	1	7.1
totals			14		14	

cryptostome bryozoans: top — abundant; bottom — abundant

pelmatozoans: top — abundant; bottom — abundant

Faunal constituents at stratigraphic unit 16. Lithologic description: biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Diceromyonia	1	8.3	—	—	1	8.3
Glyptorthis	1	8.3	—	—	1	8.3
Lepidocyclus	5	41.6	—	—	5	41.6
strophomenids	1	8.3	—	—	1	8.3
Thaerodonta	3	25.0	—	—	3	25.0
trepostome bryozoans	1	8.3	—	—	1	8.3
totals	12					

cryptostome bryozoans: top — common; bottom — rare

pelmatozoans: top — abundant; bottom — rare

Faunal constituents at stratigraphic unit 22, bed a. Lithologic description: medium crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Austinella	4	3.4	2	2.4	6	3.0
Diceromyonia	6	5.1	10	12.1	16	8.0
Glyptorthis	2	1.7	2	2.4	4	2.0
Lepidocyclus	6	5.1	5	6.0	11	5.5
Plaesiomys	6	5.1	7	8.5	13	6.5
Platystrophia	7	6.0	1	1.2	8	4.0
strophomenids	5	4.3	4	4.8	9	4.5
Thaerodonta	4	3.4	12	14.6	16	8.0
trepostome bryozoans	76	65.5	39	47.5	115	58.0
totals	116		82		198	

cryptostome bryozoans: top — abundant; bottom — abundant

pelmatozoans: top — common; bottom — abundant

Cornulites: top — common; bottom — common

Faunal constituents at stratigraphic unit 22, bed b. Lithologic description: finely crystalline biogenic dolomite.

Constituents	number on top	percent of top	number on bottom	percent of bottom	cumulative number	cumulative percent
Diceromyonia	21	25.9	24	40.6	45	32.1
Lepidocyclus	5	6.1	—	—	5	3.5
Plaesiomys	12	14.8	1	1.6	13	9.2
strophomenids	2	2.4	2	3.3	4	2.8
Thaerodonta	14	17.2	26	44.0	40	28.5
trepostome bryozoans	27	33.3	6	10.1	33	23.5
totals	81		59		140	

cryptostome bryozoans: top — common; bottom — abundant

pelmatozoans: top — abundant; bottom — abundant

Cornulites: top — common; bottom — common

Appendix B

Faunal constituents of the Brainard Shale.

Faunal constituents at stratigraphic unit 11, bed a. Lithologic description: dolomitic biomicrite.

Constituents	cumulative number	cumulative percent
Lepidocyclus	34	70.8
Plaesiomys	3	6.2
strophomenids	3	6.2
Thaerodonta	1	2.0
Zygospira	1	2.0
trepostome bryozoans	4	8.3
Foerstephyllum?	1	2.0
Liospira	1	2.0
totals	48	

cryptostome bryozoans: rare

pelmatozoans: abundant

Faunal constituents at stratigraphic unit 11, bed b. Lithologic description: crinoid-bryozoan biosparite-biomicrite.

Constituents	cumulative number	cumulative percent
Lepidocyclus	9	64.2
Plaesiomys	1	7.1
strophomenids	1	7.1
trepostome bryozoans	3	21.4
totals	14	

cryptostome bryozoans: rare

pelmatozoans: abundant

Faunal constituents at stratigraphic unit 11, bed c. Lithologic description: crinoidal biomicrite.

Constituents	cumulative number	cumulative percent
Diceromyonia	3	33.3
Lepidocyclus	4	44.4
Plaesiomys	1	11.1
strophomenids	1	11.1
totals	9	

cryptostome bryozoans: abundant

pelmatozoans: abundant

Faunal constituents at stratigraphic unit 20, bed a. Lithologic description: medium crystalline biogenic dolomite.

Constituents	cumulative number	cumulative percent
Diceromyonia	19	48.7
Lepidocyclus	3	7.6
Thaerodonta	6	15.3
trepostome bryozoans	11	28.2
totals	39	

cryptostome bryozoans: abundant

pelmatozoans: abundant

Faunal constituents at stratigraphic unit 20, bed b. Lithologic description: dolomitic bryozoan-brachiopod biomicrite.

Constituents	cumulative number	cumulative percent
Diceromyonia	3	7.3
Hypsiptycha	2	4.8
Lepidocyclus	4	9.7
Thaerodonta	3	7.3
Streptelasma	2	4.8
trepostome bryozoans	27	65.8
totals	41	

cryptostome bryozoans: abundant

pelmatozoans: common

Faunal constituents at stratigraphic unit 23. Lithologic description: medium crystalline biogenic dolomite.

Constituents	cumulative number	cumulative percent
Diceromyonia	7	26.9
Hypsiptycha	2	7.6
Lepidocyclus	2	7.6
Platystrophia	2	7.6
strophomenids	2	7.6
Thaerodonta	8	30.7
trepostome bryozoans	2	7.6
Streptelasma	1	3.8
totals	26	

cryptostome bryozoans: abundant

pelmatozoans: common

Information for Authors

Contributions in Biology and Geology Series

Manuscripts should be sent to the Editor, Mary Garity, Publications Department, Milwaukee Public Museum, 800 W. Wells St., Milwaukee, Wis. 53233.

Unpublished manuscripts on all aspects of natural science will be considered. Recent issues in the contribution series are the best guide to style, but authors of manuscripts with unique or difficult problems of presentation may consult in advance with the editor. The editor will determine whether an accepted manuscript will appear as a Contribution, Publication or Special Publication.

Copyright

Authors submitting a manuscript will receive a transfer of copyright form upon acceptance of the manuscript for publication. In consideration of the assignment of copyright, the Milwaukee Public Museum will supply the author with 100 reprints of the published contribution. Additional copies at cost may be ordered from the editor at the time galley proofs are returned.

Manuscript preparation

The original and three copies of the manuscript should be submitted to the editor. Double spacing must be used throughout, including tables, footnotes, figures, legends and literature lists. Tables and figure legends should appear on separate pages at the end of the manuscript. Copies of the manuscript will be reviewed by an appropriate staff member and two outside reviewers. Acceptance or rejection of the manuscript will be determined by an Advisory Board. Suggested revisions are the responsibility of the author.

Abstract

The abstract should tersely summarize the main findings or conclusions of an article and not merely describe the study. Uninformative phrases such as "is discussed" and "are described" should be avoided.

Illustrations

Illustrations must be sharp, glossy black and white photographs and/or neatly prepared line drawings in India ink. They should be numbered sequentially through the article. Original illustrations for papers accepted for publication will *not* be returned.

Abbreviations

Abbreviations in the text should be consistent with recent issues and/or defined. Titles of periodicals should be abbreviated as in the fourth edition of the World List of Scientific Periodicals and its supplements.

Citations

In citing literature references, the names of authors and titles must be given exactly as in the original publication, except that initials are always used for the given names of authors. The publisher and place of publication must be given and editions other than the first should be indicated.

Galleys

Galley proofs will be sent to the author along with the final, accepted, manuscript. Proofs must be corrected within 10 days and returned with the manuscript to the editor. Excessive resetting due to other than printer's error is chargeable to the author.

Reprints of this or other papers in the Museum's series may be ordered from the Milwaukee Public Museum's publication catalog, available from the Publications Office.