A PALEOENVIRONMENTAL INTERPRETATION OF THE UPPER CAMBRIAN EAU CLAIRE FORMATION OF WEST-CENTRAL WISCONSIN

BY

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ABSTRACT

The Eau Claire Formation can be divided into three lithofacies determined largely on variations in shale content and resulting bedding style. These three facies are: a shaly-thin bedded unit, a lower massive unit and an upper massive unit. A body fauna limited to brachiopods, hyolithids, a monoplacophoran and trilobites comprise the two trilobite zones, *Cedaria* and *Crepicephalus* of the Dresbachian Stage. An abundant infaunal and epifaunal trace fauna represents two shallow water ichnofacies, *Cruziana* and *Skolithos*. Observed sedimentary structures are wavy, irregular to lenticular bedding; fine horizontal and cross laminae; mud cracks, mud chips and intraformational flat pebble conglomerates; channel structures; and current, wave and mega ripples. The observed lithofacies, biofacies and sedimentary structures compare favorably with recent and ancient tidal flat environments. The three lithofacies of the Eau Claire are representative of three recognized sub-environments of a recent North Sea tidal flat. The shaly-thin bedded unit corresponds to a transition zone between a true mud flat and a sand-mud flat. The lower massive unit represents a true mud-sand flat with meandering channels which grades upward to a sand flat environment. The upper massive beds resemble foreshore deposits. This is representative of a transgressive sequence, as recognized in modern tidal flat environments.

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INTRODUCTION AND PURPOSE

The present interpretation of the depositional environment of the lower Paleozoic strata exposed in Wisconsin is one of cyclic transgression and regression of broad, shallow epeiric seas across largely Pre-Cambrian structural features which influenced sediment deposition and ultimately affected the present exposure of these lower Paleozoic units (Ostrom, 1970).

The Eau Claire Formation is the second oldest Paleozoic unit in Wisconsin. The present outcrop pattern was influenced depositionally by Pre-Cambrian structures such as the Wisconsin Dome, the Wisconsin Arch and the River Falls Syncline; and secondarily by post-Paleozoic erosion which exposes the narrow band of outcrops of the Eau Claire Formation. (Refer to text figure 1, for a map of Wisconsin with influencing structural features and keyed outcrop localities.)

The purpose of this investigation was to determine the environment of deposition of the Upper Cambrian Eau Claire Formation in west-central Wisconsin, utilizing previously determined stratigraphy (Morrison, 1968), and field and laboratory observations of biotics and sedimentary structures. The use of previously unidentified trace fauna and known paleoecology of the skeletal and ichnofauna was a primary source of information in determining the paleoenvironment.

The study was divided into three areas: Stratigraphy, paleontology/autoecology, and paleoenvironmental synthesis; which utilized observations and interpretations from the previously discussed stratigraphic and paleontologic aspects of the formation, combined with interpretations from observed sedimentary features to determine the environment of deposition.

The discussion of the stratigraphy includes a suggested revision in the number of recognizable lithofacies characterizing the Eau Claire Formation in Wisconsin. Previously undescribed trace fossils and interpreted autoecology comprises a major portion of the discussion devoted to paleontology and includes a description of two previously unreported trilobites _Brassicicephalus_ and _Welleraspis_.

Acknowledgments: The suggestion for this study came from Dr. C. W. Byers and Dr. M. E. Ostrom. Financial and material support was received from Dr. C. W. Byers and additional field support was furnished by Chevron Oil Company. The thesis was written under the direction of Dr. Charles W. Byers, Dr. Lowell R. Laudon, and Dr. Campbell Craddock. Dr. David L. Clark also provided advice and support concerning the investigation for microfossils.

Location of referenced materials:

All specimens figured or referenced in this thesis are on repository in the Department of Geology, University of Wisconsin, Madison, under catalog number 1626.

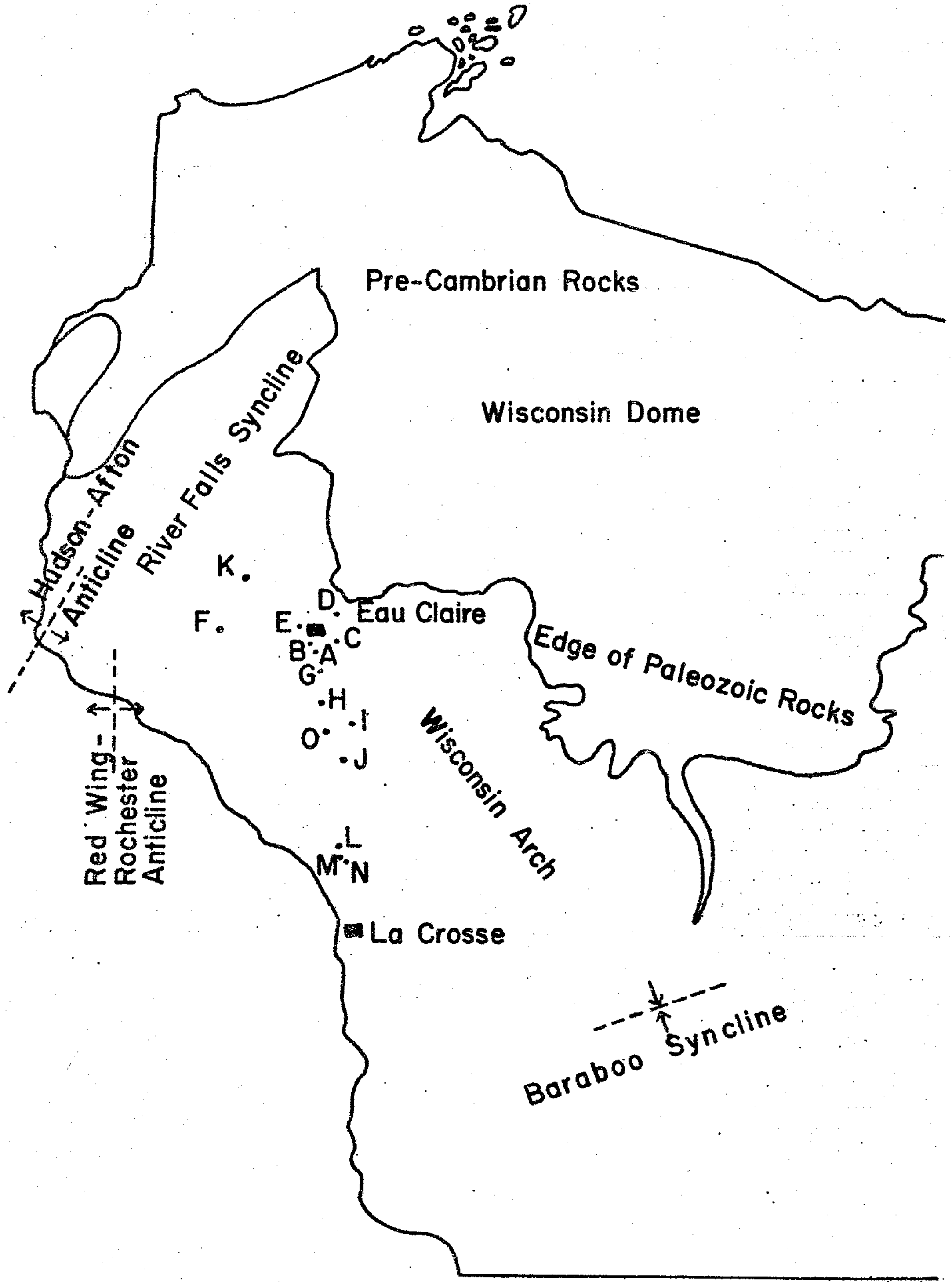


Figure I: Map of Wisconsin with Pre-Cambrian structure. Letter designations keyed to list of Eau Claire outcrop localities, table I, page

Locality	Description	Quadrangle
Chippewa Falls Quadrangle:		
A	Road-cut	T26N R9W Sec 2 Center
B	Quarry	T26N R9W Sec 2 NW¼ NW¼
C	Quarry	T26N R8W Sec 3 NW¼ NW¼
D	Road-cut	T28N R8W Sec 33 SW¼ SW¼
E	Road-cut	T21N R10W Sec 26 SW¼ SW¼
Menominee Quadrangle:		
F	Road-cut	T28N R13W Sec 12 SE¼ SE¼
Strum Quadrangle:		
G	Quarry	T25N R8W Sec 5 SE¼ NW¼
Ha	Road-cut	T24N R8W Sec 8 NW¼ NW¼
Hb	Quarry	T24N R8W Sec 18 SE¼ NE¼
Whitehall Quadrangle:		
I	Quarry	T23N R7W Sec 17 SW¼ NW¼ (not illus)
Ja	Road-cut	T22N R8W Sec 13 NW¼ NW¼
Jb	Quarry	T22N R8W Sec 13 SW¼ SW¼
New Auburn Quadrangle:		
K	Quarry	T29N R11W Sec 8 SW¼ NE¼
Galesville Quadrangle:		
L	Riverbank	T18N R8W Sec 28 SW¼ SE¼ (not illus) Sec 33 NW¼ NW¼
M	Quarry	T18N R8W Sec 5 SE¼ NE¼ (not illus)
N	Quarry	T18N R8W Sec 4 SE¼ SW¼ (not illus)
Whitehall Quadrangle:		
O	Quarry	T23N R8W Sec 9 NE¼ NW¼ (not illus)

Table I: Descriptions and locations of outcrops of the Eau Claire Formation. Letter designations are keyed to figure I.

STRATIGRAPHY OF THE EAU CLAIRE FORMATION OF WEST-CENTRAL WISCONSIN

The Eau Claire Formation has been a stratigraphic problem for some time. Morrison (1968), in summarizing the history of the early stratigraphic studies, noted the confusion and repeated changes in nomenclature. He suggested that the Eau Claire Formation of west-central Wisconsin be given formational rank and be subdivided into five distinct lithologic units, determined "largely on the basis of bedding style and shale content." He defined these (from base upwards) as: the shaly beds, the lower thin beds, the lower massive beds, the upper thin beds, and the upper massive beds (Morrison, 1968). It is important to note that this classification places the units in simple superposition. (See figure 2 for a summary of Morrison's stratigraphic column.)

Examination of Morrison's outcrops and several new exposures of the formation indicates to this writer that the five fold subdivision is not as real as had previously been assumed. It is my opinion that the lithotopes are too variable for such a detailed subdivision, and that there is good evidence that the lower four of Morrison's five units are variations in expression of two lithofacies: a shaly sandstone facies and a predominantly sandstone facies. The varying shale content within these two lithofacies produces a lateral as well as a vertical facies gradation expressed by variations in the bedding style and thickness of the sandstone beds.

I propose instead a three part subdivision of the formation, defined also upon bedding style and shale content, as follows: (from the Shawtown Formation upward)

Unit ONE: a thin to thick bedded fine grained sandstone/siltstone unit with a high clay content. The bedding style is wavy to lenticular when not destroyed by bioturbation. The sandstone beds are generally horizontally laminated. Some sandstone beds are cross-laminated and have rippled surfaces. Other sedimentary structures include ripple marks and dessication cracks. This unit is totally within the Cedaria trilobite zone of the Dresbachian Stage and contains a well developed Cruziana ichnofacies. The thickness of this unit varies from 21 ft. to 45 ft.

Unit TWO: Thick to very thick bedded fine grained sandstone beds alternating with thin to thick bedded fine grained sandstone/siltstone beds with a variable clay content. The very thick (18 in. to 10 ft.) beds are generally cross-laminated and fine upward. (The fauna is concentrated in coquinite proportions at the base of the units and decreases upward in quantity and size of particles.) The upper boundaries of the very thick beds are wavy while the basal boundaries are generally sharp and sometimes exhibit a mud cracked surface. The thin bedded sandstone/siltstone interbeds are generally wavy to lenticular, containing fine horizontal to cross-laminae in the sandstone beds. The siltstone/shale units are sometimes fissile but generally contain biogenic structures. The boundary between the Cedaria and Crepicephalus trilobite zones occurs in this unit. Ichnofacies present are a Cruziana/Skolithos facies developed in the lower portion of the unit and an excellent Skolithos facies in the approximate upper one half of the unit. This ichnofacies boundary varies with each outcrop. The thickness of this unit varies from 33 ft. to over 80 ft.

Unit THREE: Generally a clean, fine grained sandstone with low angle cross-bed sets and generally devoid of any body or ichnofauna. The body fossils when present are limited to inarticulate brachiopods, mostly fragmental and unidentifiable, (one hyolithid mold was found). A few Skolithos burrows comprise the observed ichnofauna. The thickness of this unit varies from 5 ft. to 20 ft.

Mica and glauconite are found in varying concentrations throughout the three units. The units are in superposition in that Unit One is always found in contact with the Shawtown Formation, and Unit Three, except for locality L at Galesville, is in contact with the Galesville member of the Wonewoc Formation.

The following evidence is cited in support of this recommended change:

Unit One-Shaly Thin Beds: It is my opinion that the "shaly beds" and "lower thin beds" are not recognizable as two distinct units and I am combining them into one lithofacies for the following reasons:

1) Lack of two distinct units at site of complete exposure of section:

The exposure at locality E (one and one half miles west of Eau Claire on county highway EE) is apparently a recent exposure due to road construction and to my knowledge has not been described previously. It is also the only known locality where both the lower and upper contacts of the Eau Claire Formation are present. The contact between the Shawtown and the Eau Claire is about 10 feet up the left cliff face. The next 23 ft., 7 in. of section correspond to the description of Morrison's lower thin beds. It is predominantly a thin to thick, irregularly bedded, fine grained sandstone unit interbedded with bioturbate silty shales and varies little in appearance throughout the exposure. Morrison's lower massive beds, where present, are more resistant in the weathered outcrop forming a ledge easily recognizable as the upper boundary to the lower, thinner-bedded, shaly-sandstone units. This surface is generally irregular throughout the extent of the outcrop and the lower surface of these more massive sandstone beds is usually marked by mud cracks. The entire lower unit (Morrison's shaly beds and lower thin beds) is bioturbate throughout, with zones less bioturbate than others; these thin to thick sandstone units show fine laminae and include some vertical burrows. Mud cracks and ripple marks are prominent in these less bioturbate zones. To this investigator there is no apparent vertical progression of the lower unit becoming less shaly and the sandstone beds thickening. Rather, when the shale content increases at one point on the outcrop it is generally marked by a thickening of the sandstone beds at another point on the same stratigraphic horizon.

2) The lateral variability of the beds on the outcrop:

Locality A: The lithology present corresponds to Morrison's units A and B, but not as two distinct lithofacies in superposition. Personal observation at various points along the length of the exposure on the same horizon, indicates that the thickness of any one bed varies greatly, fluctuating from one inch or less to as much as eight or ten inches. In most instances, it is impossible to trace a particular bed the length of the outcrop. While the lower portions of the weathered outcrop do appear to be shalier and thinner bedded, upon exposing a fresh surface in this area, I encountered beds as much as six inches thick. Because of the generally high shale content of this lithofacies, the lower portions of the exposure appear shalier due to particle flow down the face of the outcrop. The generally higher moisture content in the sediments at the base of the outcrop also contribute to the clayey appearance of the exposure.

Ostrom also noted the lateral variability of the shale content of this unit. While he described the upper portions of the section to be somewhat sandier, he observed that in the lower 32 ft. of section the "shale of this unit appears to grade laterally to west into lithology similar to overlying sandstone." (Ostrom, 1970, p. 53).

Locality G (Morrison's 8): Recent quarrying at an exposure approximately two and one-half miles south of Bracket on county highway D has added approximately another four feet of section below the quarry floor since the section was described by Morrison. Morrison assigned the lower two feet of exposure to his shaly beds. However, the additional four feet of section contain sandstone beds averaging four to six inches, interbedded with thinner shaly sandstone beds. The entire lower 21 ft. of the outcrop is very bioturbate and contains an excellent Cruziana facies. (Page 32 refers for described section. Plate III illustrates the Cruziana fauna.)

The irregular, wavy bedding and the variation in bedding thickness, the degree of bioturbation of the bioturbate zones, and the appearance of the weathered surfaces sometimes give the appearance that the lower unit is indeed shalier near the base of the exposures as at localities A and G. However, it is my observation that the zones of finely laminated, thin to thick bedded, rippled and/or mud cracked sandstone units occur with equal frequency throughout the lower 24 to 45 ft. of section.

3) Abrupt lateral lithofacies change; further indication of the lateral variability of the shale in the lower unit:

Evidence of the abrupt lateral facies change of lithofacies within the formation was revealed by an altimeter check of the base of the Eau Claire at two outcrops approximately one-half mile apart (see note). The results indicated that the key bed ("rusty foot") was the same unit at both locations. However, the 45 ft. of section exposed at locality A corresponds to the lithology of my unit one (Morrison's units A and B), while at locality B, lithology corresponding to my units one and two (Morrison's lower three units) occurs within the same amount of measured section. (Pages 18 and 20 refer for described stratigraphic columns of localities A and B.)

There are two other localities east of Eau Claire which exhibit the same facies change present at A and B. Only one of these two localities has been described, locality C, page 23. The undescribed section corresponds both in lithology and thickness to the section at locality A.

NOTE: Dr. Byers and myself checked several of my field measurements with a Wisconsin State Geological Survey altimeter. Readings were taken over a period of three days and each reading was taken several times at each locality and on various days to insure a consistency in results. Three separate readings were taken at these particular outcrops by both Dr. Byers and myself and the readings were all consistent.

Unit Two-Lower Massive Beds: The recommendation for combining of Morrison's Units C and D into one recognizable lithofacies is based on the following evidence:

Locality E: This is the only known outcrop where the complete stratigraphic column of the Eau Claire formation is exposed and can be cited along with sections F, H and J as evidence that Morrison's units C and D are the same unit with variations in bedding thickness and shale content. There is little apparent change throughout the upper 46 ft. of section until the top 7 ft. (The uppermost seven feet corresponds to unit three, Morrison's unit E.) The middle unit corresponds to the lithofacies Morrison defined as his unit C and I define as Unit Two. While the thick to very thick cross-bed sets of this lithofacies are somewhat thinner than the observed thickness of similar beds at other exposures, (18 in. to 3 ft. as opposed to 3 ft. to 10 ft. at most outcrops) the same consistent vertical sequence of thick to very thick cross-bedded sandstone units interbedded with thin bedded sandstone/shale units characterizing this middle lithofacies, is present throughout the 39 ft. of exposure. There is no unit present at this locality corresponding to the description of Morrison's "upper thin beds".

Localities H and J (Morrison's 9 and 13):

Exposures at Strum (H) and Whitehall (J) also demonstrate the questionable existence of the upper thin beds. At Strum there is a total of 120 ft. of section with a 20 ft. covered interval between two localities one and one-half miles apart. The units both above and below this covered interval are similar in lithology and correspond to the description of Morrison's lower massive beds. The glauconite content of the sediment increases upward in the section at Hb and is high at Ha. The lower 44 ft. at Hb contains a Cedaria trilobite fauna. The top 16 ft. at Hb and the total exposure at Ha are within the Crepicephalus zone. At Ha the shale content decreases upward and the bedding becomes more massive characterized by low angle cross laminae. The only body fossils present are fragmentary brachiopod shells and an occasional mold of a trilobite pygidium or glabella (Lonchocephalus) in the finely laminated sandstone. A well developed Skolithos facies is present in the upper 28 ft. of section at this locality also. The amount of section here and at Whitehall was measured both by handleveling and tape measure, and checked with an altimeter. (Use of the altimeter determined the 20 ft. covered interval at Strum and the probability of a 16 ft. overlap in section between the two localities at Whitehall.)

The exposures at Whitehall are similar to Strum in that the lower massive units are present at both localities Ja and Jb. Similar lithology occurs in the upper part of the unit in the quarry at Whitehall (Jb) and in the lower 15 ft. of the outcrop at the roadcut approximately a mile north on county D (Ja). Glauconite content increases in the upper portion of the section at Jb and is high in the lower 15 ft. at Ja. Crepicephalus fauna is encountered at Jb and is present throughout Ja. The amount of shale in the upper of the two exposures at Whitehall is somewhat greater than at Strum, contributing to the less massive appearance of these upper units at Whitehall. This zone more closely resembles the upper portion of Unit 2 at locality E. As at locality E, there is no lithology present at localities H or J which corresponds to Morrison's "upper thin beds".

Locality F:

The lower seven ft. of a third outcrop in Menominee also corresponds to the lithofacies of Unit Two but exhibits thin to thick sandstone beds separated by thin coats of shale which are up to one inch thick in places. The sands are generally finely laminated and exhibit no crossbedding. The shales are slightly bioturbate as at Strum and Whitehall and the sands contain a well developed *Skolithos* facies. (Plate IV refers). The total shale content is much less than at Whitehall, yet more than at Strum and the sands are nearly free of glauconite. A distinctly recognizable brachiopod *Lingullela* (*Lingulepis*) *acuminata* is present at all three localities in this unit and has been recognized as present in the fauna of the *Crepicephalus* zone (Twenhofel et al., 1935) Page 31 refers for illustrated section of locality F.

Discussion:

The variability in the amount of glauconite and the degree of shaliness in the upper 15-20 feet of these lower massive units at various localities illustrated the ambiguity of the existence of these upper thin beds as a distinct unit. The glauconite in the Eau Claire appears to be detrital (Porenga, 1964), and the greater concentrations at various localities is therefore a function of the depositional current and direction of source, as is the shale. The presence of glauconite is an unreliable horizon marker, and more likely illustrates facies variability just as the varying amounts of shale in both Units One and

Two contribute to the changes in bedding style and thickness.

Unit Three-Upper Massive Beds:

The uppermost unit (Morrison's upper massive unit) occurs at seven separate localities (E, F, H, J, M, N, O). This unit is a cleaner but still fine-grained, buff colored sandstone with low angle cross bed sets. The sediment also contains a lesser quantity of brachiopod fragments. No body fossils other than the brachiopod fragments and one hyolithid mold (at locality E) have been found in this unit. A *Skolithos* facies is present here, but is less common than in the lower massive unit. Mud cracks are still present but not as deeply developed nor as abundant as in the lower units. This upper unit ranges from 20 ft. at Whitehall (J) and Bruce Valley Quarry (O) to five feet at most other localities. (Section O is not illustrated in this thesis. However, a complete section is described in Ostrom, 1970, p. 56. The contact between unit 2 and unit 3 is found at approximately the 27 ft. level.) The lithofacies change is accompanied by a break in slope; this uppermost unit being more friable and less resistant to weathering. At these seven localities the Eau Claire/Galesville contact is also present. The only other known locality where the contact between the Eau Claire and Galesville is exposed is at Galesville, Wisconsin (Locality L). (The section at Galesville is not described in this thesis. For a complete illustrated section refer to Ostrom, 1970, p. 66-67.) Here the Galesville rests on what would appear to be the lower massive units of the Eau Claire (Ostrom, 1970). *Crepicephalus* fragments and a *Skolithos* facies are present. A check with an altimeter indicates an exposed 20 ft. of cut out at this location and a total of 60 ft. of cut out when checked at a locality one and one-half miles south of Galesville (locality M). (Section at M and N was not described as continually falling debris discouraged this writer from giving the quarry faces anything other than a cursory examination.)

In summary, I feel there is justification for dividing the formation into three distinct lithologic units: a shaly thin bedded facies, a lower massive facies and an upper massive facies. Figure 3, is a summary description of the lithology and relative thicknesses of the three facies. While the three units seem to occur in a superposition, the lithofacies exhibit lateral variability as well. (Refer to localities A, B, H, J, and F).

The bedding thickness and style of the three lithofacies varies with the outcrop; being influenced by the variation in the amounts of shale present. The complete section exposed west of Eau Claire (locality E) gives the best evidence for delineating three lithofacies. The concept of a three part subdivision is not new (Thwaites, 1923). However, this writer was unaware of Thwaites' opinion and concluded the three part subdivision independently during summer field investigations.

Further stratigraphic study is recommended to better define the facies shifts and more precisely describe the variations within the facies. Well logs and cuttings from the Wisconsin State Geological Survey could be utilized to aid in the correlation of the three lithofacies and locate zones of transition with recognized lithofacies of the Eau Claire in the subsurface of Minnesota and Illinois. Information on changes in grain size and sediment composition could also be gained from the well logs and cores which would give valuable insight into environmental changes and subsurface structure, enabling more complete interpretation of the Eau Claire exposed in Wisconsin. An expansion of the inventory of known outcrops of the Eau Claire formation would also be useful in further geologic studies of the area.

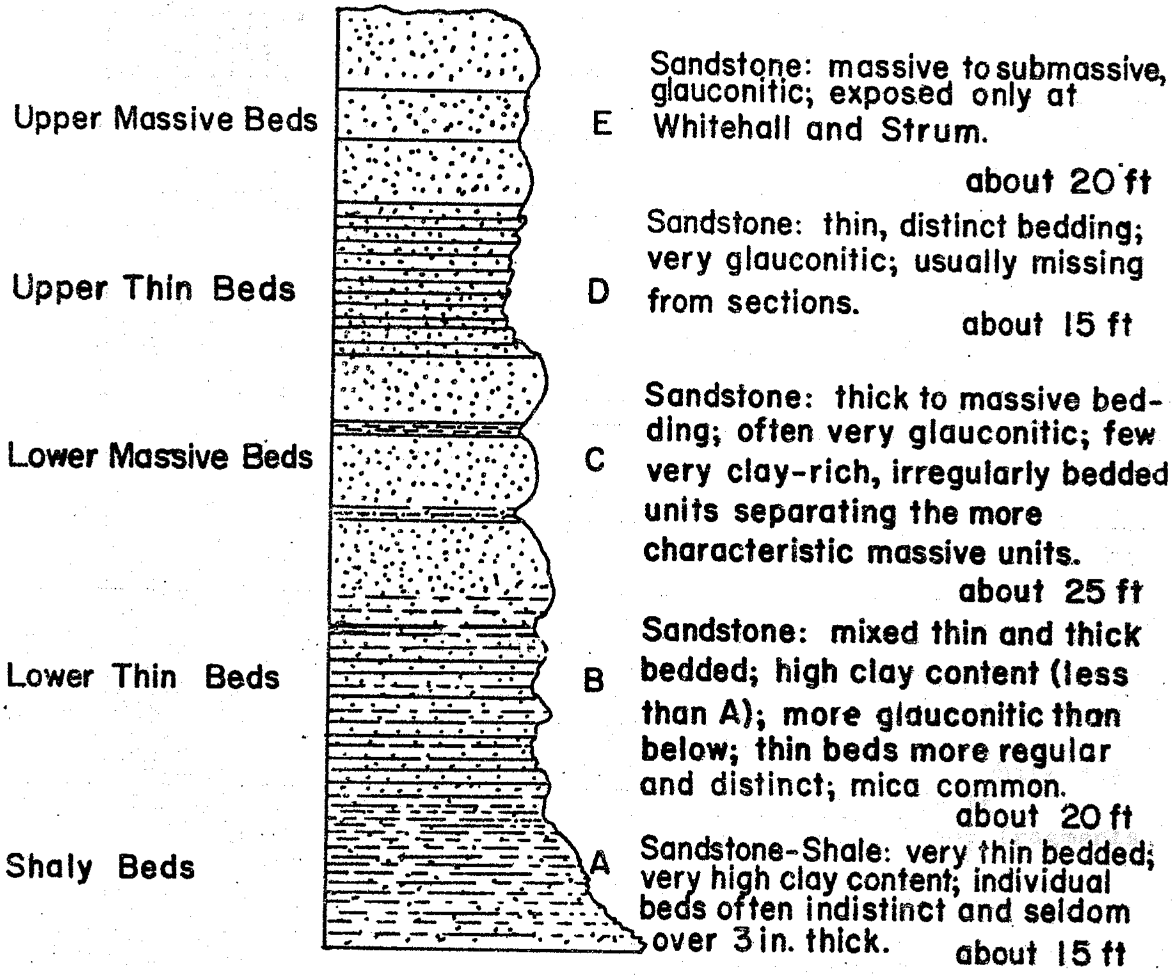
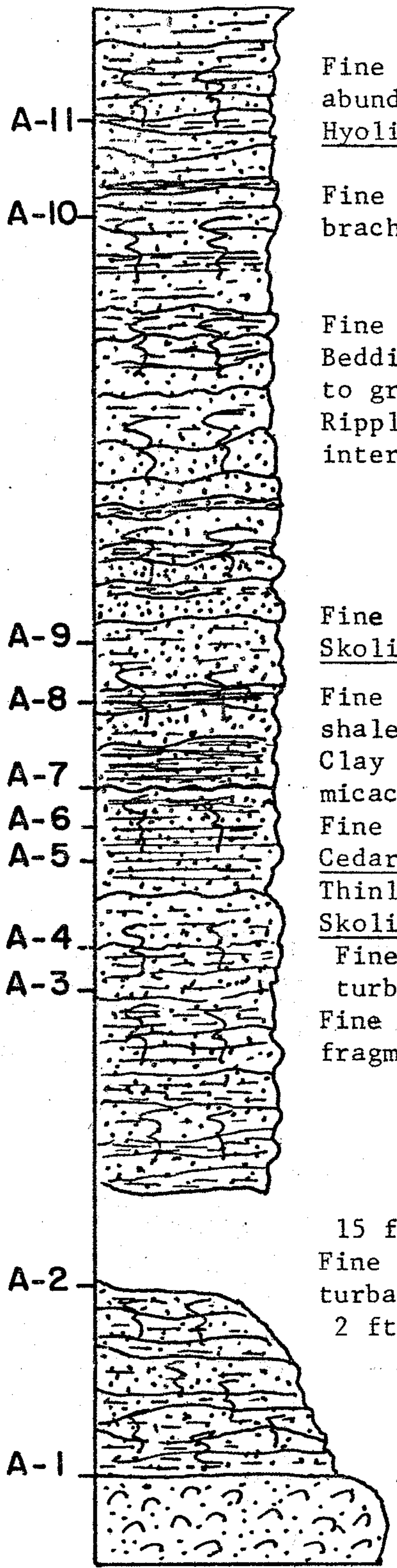


Figure 2: Summary of Morrison's stratigraphic column for the Eau Claire Formation (Morrison 1968, p. 21).

LOCALITY A:
(Description modified from that of Ostrom, 1970, p. 53)

Lithofacies 3 2 1



Scale: 1 in. = 2 ft.

Fine gr., pinkish-white s.s., abundant mica. Lingullela, Hyolithes. 26 ft.

Fine gr. s.s./micaceous. Abundant brachiopod and trilobite fragments. 25 ft.

Fine gr. s.s./silty shale; irregularly bedded. Bedding thickness varies from less than 1 in. to greater than 8 in., extent of outcrop. Ripple marks common. Bioturbate, silty shales interbedded with finely laminated s.s. beds.

Fine gr. micaceous s.s., Cedaria, Hyolithes, Skolithos, Planolites. 20 ft. 6 in.

Fine gr. s.s. w/micaceous laminae. Upper surface shale coated. Planolites. 20 ft.

Clay coated ripples of fine gr. pinkish white s.s. micaceous. Hyolithes, Planolites. 19 ft.

Fine gr. s.s. w/trilobite and brachiopod fragments. Cedaria. 18 ft. 4 in.

Thinly laminated s.s./siltstone, micaceous. Skolithos. 18 ft.

Fine gr. s.s., pinkish white, micaceous. Bioturbate, Planolites, Obolus. 17 ft. 3 in.

Fine gr. s.s./silty shale, abundant brachiopod fragments. Lingullela. 17 ft.

15 ft. covered interval

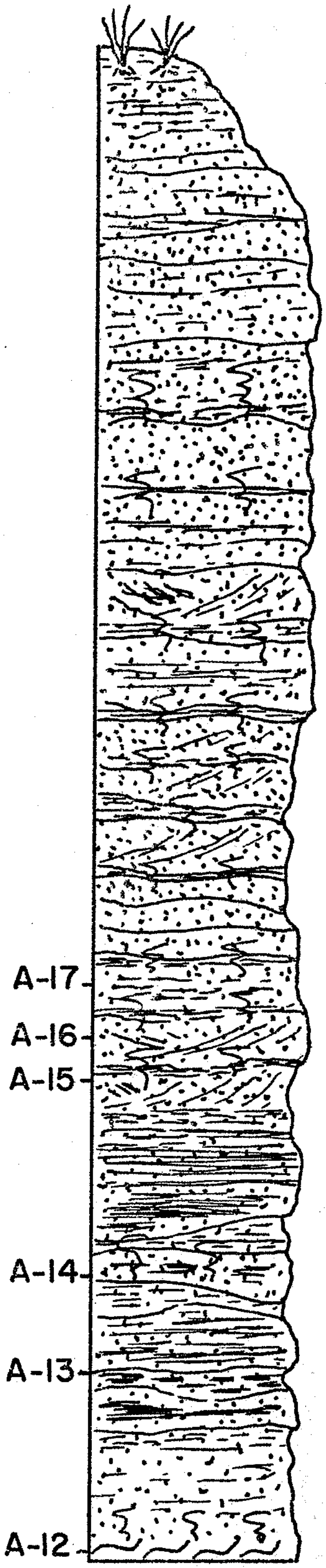
Fine gr. s.s., light tan, thin bedded. Bioturbate. Numerous brachiopod fragments. Obolus. 2 ft.

Eau Claire (about 8 ft. above road level)

Shawtown

Md. gr. s.s., fe stained, well cemented. Brachiopod fragments. Obolus.

LOCALITY A (continued):



Scale: 1 in. = 2 ft.

Fine gr. s.s./shale, light tan to while, shales grey-green. Mud cracks, ripple marks throughout exposure. Skolithos, Cruziana, Rusophycus trails throughout exposrue. Bedding partially destroyed by biogenic mixing.

Fine gr. s.s. becoming biogenically mixed. Hyolithes, Menominia, Lingullela. 33 ft.

Fine gr. s.s. w/low angle x-bedding. Zones of biogenically mixed s.s./shales. Skolithos, brachiopod fragments. 32 ft. 6 in.

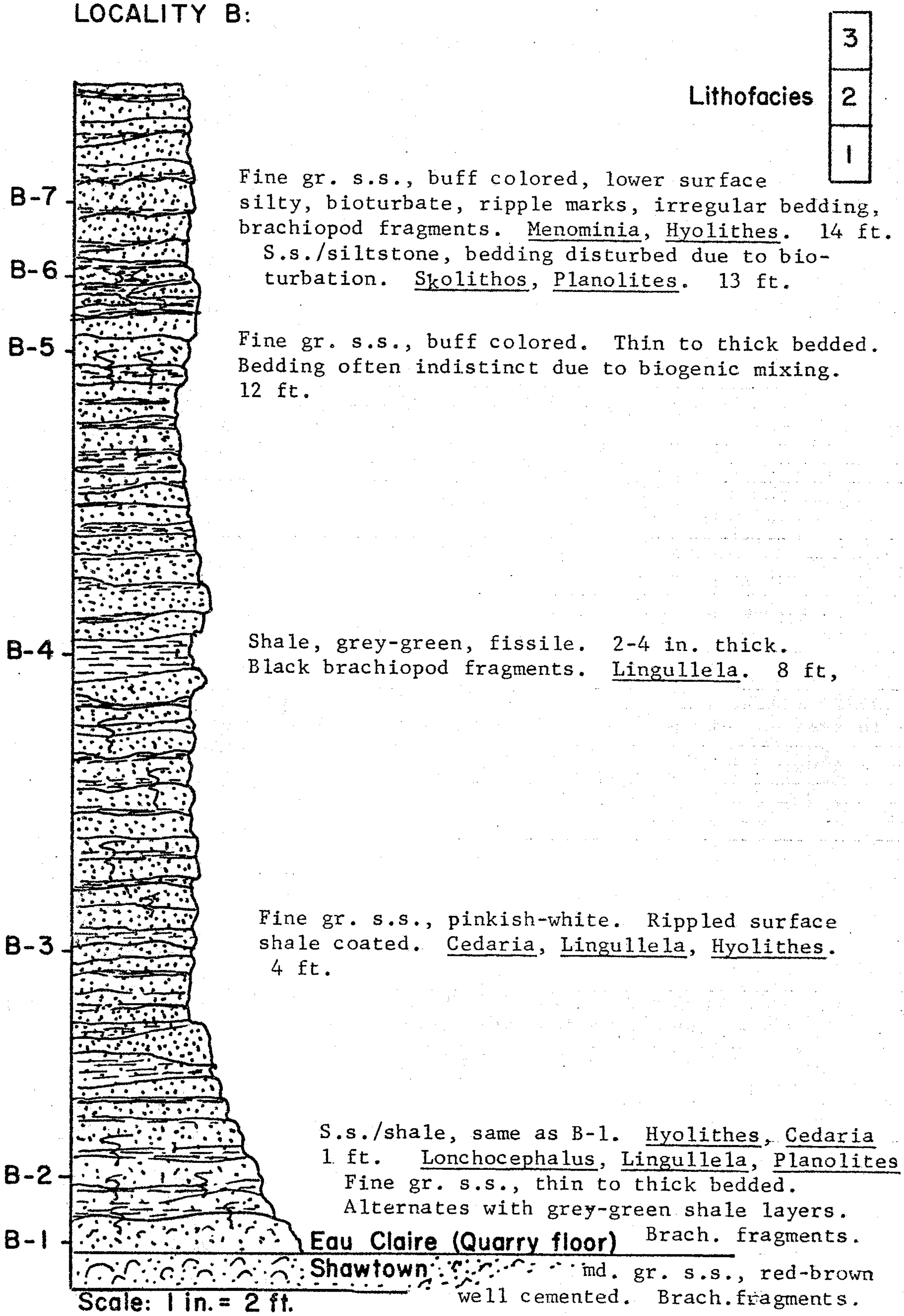
Fine gr. s.s., pinkish-white, w/low angle x-bed sets. Clay chips, trilobite and brachiopod fragments. Lingullela, Cedaria, Lonchocephalus, Hyolithes. 32 ft.

Fine gr. s.s./grey-green shale. Bioturbate. Brachiopod fragments. Planolites. 30 ft.

Fine gr. s.s., thinly laminated. Shale layers abundant mica. Lingullela. 29 ft.

Fine gr. s.s., bioturbate shale layers. Mud cracks. Planolites, Cedaria, Hyolithes. 27 ft. 2 in.

LOCALITY B:



Fine gr. s.s., buff colored, lower surface silty, bioturbate, ripple marks, irregular bedding, brachiopod fragments. Menominia, Hyolithes. 14 ft.

S.s./siltstone, bedding disturbed due to bioturbation. Skolithos, Planolites. 13 ft.

Fine gr. s.s., buff colored. Thin to thick bedded. Bedding often indistinct due to biogenic mixing. 12 ft.

Shale, grey-green, fissile. 2-4 in. thick. Black brachiopod fragments. Lingullela. 8 ft,

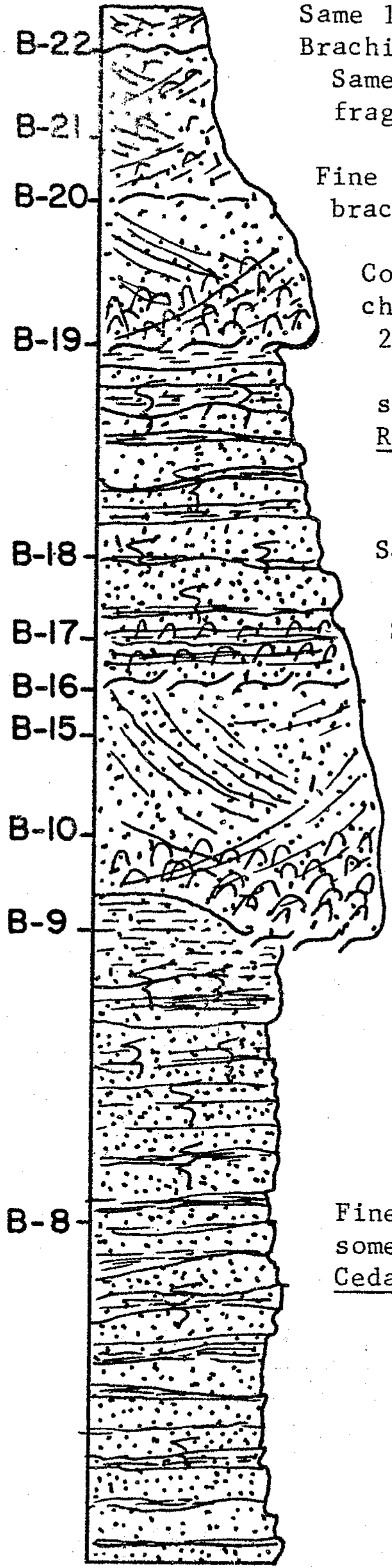
Fine gr. s.s., pinkish-white. Rippled surface shale coated. Cedaria, Lingullela, Hyolithes. 4 ft.

S.s./shale, same as B-1. Hyolithes, Cedaria 1 ft. Lonchocephalus, Lingullela, Planolites

Fine gr. s.s., thin to thick bedded. Alternates with grey-green shale layers. Brach. fragments.

md. gr. s.s., red-brown well cemented. Brach. fragments.

LOCALITY B (continued):



Same lithology as B-20. Ripple marks w/mud cracks. Brachiopod fragments. 31 ft.

Same lithology as B-20, abundant brachiopod fragments. 30 ft.

Fine gr. s.s. w/low angle x-bedding. Lonchocephalus, brachiopod fragments. 29 ft. 6 in.

Coquinite of trilobite and brachiopod molds, mud chips, and pebbles composed of brachiopod frag. 28 ft.

s.s/shale interbeds. Bioturbate. Cruziana, Rusophycus, ripple marks and mud cracks.

Same lithology as B-16. Monomorphichnus.

Same lithology as B-16. Rusophycus, Cruziana.

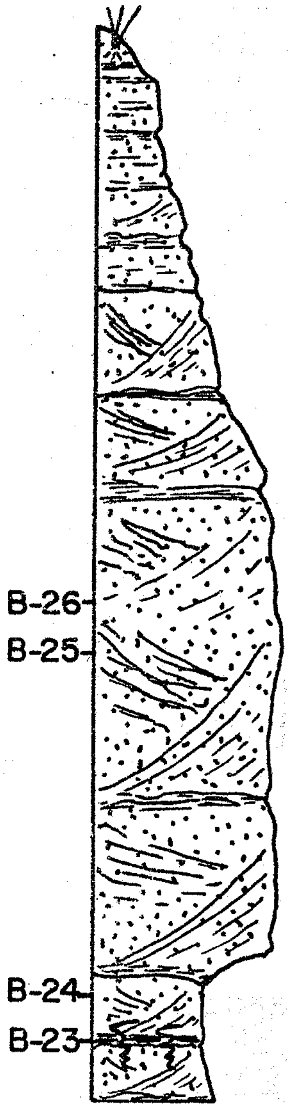
S.s./shale-finely laminated. Trilobite coquinites. Mud cracks. Cedaria, Menominia. 24 ft. Planolites.

Fine gr. glauconitic s.s., buff colored. Low angle x-bedding. Coquinites of trilobite hyolithid and brachiopod fragments at base of thick beds. Cedaria, Menominia, Hyolithes Lonchocephalus, Lingullela, mudcracks. 22 ft.

Fine gr. s.s., buff colored, finely laminated, some glauconite. Abundant brachiopod fragments. Cedaria, Menominia, Hyolithes, Skolithos. 19 ft.

Scale: 1 in. = 2 ft.

LOCALITY B (continued)



Fine gr. s.s., micaceous, light tan color. X-bedding. Hyolithes. 36 ft.

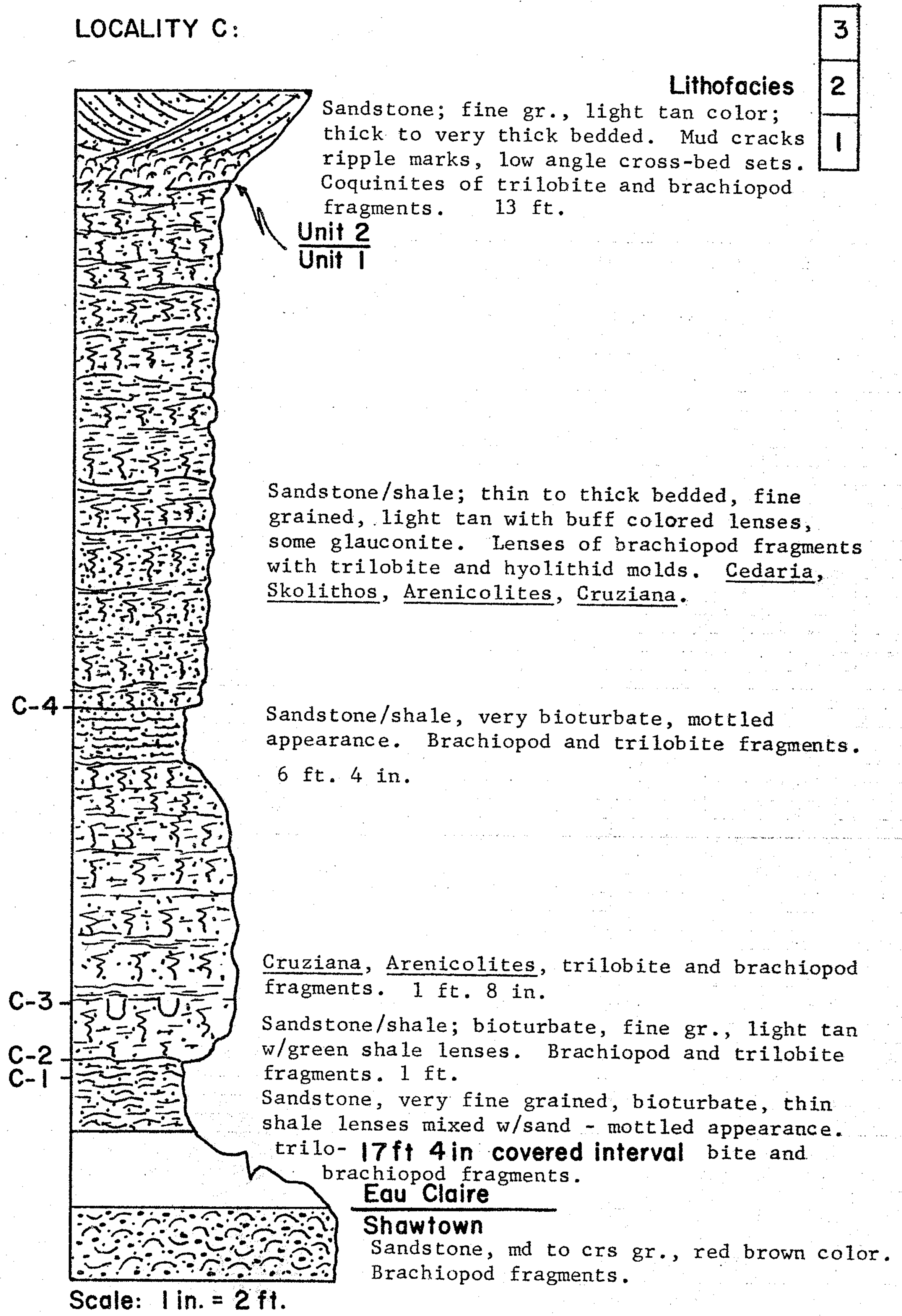
Fine gr. s.s., micaceous, abundant brachiopod fragments. X-bedding. 35 ft. 6 in.

Same lithology as B-23. Crepicephalus, Lonchocephalus, Coosia, Hyolithes. 33 ft.

Fine gr. s.s., abundant brachiopod fragments. X-laminae, micro-ripple marks. Biogenic structure. Rusophycus, Cruziana, Monomorphichnus Crepicephalus, Lonchocephalus, Brassicicephalus, Hyolithes, Lingullela. 32 ft. 6 in.

Scale: 1 in. = 2 ft.

LOCALITY C:



Sandstone; fine gr., light tan color; thick to very thick bedded. Mud cracks ripple marks, low angle cross-bed sets. Coquinites of trilobite and brachiopod fragments. 13 ft.

Sandstone/shale; thin to thick bedded, fine grained, light tan with buff colored lenses, some glauconite. Lenses of brachiopod fragments with trilobite and hyolithid molds. <u>Cedaria</u>, <u>Skolithos</u>, <u>Arenicolites</u>, <u>Cruziana</u>.

Sandstone/shale, very bioturbate, mottled appearance. Brachiopod and trilobite fragments.

6 ft. 4 in.

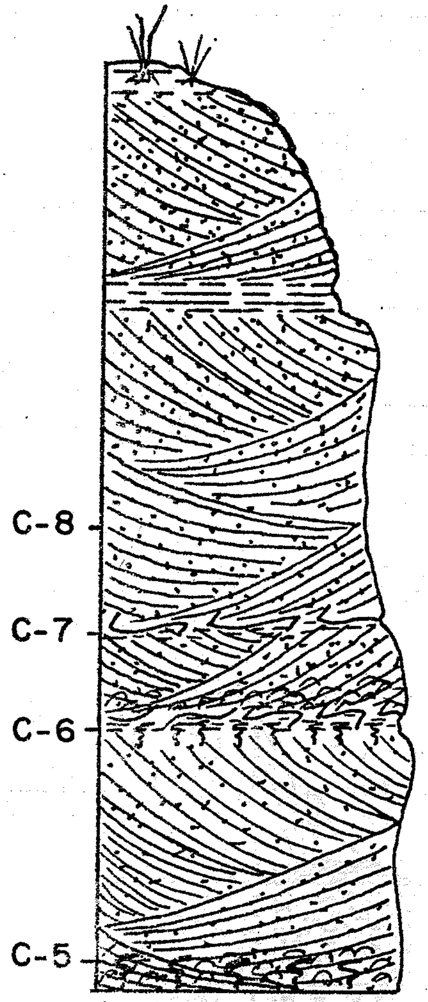
<u>Cruziana</u>, <u>Arenicolites</u>, trilobite and brachiopod fragments. 1 ft. 8 in.

Sandstone/shale; bioturbate, fine gr., light tan w/green shale lenses. Brachiopod and trilobite fragments. 1 ft.

Sandstone, very fine grained, bioturbate, thin shale lenses mixed w/sand - mottled appearance. trilobite and brachiopod fragments.

Sandstone, md to crs gr., red brown color. Brachiopod fragments.

LOCALITY C (continued):



23 ft. 6in.

Scale: 1 in. = 2 ft.

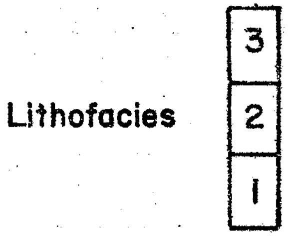
Palaeacmaea in fine grained sandstone, buff colored. 19 ft.

Fine grained sandstone, buff colored. Mud cracks, ripple marks. 18 ft.

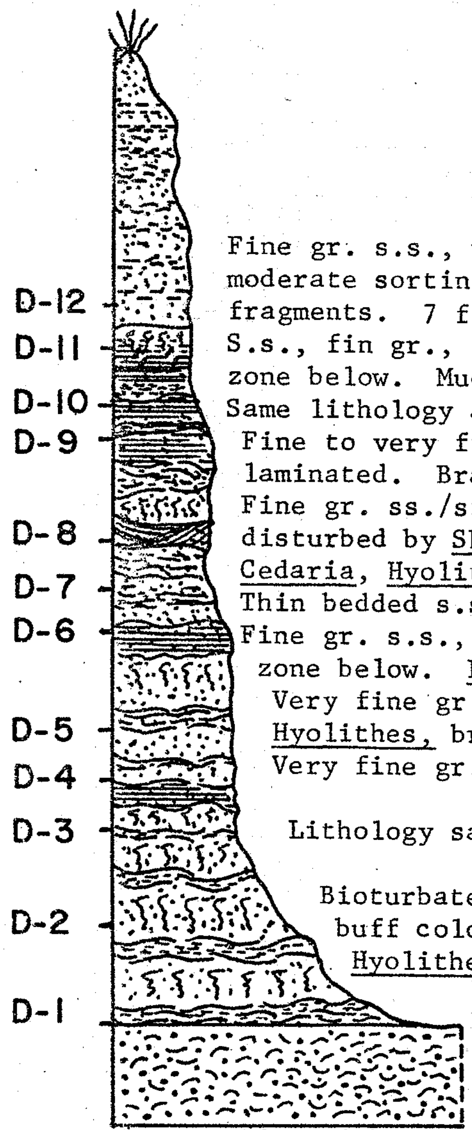
Fine grained sandstone, buff colored. Thin shale layer with *Planolites*. Mud cracks, ripple marks. *Cedaria*, *Hyolithes*, brachiopod fragments concentrated in coquinites at base of low angle cross-bed sets. 17 ft.

Very fine grained, buff colored sandstone, low angle cross-bedding, mud cracks, thick to very thick bedding. Coquinites at base of thick beds. *Cedaria*, *Hyolithes*, *Skolithos*. 15 ft.

LOCALITY D (Morrison's 3):
(Description modified from that of Morrison, 1968, p. 10)



11 ft.



Fine gr. s.s., non-glauconitic, subangular to sub-rounded, moderate sorting, light tan. Hyolithes, Obolus, trilobite fragments. 7 ft. 3 in.

S.s., fin gr., thinly laminated; Skolithos, bioturbate zone below. Mud cracks, Hyolithes, brach., tril. frag.

Same lithology as below. Planolites, brach, Hyolithes frag.

Fine to very fine gr. s.s., mica, some glauc., thinly laminated. Brachiopod fragments and surface trails. 6 ft.

Fine gr. ss./silty shale w/low angle x-bed laminae, beds disturbed by Skolithos, Planolites. Shale coatings. Cedaria, Hyolithes. 5 ft.

Thin bedded s.s./shale sequence., Arenicolites, Hyolithes

Fine gr. s.s., thinly laminated w/sandy shaly bioturbate zone below. Planolites, brachiopod fragments. 4 ft.

Very fine gr. s.s.; subangular, good sorting, mica. Hyolithes, brachiopod and trilobite fragments. 3 ft.

Very fine gr. s.s., laminated w/mica. Obolus.

Lithology same as below. Obolus. 2 ft.

Bioturbate, fine gr. s.s./silty shale; grey-green to buff colored. Zones of subangular md to crs gr. s.s. Hyolithes, Cedaria, and Obolus. 1 ft.

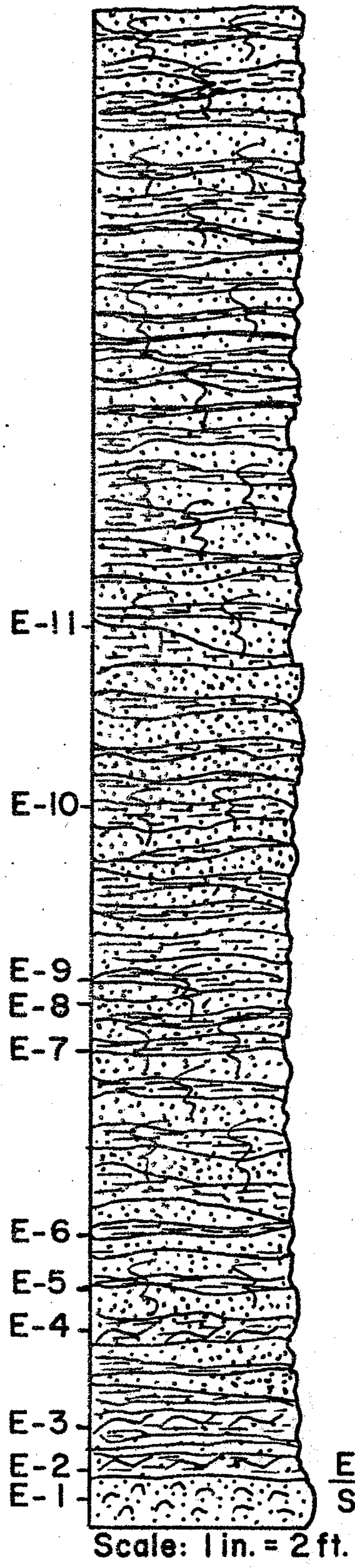
Eau Claire

Shawtown

Sandstone, red-brown, md to very crs gr. well rounded, abundant brach fragments.

Scale: 1 in.= 2 ft.

LOCALITY E:



Lithofacies 3 / 2 / 1

Sandstone/silty shale, interbedded and biogenically mixed.

Sandstone, fine gr., lense, pinkish-white, glauconitic, abundant brachiopod fragments. Planolites, Arenicolites. 9 ft.

Sandstone, fine gr., poorly sorted. Lower surface has biogenic structure. Planolites, Cedaria, Obolus. 7 ft.

Fine gr. s.s., pinkish-white, upper surface mud cracked shale coat. Cedaria, Obolus. 5 ft.

Silty shale, grey-green with trilobite thorax, Planolites.

Md to fine gr. s.s., with clay lenses. Some mica. Brachiopod fragments. Planolites, Cruziana. 4 ft., 3 in.

Crs gr. s.s. lense with brachiopod frag. 2½ft.

Fine gr., micaceous s.s., with shale, biogenic mixing. Brachiopod fragments. 2 ft.

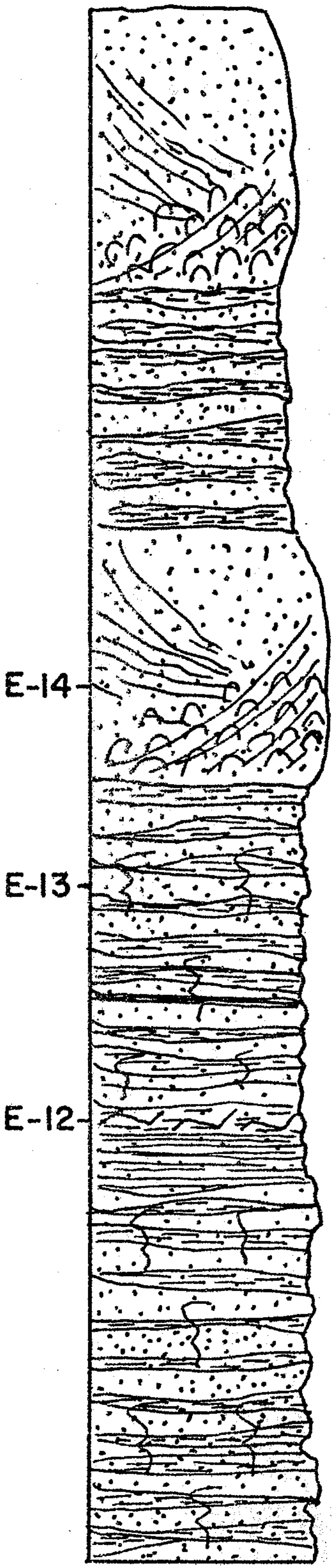
Silty-shale, grey-green. Mud cracks. 18 in.

Fine to md gr. s.s., pinkish-white with shale coating. Mud cracks. (E-2, same lith. w/mud cracks. Brachiopod fragments.)

Eau Claire (about 10 ft. above road level)

Shawtown S.s., md to crs gr., red brown, Brach. fragments.

LOCALITY E (continued):



Fine gr. s.s., some glauconite. Coquinite chips of brachiopod, trilobite and hyolithid fragments. Cedaria, Hyolithes. 24 ft., 7 in.

Unit 2

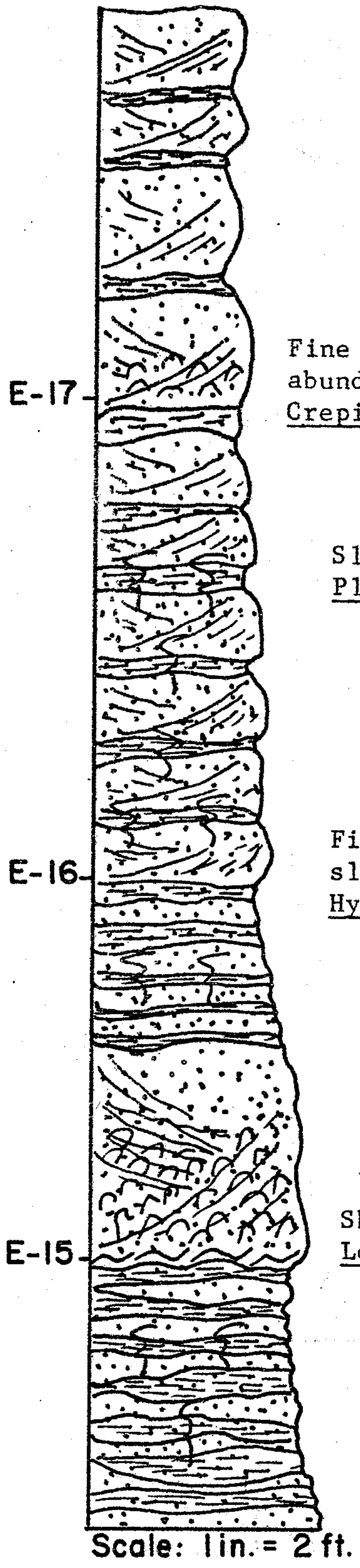
Unit 1

Fine gr. s.s., buff colored. Brachiopod frag. Skolithos, Cruziana, Planolites. 22 ft., 6 in.

Fine gr. s.s., thinly laminated, glauconitic. Micro-ripples, mud cracks. 20 ft.

Scale: 1 in. = 2 ft.

LOCALITY E (continued):



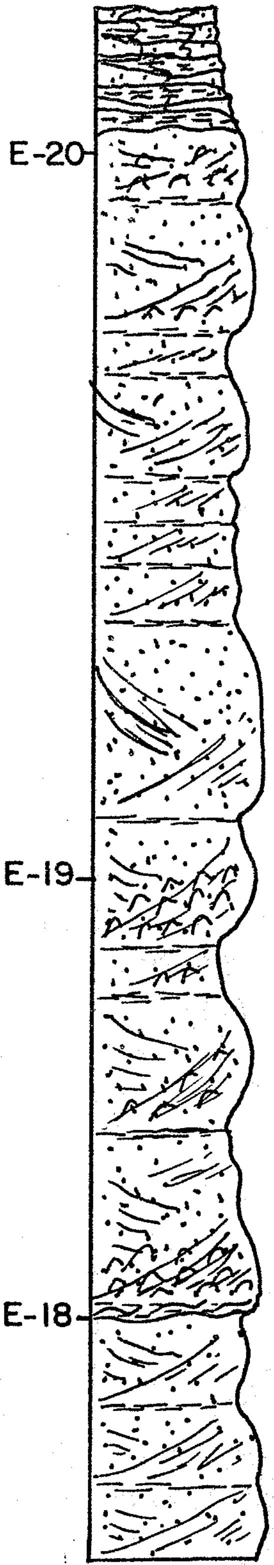
Fine gr. s.s., glauconitic. Fine cross-laminae with abundant fossil fragments. Hyolithes, Obolus, Crepicephalus, Lonchocephalus. 43 ft.

Slightly bioturbate silty-shale interbeds. Planolites, Skolithos.

Fine gr. s.s., glauconitic, with shale interbeds slightly bioturbate. Brachiopod fragments. Hyolithes, Planolites. 38 ft. 7 in.

Shell coquinite above mud cracked ripple surface. Lonchocephalus, Hyolithes, Obolus. 34 ft., 7 in.

LOCALITY E (continued):



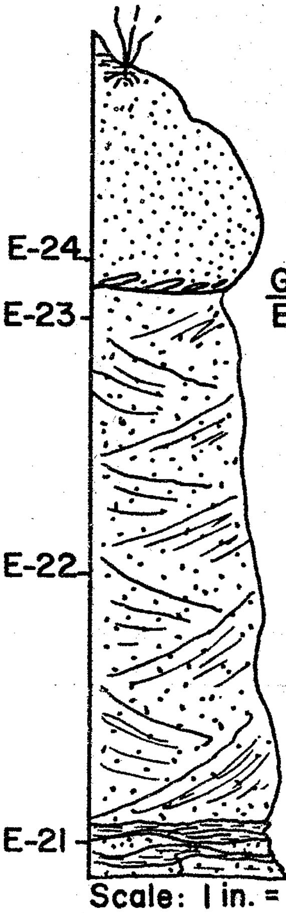
Fine gr. s.s., some glauconite. Brachiopod frag. Mud chips, ripple marks. 62 ft.

Fine gr. s.s., glauconitic, some md sized qtz gr. sub-rounded. Low angle cross-laminae w/shell coquinite. <u>Crepicephalus</u>, <u>Hyolithes</u>, <u>Obolus</u>.
54 ft., 6 in.

Fine gr. s.s., some glauconite. Lower surface mud cracked. Low angle cross-laminae. Trilobite and brachiopod fragments. <u>Hyolithes</u>, <u>Lonchocephalus</u> <u>Crepicephalus</u>. 50 ft.

Scale: 1 in. = 2 ft.

LOCALITY E (continued):



Crs gr. s.s., red brown, well cemented. Interformational conglomerate, pebbles of E. C. lith. imbricate in Galesville.

69 ft. 7 in.

Same lithology as E-22. Low angle cross-bedding.

Fine gr. s.s., friable, buff colored, slightly glauconitic. Brachiopod fragments. Hyolithes. Low angle cross-bedding. 66 ft.

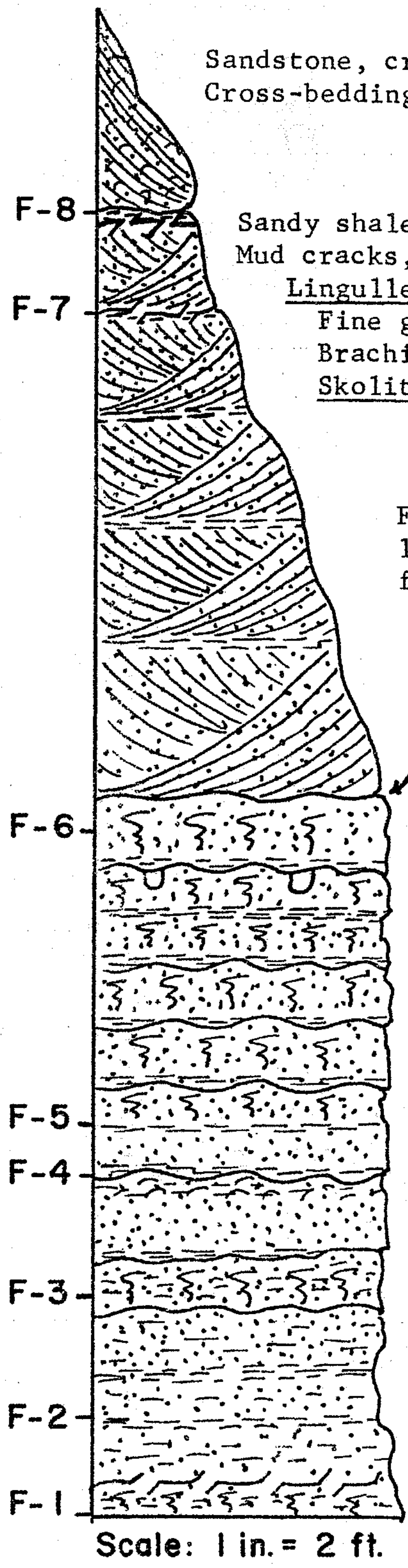
Silty shale w/s.s. lenses. Bioturbate, Planolites. 64 ft.

Scale: 1 in. = 2 ft.

LOCALITY F:

Lithofacies

3
2
1



Sandstone, crs gr., buff colored. Well rounded Cross-bedding w/some brachiopod fragments at base.

Galesville

Eau Claire

Sandy shale w/mud partings. Mud cracks, Arenicolites, Skolithos, Lingullela. 13 ft. 5 in.

Fine gr. s.s., buff colored, non-glauconitic. Brachiopod fragments and mud cracks. Lingullela, Skolithos, Monocraterion. 12 ft. 10 in.

Fine gr. s.s., buff colored w/some shale layers. Low angle x-bedding. Brachiopod fragments.

Unit 3

Unit 2

S.s., thinner bedded, white, fewer brachiopod fragments, shales thicker, more bioturbate. Ripple marks increase. Arenicolites, Diplocraterion, Skolithos, Obolus. 7 ft. 5 in.

Fine gr. s.s. w/abundant brachiopod fragments. Skolithos, Planolites. 3 ft. 11 in.

Fine to very fine gr. s.s., white w/some glauconite and mica. Clay zones w/mica. Brachiopod fragments, ripple marks. 3 ft.-6 in.

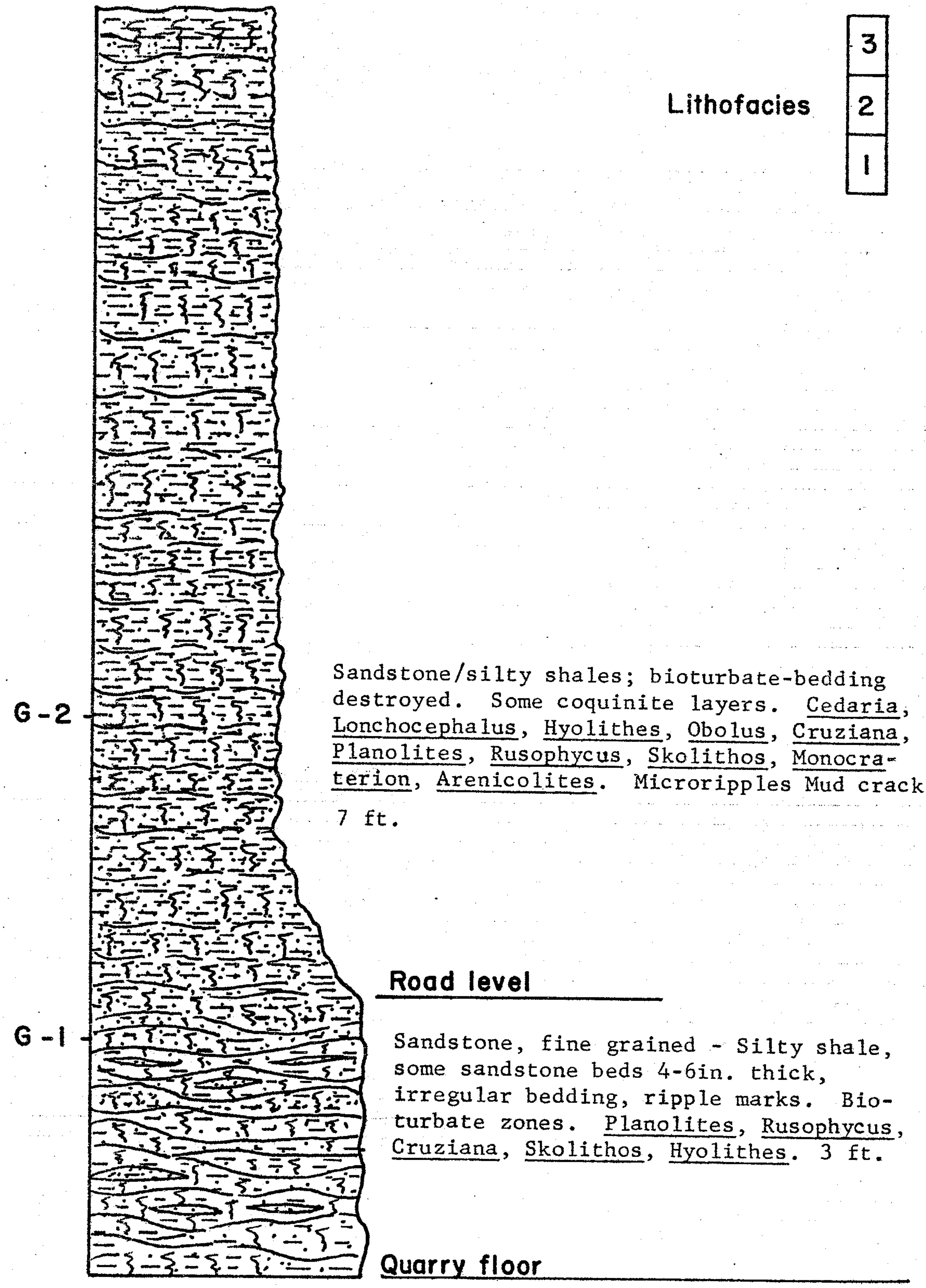
Fine gr. s.s. w/brachiopod fragments, ripple marks. Skolithos and surface trails. 2 ft-4 in.

Thin bedded s.s., pinkish-white. Interbedded w/grey green shales. Some glauc. Brach fragments. 1 ft.

Grey-green sandy shale Skolithos, Planolites, mud cracks.

Road level

LOCALITY G (Morrison's 8):
(Description modified from that of Morrison, 1968, p. 14)



Sandstone/silty shales; bioturbate-bedding destroyed. Some coquinite layers. Cedaria, Lonchocephalus, Hyolithes, Obolus, Cruziana, Planolites, Rusophycus, Skolithos, Monocraterion, Arenicolites. Microripples Mud cracks.

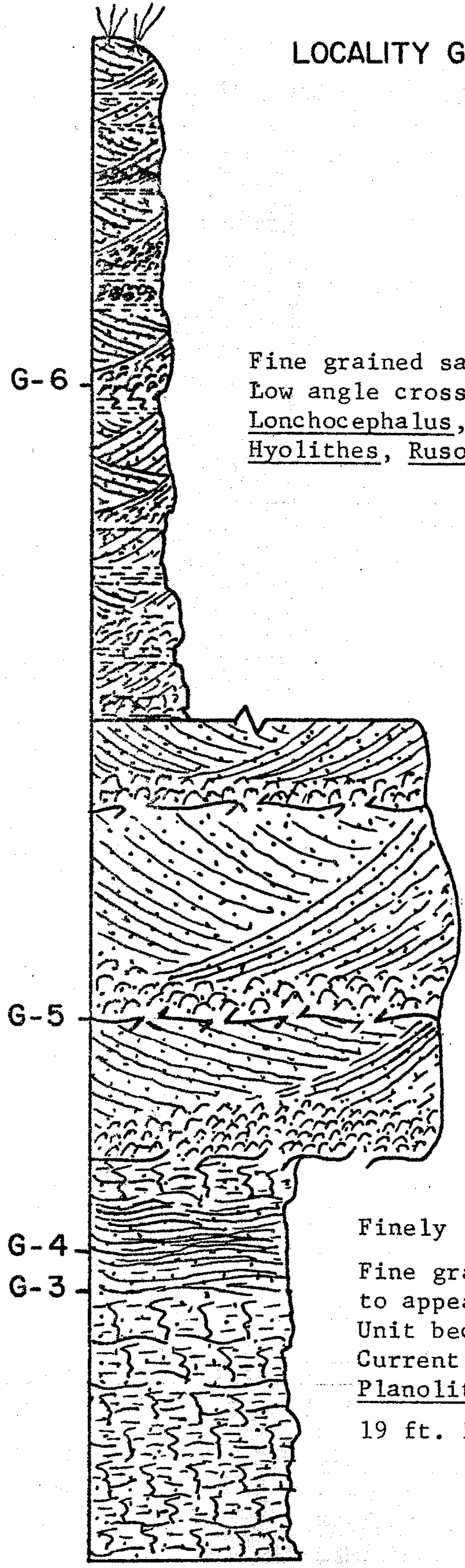
7 ft.

Sandstone, fine grained - Silty shale, some sandstone beds 4-6in. thick, irregular bedding, ripple marks. Bioturbate zones. Planolites, Rusophycus, Cruziana, Skolithos, Hyolithes. 3 ft.

Scale: 1 in. = 2 ft.

LOCALITY G (continued):

33 ft. 3 in.



Fine grained sandstone; mudcracks, current marks. Low angle cross-bed sets with coquinites of Lonchocephalus, Crepicephalus, Welleraspis, Hyolithes, Rusophycus. 28 ft.

Fine grained sandstone with zones of mud cracks and ripple marks. Coquinites, mud chips in low angle laminae. Cedaria, Hyolithes. 22 ft. 7 in.

Unit 2

Unit 1

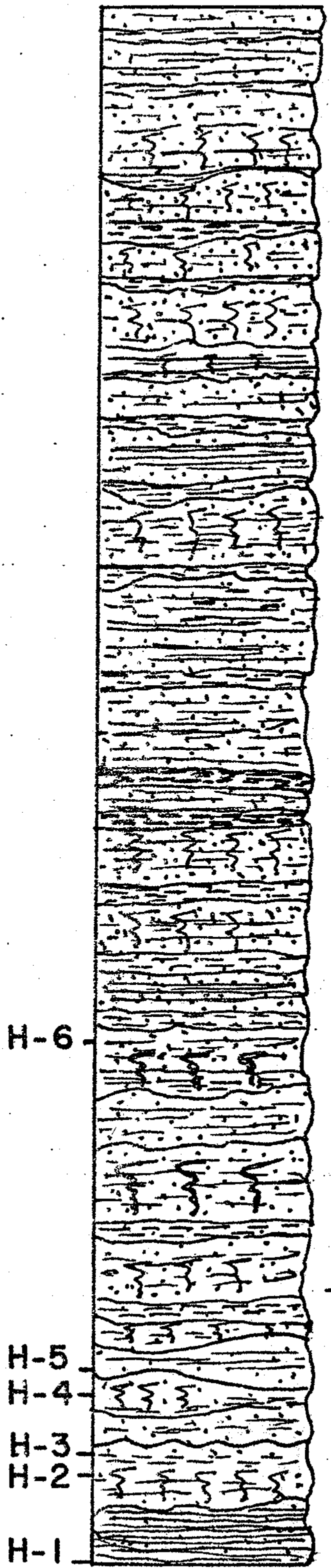
Finely laminated sandstone/shale. Cedaria.

Fine grained sandstone, fine laminae beginning to appear, laminae composed of shell hash. Unit becomes less biogenically disturbed. Current mark, 18 in. long. Oriented SW-NE. Planolites, Cedaria, brachiopod fragments.

19 ft. 5 in.

Scale: 1 in. = 2 ft.

LOCALITY Hb (Morrison's 9):
(Description modified from that of Morrison, 1968, pp. 15-16.)



Claystone, grey-green, micaceous, thin-bedded, interbedded w/fine gr., thinly laminated s.s. Generally bioturbate throughout. Bedding disturbed, not destroyed. Skolithos, Planolites.

Fine gr. s.s., micaceous, finely laminated w/brachiopod fragments. Interbedded w/slightly bioturbate layers. Rusophycus, Cruziana, Planolites, Hyolithes, trilobite and brachiopod fragments. 5 ft. 5 in.

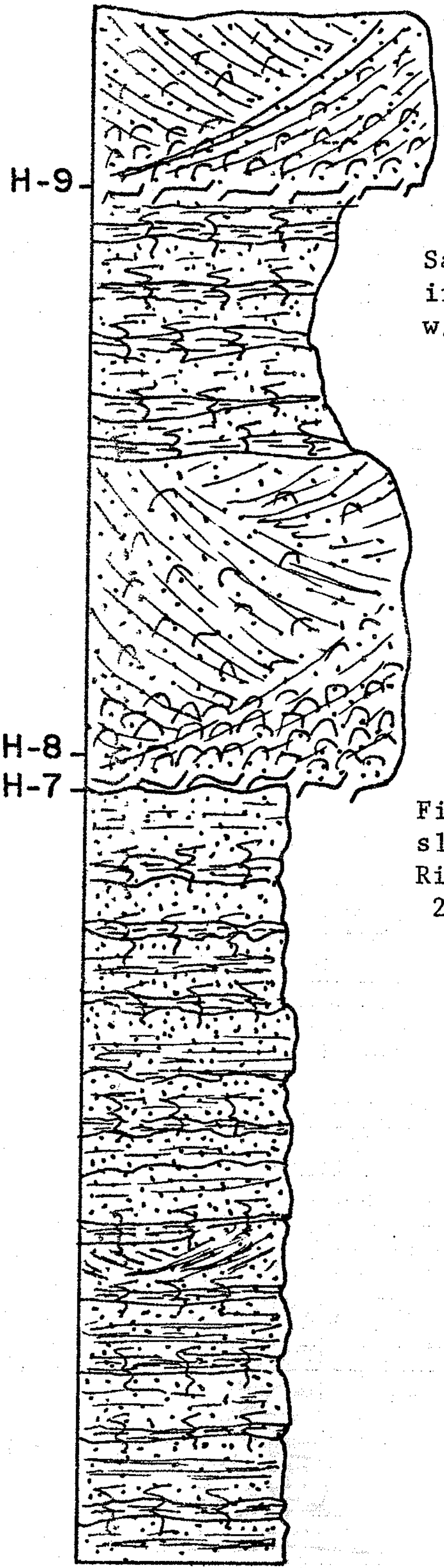
Road level

Fine gr. s.s., micaceous, grey. Hyolithes, 2 ft.
Menominia, Lonchocephalus, Skolithos, Planolites.
Planolites, Hyolithes, Skolithos, brach. frag.
Same lithology as H-2, ripple marks, trilobite and brachiopod fragments. 20 in.
Fine gr. s.s., subangular, micaceous. Planolites Rusophycus, Arenicolites, Hyolithes, brach. frag.

Lowest level of quarry 1 ft.

Scale: 1 in. = 2 ft.

LOCALITY Hb (continued):



Fine gr. ss., tan, glauconitic, low angle x-bedding w/coquinite of trilobite debris. Mud cracks. Cedaria, Menominia. 30 ft.

Sandstone/shale mixed, yellow brown, irregularly bedded, zones of bioturbation w/mottled appearance. Planolites.

Sandstone, light tan, fine to very fine gr., glauconitic. Beds pinch and swell throughout extent of the outcrop. Low angle x-bed sets w/ coquinite of trilobite and brach fragments. Mud cracks. Cedaria, Brassicicephalus, Menominia, Hyolithes, 24 ft 2 in.

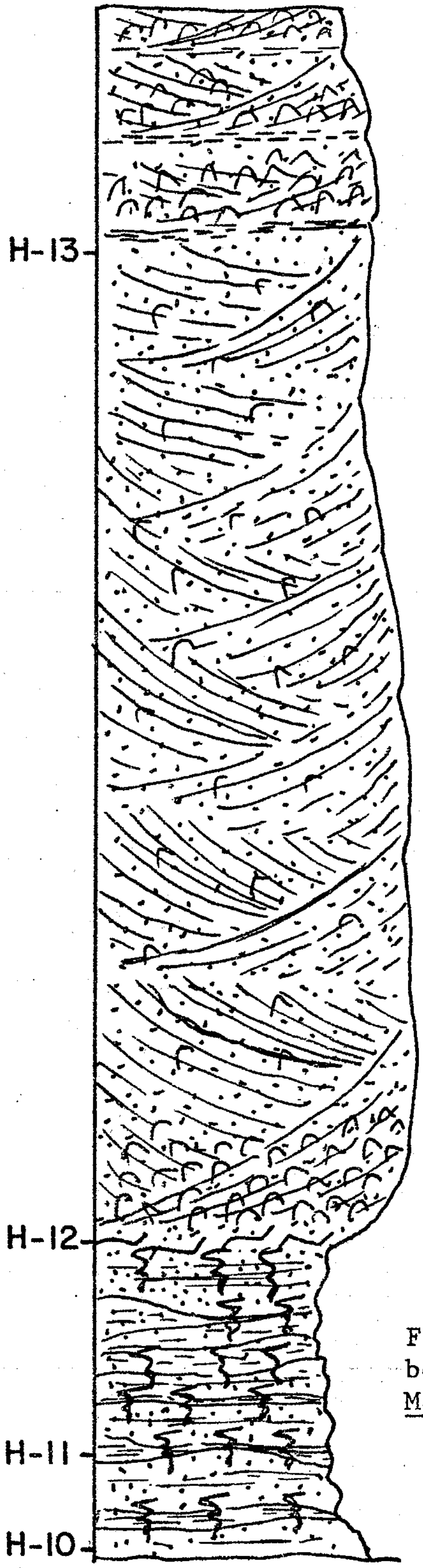
Unit 2

Unit 1

Fine to ver fine gr. s.s., grey tan, slightly micaceous, some glauconite. Ripple marks, brachiopod fragments. Cedaria 24 ft.

Scale: 1 in. = 2 ft.

LOCALITY Hb (continued):



Sandstone, fine gr., buff colored, glauconite content increasing. Some clay partings. Crepicephalus, Lonchocephalus, Welleraspis, Brassicicephalus. 44 ft. 7 in.

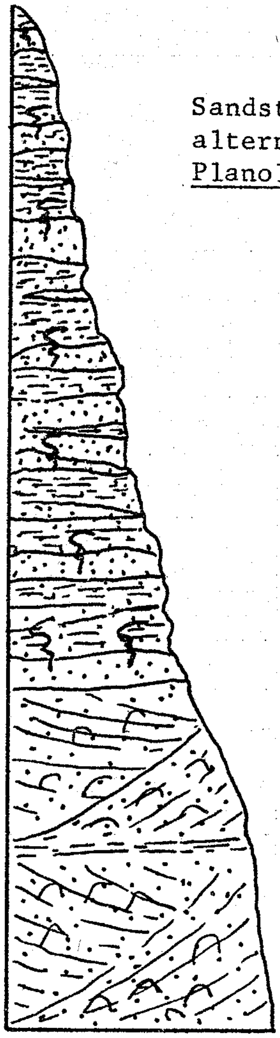
Sandstone, fine gr. buff colored. Little glauconite. Low angle x-bedding w/coquinite of trilobite fragments and mud chips. Cedaria. 35 ft.

Fine gr. s.s./shale sequence, thin, irregular bedding. Bioturbate. Rusophycus, Cedaria, Menominia, Cruziana. 33 ft.

Scale: 1 in. = 2 ft.

LOCALITY Hb (top of exposure):

Exposure Hb separated from Ha by approximately 2 miles. Covered interval of 20 ft.



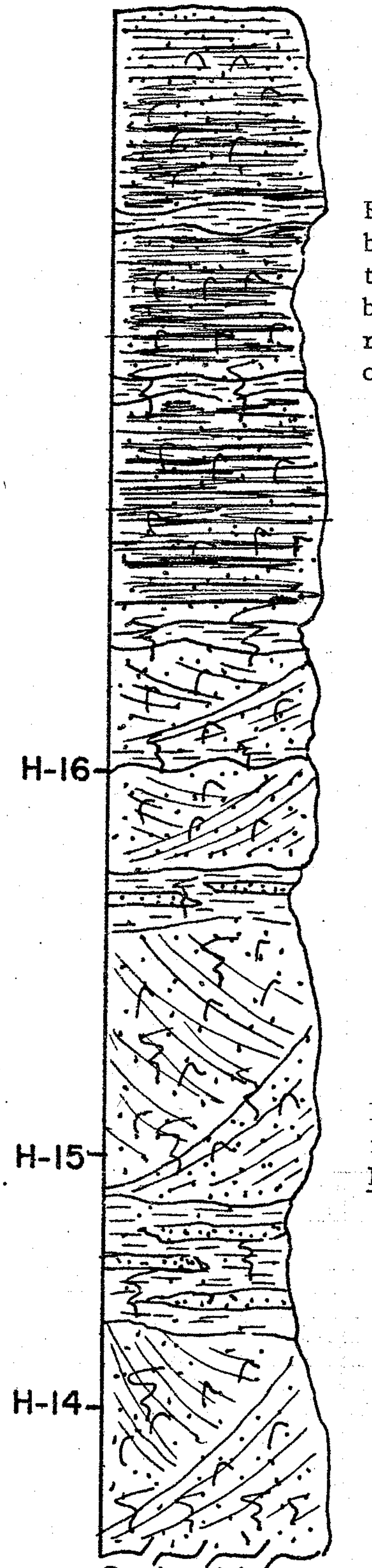
Sandstone, fine gr., thin bedded, very glauconitic, alternating with silty shales. Surface trails, Planolites, Skolithos. 60 ft. 5 in.

Fine grained s.s., thick bedded. Glauconite increases upward in section. Crepicephalus fragments.

Scale: 1 in. = 2 ft.

LOCALITY Ha (Morrison's 9):
(Description modified from that of Morrison, 1968, p. 15)

Lithofacies 3 2 1



Fine gr. s.s., thinly laminated, thick bedded, glauconitic. Skolithos, Hyolithes, trilobite fragments. Interbedded w/slightly bioturbate grey-green silty shale. Mud cracks, ripple marks. Irregularly bedded. Thickness of s.s. beds varies from 2 ft. to 4 ft.

Fine gr. s.s., glauconitic w/brachiopod fragments. Current ripples. Cruziana, surface trails. 8 ft.

Fine gr. s.s., glauconitic, abundant brachiopod fragments. Arenicolites, surface trails, Lonchocephalus, Hyolithes. 4 ft.

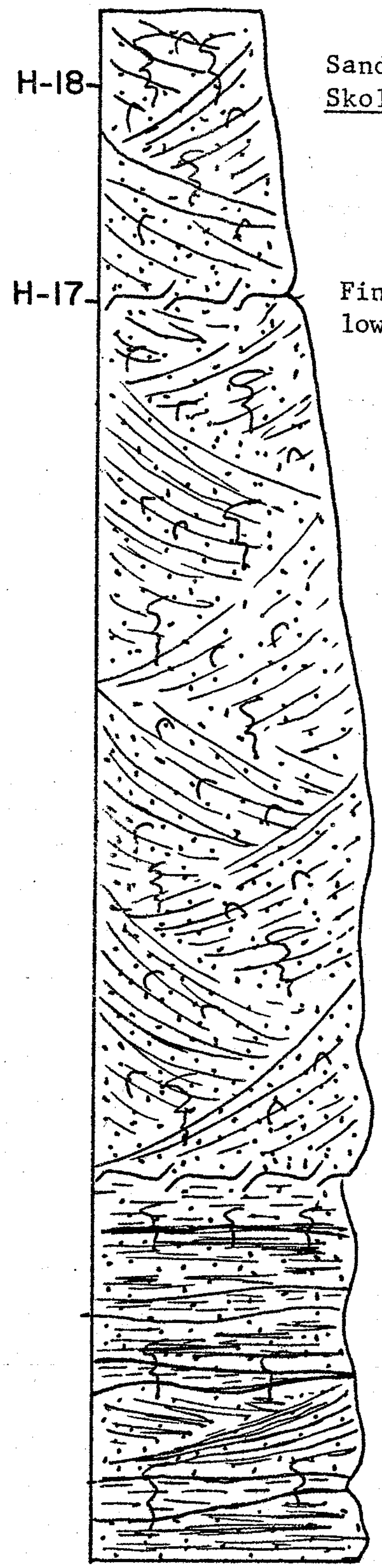
Sandstone/shale interbedded.

Fine gr. s.s., glauconitic. Brachiopod fragments. Low angle X-bedding. Mud cracks. Planolites, Rusophycus. 18 in.

Measured from first good exposure at base of hill.

Scale: 1 in. = 2 ft

LOCALITY Ha (continued):



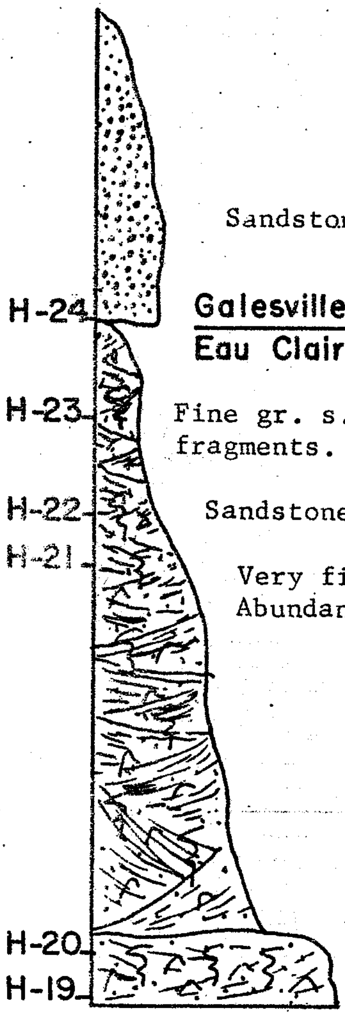
Sandstone, same as H-17. <u>Lingullela</u>, <u>Arenicolites</u>, <u>Skolithos</u>.

Fine gr. s.s., very glauconitic, mud cracks, low angle x-bedding. Brachiopod fragments. 29 ft.

Fine gr. s.s., buff colored, very glauconitic. Thin x-laminae, thick to very thick bedded. Brachiopod fragments. Mud cracks. <u>Skolithos</u>.

Scale: 1 in. = 2 ft.

LOCALITY Ha (continued)



Sandstone, crs gr., well rounded, red brown, friable.

Galesville

Eau Claire Very fine gr. s.s., light tan. Diplocarterion. 38 ft. 8 in. Arenicolites.

Fine gr. s.s., buff colored, low angle x-bedding. Brach. fragments. Skolithos. 37 ft. 8 in.

Sandstone, same as H-21, Skolithos, Arenicolites. 36 ft.

Very fine gr. s.s., yellow-brown, low angle x-bedding. Abundant brachiopod fragments. Skolithos. 35 ft. 8 in.

Sandstone, same as H-17, Arenicolites **Unit 3**

Unit 2

Sandstone, same as H-17, Skolithos.

Scale: 1 in. = 2 ft.

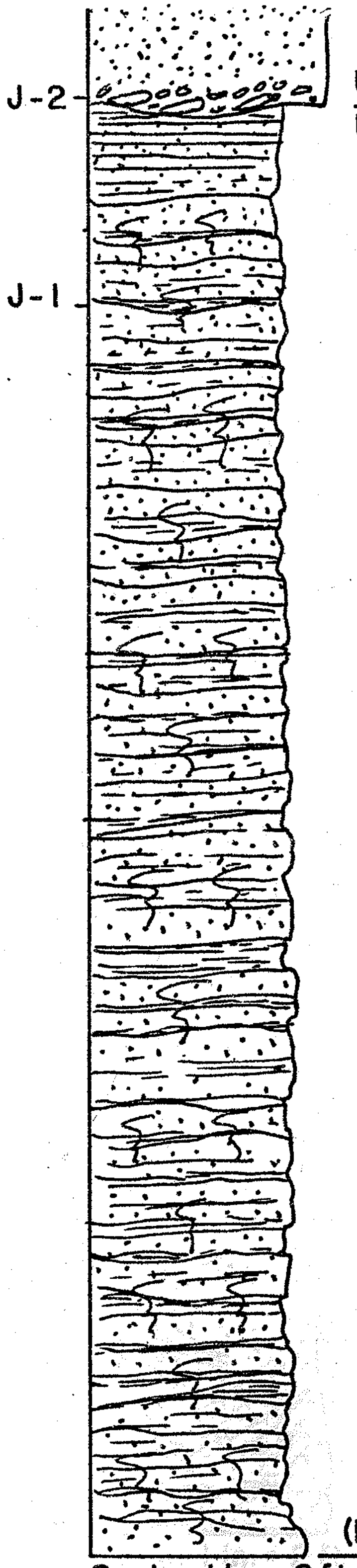
LOCALITY Jb:

Lithofacies

3

2

1



15 ft., 7 in.

Unit 2

Unit 1

Fine gr. s.s., interbedded with thin silty shales. Fine laminae disturbed by bioturbation. Imbricate, finely laminated s.s. pebbles and coquinite chips in a fine gr. massive s.s. Trilobite and brachiopod fragments.

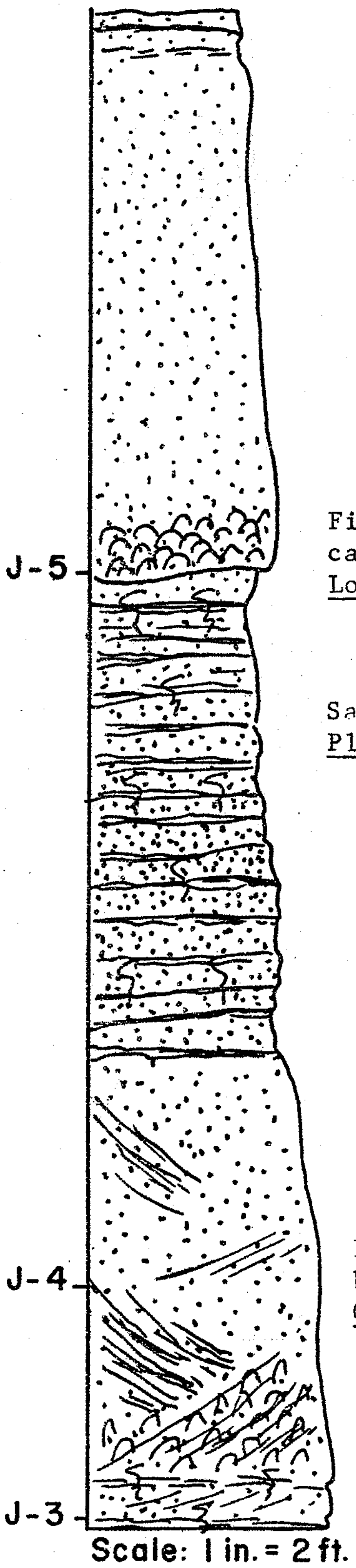
Fine gr. s.s./shale. Bioturbate. Brachiopod fragments. <u>Cedaria</u>, <u>Hyolithes</u>.

Sandstone/shale mixed. Biogenic structure, disturbed bedding with zones of mottling. Sandstone, buff colored. Shale, grey-green. <u>Planolites</u>, <u>Skolithos</u>, <u>Cruziana</u>.

(Exposure approximately 6 ft. above quarry floor)

Scale: 1 in. = 2 ft.

LOCALITY Jb (continued):



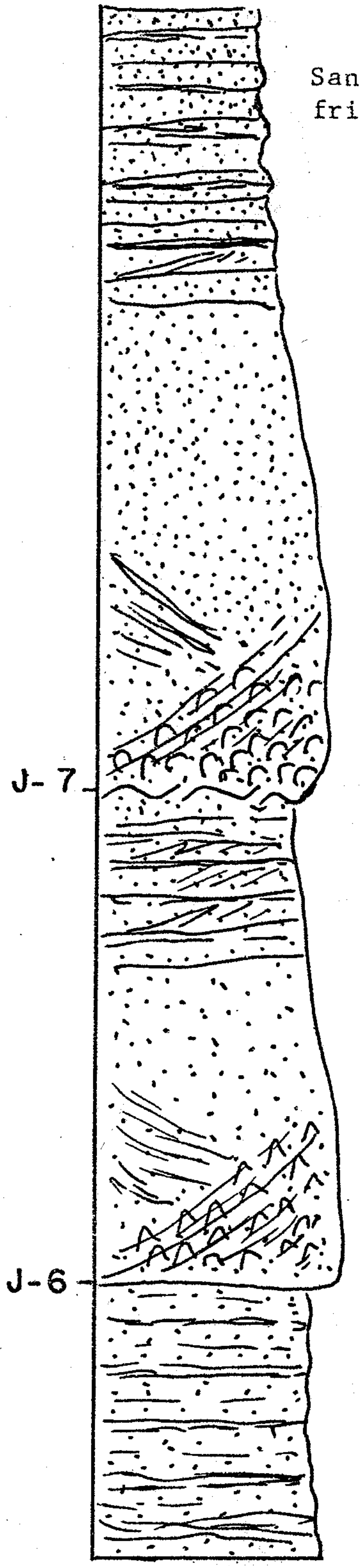
Fine gr. s.s., yellow tan, some glauconite. Flute casts at basal contact of massive bedded unit. Lonchocephalus, Brassicicephalus, Hyolithes. 28 ft.

Sandstone/shale interbedded. Slightly bioturbate. Planolites.

Fine gr. s.s., cross-bedded. Trilobite and brachiopod fragments. Some glauconite. Cedaria. 20 ft.

Fine gr. s.s., low angle cross-bedding. In a 10 cm. thick with 5 mm. bioturbate shale layers. Cedaria, Planolites. 17 ft., 7 in.

LOCALITY Jb (continued):



Sandstone, fine gr., abundant glauconite. Mostly friable with some thin beds. Little shale.

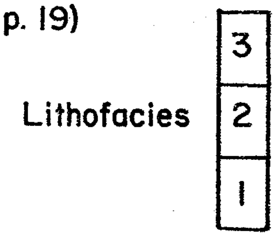
Fine gr. s.s., glauconitic. Mud cracks on basal surface. Shell coquinite with mud chips. Cedaria, Hyolithes, brachiopod fragments. 40 ft.

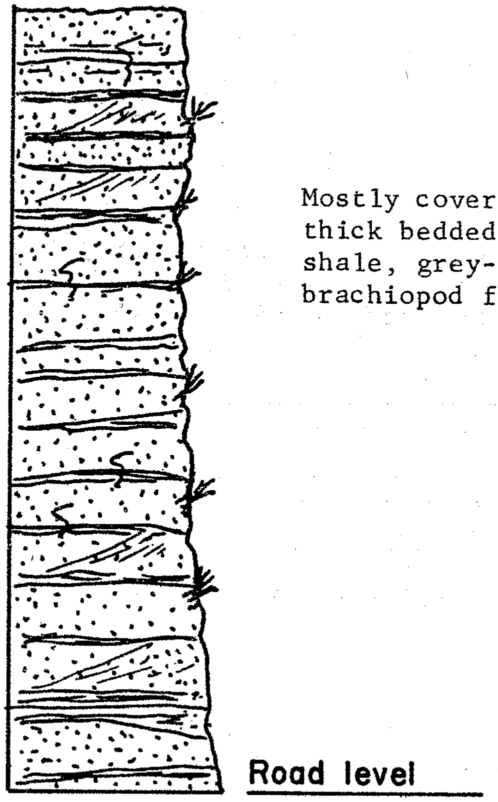
Fine gr. s.s., glauconitic. Coquinite at base of unit. Cedaria, Hyolithes, brachiopod fragments. 35 ft.

Scale: 1 in. = 2 ft.

LOCALITY Ja (Morrison's 13):

(Description modified from that of Morrison, 1968, p. 19)



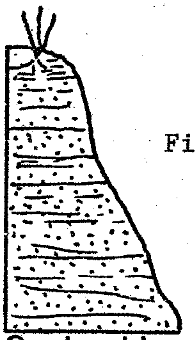


Mostly covered. Fine gr. s.s., thin to thick bedded, glauconitic. Interbedded with shale, grey-green. Surface trails and brachiopod fragments. 8 ft.

Localities Ja and Jb separated by approximately one mile. Altimeter check indicates probability of an overlap of approximately 15 ft. between the two sections.

LOCALITY Jb (continued):

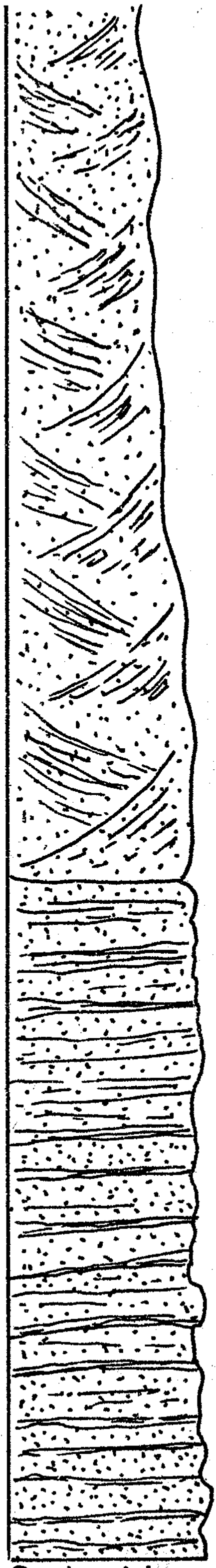
50 ft. 7 in.



Fine gr. s.s., friable, glauconitic.

Scale: 1 in. = 2 ft.

LOCALITY Ja (continued):

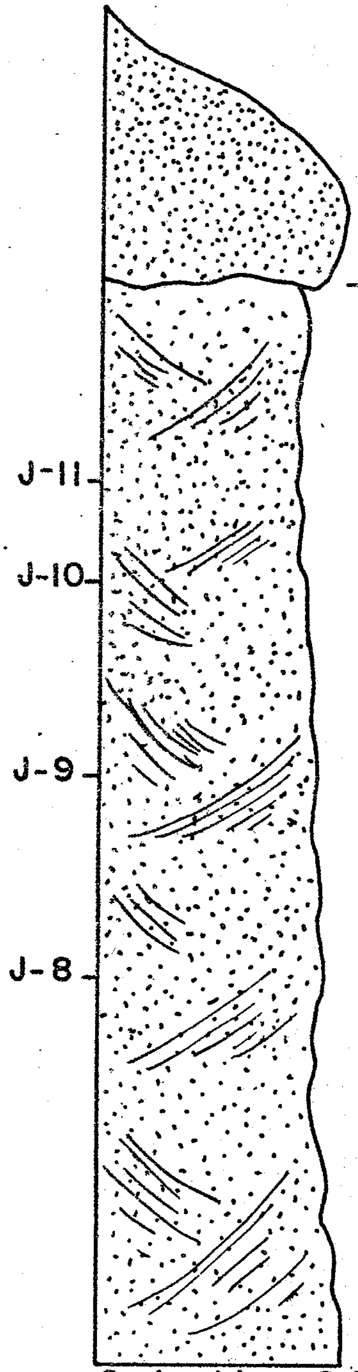


Sandstone, fine gr., grey-green to yellow grey. Some glauconite. Low angle cross-bedding. Abundant brachiopod fragments. 24 ft.

Sandstone, fine gr., thin to thick bedded, glauconitic. Shale lenses. Brachiopod fragments and surface trails. 15 ft.

Scale: 1 in. = 2 ft.

LOCALITY Ja (continued):



Sandstone, crs to md gr., yellow brown. Friable.

Galesville

Eau Claire **35 ft.**

Fine to very fine gr. s.s. Some glauconite. Low angle cross-bedding. Very friable. 33 ft.

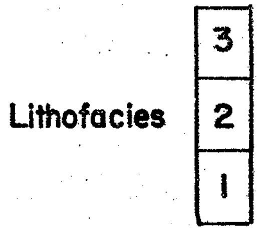
Very fine gr. s.s, buff colored. Low angle cross-bedding. Very friable. Crepicephalus, trilobite and brachiopod fragments. 32 ft., 6 in.

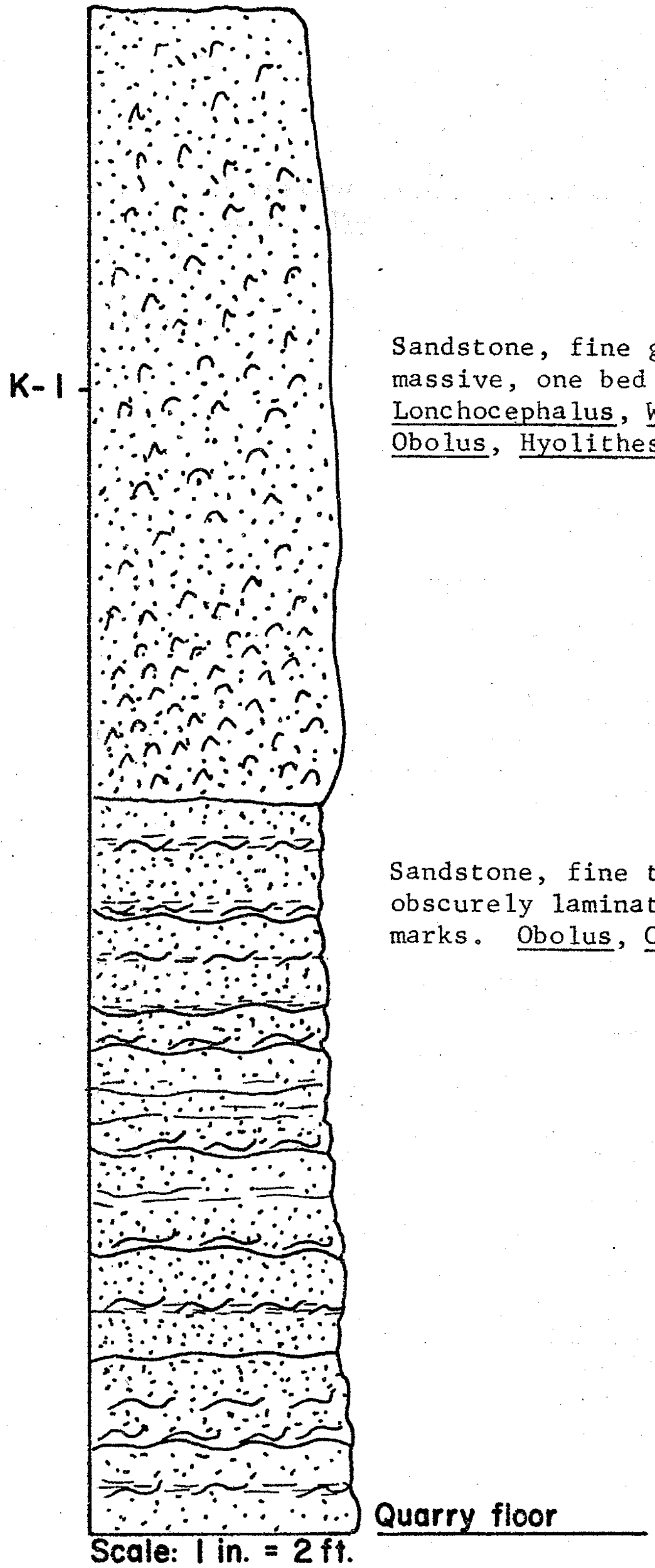
Very fine gr. s.s., glauconitic. Some mica Brachiopod fragments. 30 ft.

Fine gr. s.s., very glauconitic. Low angle cross-bedding. Brachiopod and trilobite fragments. Lonchocephalus, Hyolithes. 28 ft.

Scale: 1 in. = 2 ft.

LOCALITY K:
(Description modified from that of Twenhofel et al., 1935, p. 1740)



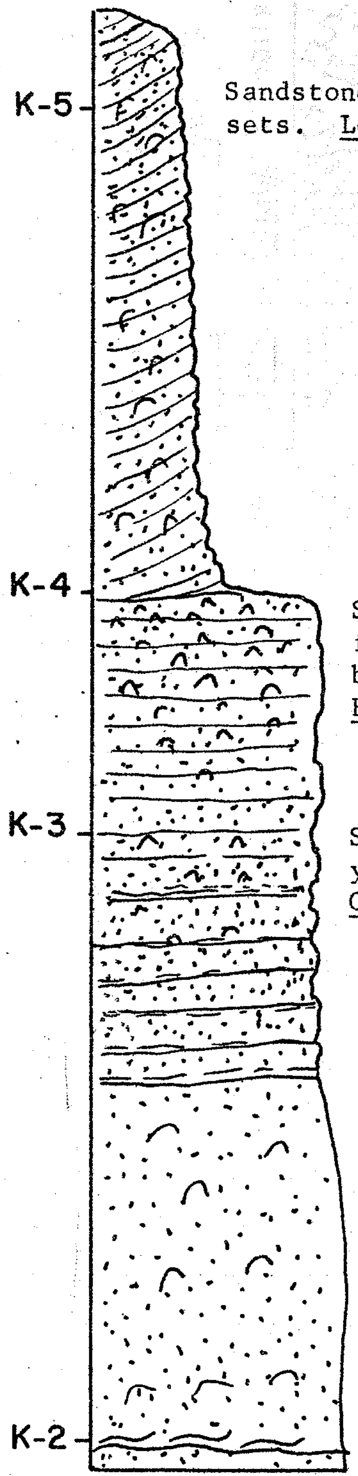


Sandstone, fine gr., light tan color, massive, one bed 8 ft., Crepicephalus, Lonchocephalus, Welleraspis, Dicellomus, Obolus, Hyolithes. 12 ft.

Sandstone, fine to md gr., brown-yellow, obscurely laminated, mud cracks and ripple marks. Obolus, Cedaria, Menominia. 7 ft.

Scale: 1 in. = 2 ft.

LOCALITY K (continued):



Scale: 1 in. = 2 ft.

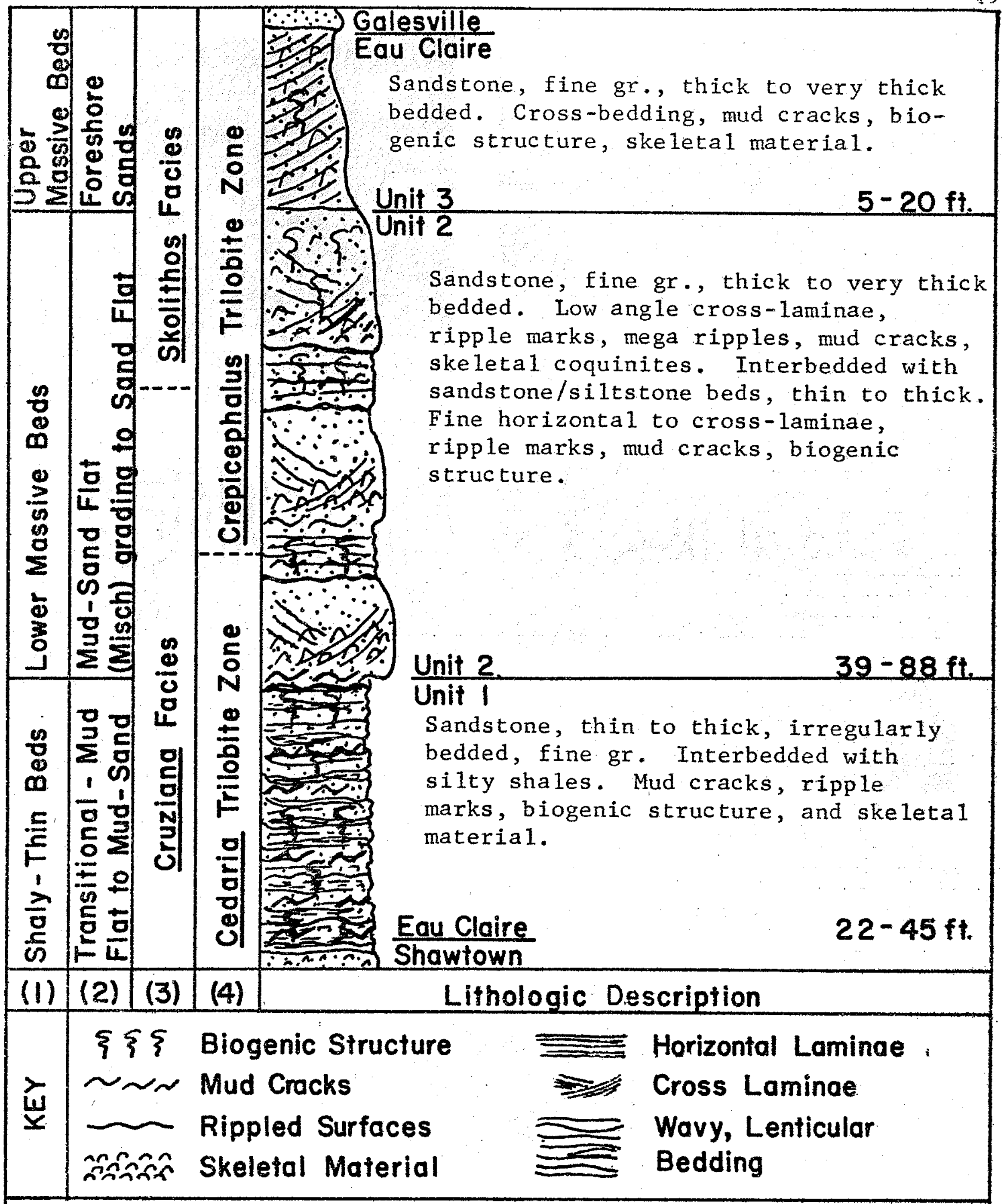
31 ft.

Sandstone, fine gr., light brown, thinly bedded cross-sets. Lonchocephalus, Dicellomus.

Sandstone, very fine gr., light tan, highly fossiliferous, fauna parallel to thin to thick bedding. Crepicephalus, Lonchocephalus, Coosia, Hyolithes, Dicellomus. 22 ft., 4 in.

Sandstone/siltstone, interlensing, greenish-yellow, fine gr., Lonchocephalus, Lingulella, Coosia. 20 ft.

Sandstone, fine gr., light tan, interference ripples with mud cracks. Brachiopod and trilobite fragments. Hyolithes. 16 ft.



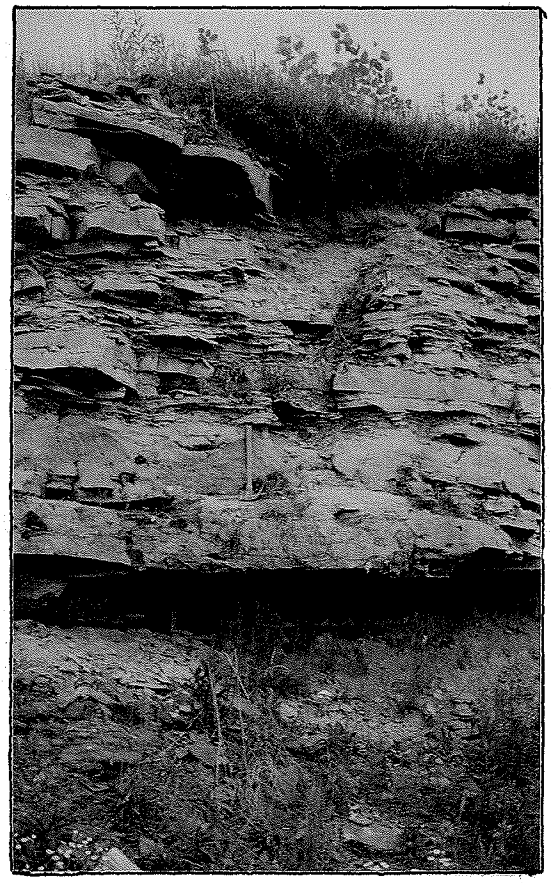
Sandstone, fine gr., thick to very thick bedded. Cross-bedding, mud cracks, biogenic structure, skeletal material.

Sandstone, fine gr., thick to very thick bedded. Low angle cross-laminae, ripple marks, mega ripples, mud cracks, skeletal coquinites. Interbedded with sandstone/siltstone beds, thin to thick. Fine horizontal to cross-laminae, ripple marks, mud cracks, biogenic structure.

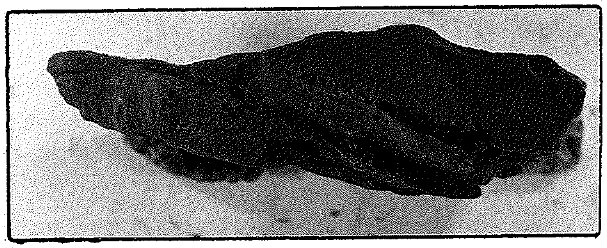
Sandstone, thin to thick, irregularly bedded, fine gr. Interbedded with silty shales. Mud cracks, ripple marks, biogenic structure, and skeletal material.

Figure 3: Composite section illustrating the recognized lithofacies, (1); the tidal flat sub-environments, (2); the two ichnofacies, (3); and the trilobite zones within the Eau Claire Formation of west-central Wisconsin.

Lithofacies 1



Lithofacies 2



Lithofacies 3

Plate I: Examples of the lithofacies of Eau Claire Formation.

PALEONTOLOGY AND AUTOECOLOGY

Body Fauna

Phylum Arthropoda

Class Trilobita

Order Ptychopariida Swinnerton 1915

Suborder Ptychopariina Richter 1933

Superfamily Raymondinidae Clark 1924

Family Raymondinidae Clark 1924

Subfamily Raymondininae Clark 1924

Brassicicephalus Lochman 1940

Plate II, fig. 6, (1626/34)

Description: Subquadrate glabella with rounded front. Pre-glabellar field absent. Glabella large, comprising 75% of total fixed cheek. Pygidium not present.

Discussion: Original description by Lochman, 1940. The most recent reference is by Howell et al., 1944, p. 993-1003. Brassicicephalus is listed as a member of the Cedaria triolobite zone. However, there is no previous reference of Brassicicephalus being present in the Eau Claire Formation of west-central Wisconsin

Subfamily Cedariinae Raymond 1937

Cedaria woosteri Whitfield

Plate II, fig. 8 (1626/35, 1626/36)

Description: A semi-circular cephalon with free cheeks generally still attached, but genal spines missing. The pygidium is also semi-circular with a flat border furrow. Varying sizes are present. Average size: Cephalon - 2.5 cm wide by 1.4 cm deep. Pygidium - 1.8 cm wide by 1 cm long.

Discussion: Original description by Whitfield, 1877. The most recent reference is by Raasch, 1935. Cedaria is the most abundant member of the Cedaria trilobite zone in the Eau Claire Formation.

Superfamily Marjumiacea Kobayashi 1935

Family Coosellidae Palmer 1954

Coosia willowensis Nelson 1951

Plate II, fig. 7, (1626/37)

Description: The cephalon is not present. Pygidium is semi-circular with a large flat border with slight posterior inward bend at median. All pygidial furrows faint.

Discussion: Original description is by Nelson, 1951. Coosia is present in the Crepicephalus trilobite zone. The least abundant member of the assemblage; I encountered three specimens.

Superfamily Emmrichellacea Kobayashi 1935

Family Crepicephalidae Kobayashi 1935

Crepicephalus cf. *iowensis* Owen 1852

Plate II., fig. 9, (1626/38)

Description: Large tapering glabella with rounded front and faint furrows. Prominant eye ridges. Free cheeks with long genal spines present but not attached. Pygidium is sub-rectangular with a flat border. Border is widest at base of the spines.

Discussion: Original description is by Owen, 1852, p. 576. The most recent reference is by Howell et al., 1944. *Crepicephalus* alternates with *Lonchocephalus* as the most abundant member of the *Crepicephalus* trilobite zone.

Superfamily Solenopleuracea Angelin 1854
Family Lonchocephalidae Hupé 1953
Lonchocephalus cf. *chippewaensis* Owen 1852
Plate II, fig. 12, (1626/39, 1626/40)

Description: A well-defined, tapering glabella with 2 - 3 deep furrows and a pronounced pre-glabellar field. Has an occipital spine. Pygidium is subtriangular with deep furrows and downturned border.

Discussion: Original description by Owen, 1852, p. 575. The most recent reference is by Nelson, 1951. *Lonchocephalus* occurs in both the *Crepicephalus* zone and the *Cedaria* zone. The condition of the specimens in the *Cedaria* zone is such that species distinction is impossible. According to Twenhofel et al., 1935, L. *chippewaensis* is limited to the *Crepicephalus* zone and a new species occurs in the *Cedaria* zone; however Twenhofel did not identify this new species.

Superfamily Norwoodiacea Walcott 1916

Family Menominiidae Walcott 1916

Menominia cf. calymenoides (Whitfield)

Plate II., fig., 10, (1626/41)

Description: A small cephalon with convex pre-glabellar field and a tapering glabella. Eyes are small and free cheek is not present. One unrecoverable specimen of articulated thoracic segments and pygidium was found on the outcrop.

Discussion: Original description is by Whitfield, 1877, p. 52. The most recent reference is Howell et al., 1944. Menominia occurs as the least abundant member of the Cedaria trilobite zone.

Superfamily Solenopleuracea Angelin 1854

Family Lonchocephalidae Hupé 1953

Welleraspis Kobayashi 1935

Plate II., figs. 13 & 14, (1626/42)

Description: Glabella is subrectangular and larger than Lonchocephalus. Occipital spine present. Pygidium was not recognized.

Discussion: No previous reference is made of its occurrence in the Eau Claire Formation. Several hypostomes have been found which also match the illustration in the Treatise on 0280. It is present as a member of the Crepicephalus zone.

Phylum Brachiopoda

Class Inarticulata Huxley 1869

Order Lingulida Waagen 1885

Superfamily Lingulacea Menke 1828

Family Obolidae King 1846

Subfamily Obolinae King 1846

Obolus Eichwald 1829

Obolus _rhea_ Walcott 1898

Plate II., fig., 2, (1626/29)

Description: Generally elongate ovate, with moderate expression of concentric growth lines but no apparent radiating striae. The central portion of the shell exterior is a yellow beige while the outer periphery is a black grey. Dorsal valve more ovate and more strongly convex than the ventral valve. Some shells exfoliated. Inner surface and muscle scars unobserved . Size varies (.3-.5 cm), generally small.

Discussion: Walcott, 1912 described O. _rhea_ as occurring in the Upper Cambrian "St. Croix sandstone" at Eau Claire, Eau Claire county, Wisconsin. Twenhofel et al., 1935, is the most recent reference to the occurrence of O. _rhea_ in the Eau Claire Formation.

Obolus _matinalis_ (Hall)

Plate II., fig., 1, (1626/30)

Description: Generally a subovate to subrounded shell with moderately pronounced growth lines. Some specimens are 15 mm, while the average size is 10 mm. When shell exterior is preserved; a light grey color.

Discussion: The original description is by Owen, 1852. The most recent reference is Walcott, 1912.

Dicellomus Hall 1871

Dicellomus politus (Hall)

Plate II., fig. 3, (1626/33)

Description: General shape ovate with a very convex ventral valve. Outer surface is usually smooth and shiny. Sometimes faint growth lines are present.

Discussion: Original reference is by Walcott, 1912. Most recent reference is Twenhofel et al., 1935.

Subfamily Lingulellinae Schuchert 1893

Lingulella quadrilateralis (Walcott)

Plate II., fig. 5, (1626/31)

Description: A moderately convex quadrilaterally shaped ventral valve. Exterior surface is mostly exfoliated. Outer shell surface is present; has concentric growth lines and a pinkish brown color.

Discussion: Original reference is by Walcott, 1912. The most recent reference is Twenhofel et al., 1935.

Lingulella (Lingulepis) acuminata (Conrad)

Plate II., fig. 4, (1626/32)

Description: Shell of varied size. Ventral valve is strongly subacuminate with elongate beek and moderately convex. Some shells exhibit shiny surfaces and are marked by strong, closely spaced concentric growth lines. Interior surface unobserved.

Discussion: Original reference is by Walcott, 1912. Twenhofel et al., 1935, referred to this genus as Lingulepis acuminata.

A DISCUSSION OF THE AUTOECOLOGY OF THE LINGULID INARTICULATE BRACHIOPODS

The inarticulate brachiopods found within the Eau Claire Formation are members of the order Lingulida. Ecological studies of the recent genera Lingula and Glottidia indicate that these two genera are burrowing suspension feeders inhabiting shallow water mud flats (Craig, 1951). Lingula constructs a generally vertical burrow to an approximate depth of one foot, binding the walls of the burrow with mucus and fixing the pedicle to shell fragments or hard, sandy mud. Their burrows are exposed at low tide and covered by three to four feet of water at high tide. Lingula is known to be tolerant to brackish water but does not naturally inhabit fresh water environments. The known depth range of Lingula and Glottidia is from 0-30 meters with a wide geographic distribution ($40^{o}N-30^{o}S$). They are gregarious, living in shoals, banks or mud flats.

Paleoecological investigations indicate that *Lingula* has consistently inhabited a similar niche throughout geologic time. Ferguson (1963), found many of the Mississippian *Lingula squamiformis* in a vertical position, anterior end up which compares favorably with the life position of the recent *Lingula*. Craig, in comparing the known ecology to the inferred paleoecology of *Lingula*, also found vertically oriented specimens anterior end up in the Top Hosie Shale of Scotland (Craig, 1951). It has therefore been assumed that the members of the family Lingulidae occupied a similar niche throughout geologic time (A. J. Rowell, 1965; Rudwick, 1970).

The inarticulate brachiopods found in the Eau Claire Formation, while members of the order Lingulida, are members of the family Obolidae. There are no known living representatives of this family and no paleoecological studies of significance have been conducted on this group. The early lingulaceans lacked the characteristic parallel sided shell shape of the known burrowers and it is Rudwick's opinion that this lack is sufficient evidence that not all early lingulides were burrowers. It is possible that they had a more normal epifaunal habit, using their pedicle to anchor their shell in the soft substrate (Rudwick, 1970). My personal observations of the brachiopod fauna in the Eau Claire Formation would seem to support this conclusion. While vertical burrows are nearly everywhere present in the Eau Claire, I found no brachiopods in these burrows nor did I find any brachiopods in what I would interpret to be a brachiopod life position, infaunal or epifaunal.

It is most likely therefore, that the assemblages of brachiopod shells in the Eau Claire Formation comprise a thanatocoenose. The disarticulated, exfoliated and fragmentary shells indicate they underwent rather rigorous depositional processes. However, this is not to say they weren't indigenous to the area. Assuming that these brachiopods were shallow water forms as the best information available indicates, it is very possible their habitat was adjacent to the site of deposition and the burrows, if they were indeed infaunal, are therefore not present in the exposed Eau Claire Formation.

Calyptoptomatids

Class Calyptoptomatida Fisher

Order Hyolithida Matthew 1899

Suborder Hyolithina Matthew 1899

Family Hyolithidae Nicholson 1872

Hyolithes primordialis

Plate II., fig. 15, (1626/27, 1626/28)

Description: A conical shell with a sub-triangular cross-section. Growth lines present on the exterior. No apparent ribs. Molds of operculum present but unattached. Sub-trigonal in shape.

Discussion: The original reference is by Whitfield, 1877. The most recent reference is Twenhofel et al., 1935. Yochelson (1961), based on a re-examination of Walcott's material from the Burgess Shale, interprets *Hyolithes* as a "virtually sessile, benthonic organism, the longest side of the shell being ventral." This interpretation is based on shell morphology and what he interprets as supports attached to the operculum. The presence of bryozoan encrustations and the morphologic features of size, shape and weight of shell are evidence against a pelagic habit. While internal anatomy is unknown, there is no evidence from shell morphology that indicates the hyolithids developed any mechanism for retaining buoyant gases in compensation for shell weight.

Assuming a benthonic habit, orienting the longest side as ventral gives the greatest stability to the organisms. The extra length of the ventral side would then act as a shelf or glide surface for the internal organs to move upon when feeding and lessen the chances of sediment entering the feeding mechanism. A sessile, benthonic existence would almost necessitate an optimum orientation to current and a suspension feeding habit. Howell and Stubblefield (1950), suggested that the supports of the operculum would also aid in stability of the shell as well as assisting in holding the operculum open when feeding. With the operculum attached dorsally, gravity would then aid in its closing. Figure 4, is an illustration from Yochelson (1961), demonstrating operculum and support movement.

Sysoyev (1959), also postulates an epifaunal benthonic habit on the shallow, muddy substrate of the central part of the shelf zone. While the water movement in this zone gave rise to normal abrasion, Sysoyev cites the lack of organs of attachment or for anchoring and a thin shell as evidence that these hyolithids could not withstand very intense water movement. His evidence that the hyolithids inhabited shallow water is based on the complete absence of hyolithids in basin deposits in the beds he has examined in Russia.

Considering the great concentrations of the hyolithids on bedding surfaces and shell material (brachiopod) that is found in the sediment filling the molds of hyolithids in the Eau Claire Formation, it is my opinion that these accumulations are the result of sediment transport and do not represent a biocoenose. However, I do not feel that the amount of transport has been great. These unoccupied shells are fragile and yet in most instances they are fairly complete. Some specimens are missing the apex.

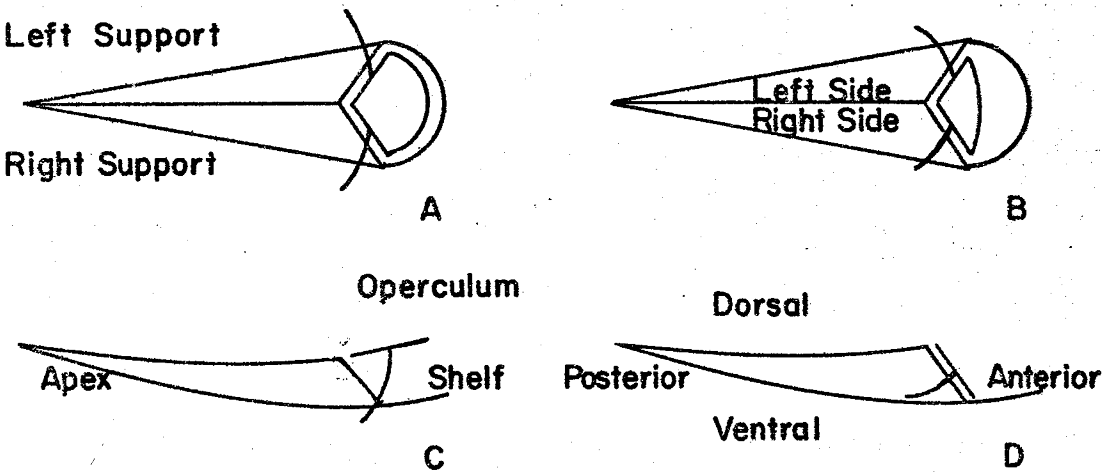


Figure 4: Schematic reconstruction of Hyolithes.
A C: Dorsal and right side views with aperture open.
B D: Dorsal and right side views with aperture closed.
(from Yochelson, E. L., 1961, text figure 1, p. 159)

Phylum Mollusca

Class Monoplacophora Wenz

Order Trybidioidea Lemche 1957

Superfamily Tryblidacea Pilsbry 1899

Family Palaeacmaeidae Grabou and Shimer 1909

Palaeacmaea Hall and Whitfield 1872

Palaeacmaea cf. irvingi Whitfield 1877

Plate II., fig. 11, (1626/26)

Description: An oval, cup-shaped shell with apex slightly off center and strong concentric rugae. One specimen was found in the Eau Claire Formation. Height 1/2 of length. Muscle scars unknown.

Discussion: Original description is by Whitfield, 1877. The most recent reference is Twenhofel et al., 1935. One specimen was found within a very thick sandstone bed in the Cedaria trilobite zone, oriented apex up. Fossil monoplacophorans have been established as living in epicontinental seas (Treatise on Inv. Paleon. I, Mollusca 1, p. 177). However, the only known recent monoplacophoran, Neopilina galatheae Lemche, was dredged from a depth of 3590 meters from a dark muddy substrate. Lemche (1957), made the original observations and descriptions of the ten living specimens recovered. It is his opinion that these monoplacophorans are filter feeders lying on their backs. His most convincing evidence for this interpretation is related to several morphological features:

a) the foot is too weak for any strong movement.

b) If a deposit feeder, the water intake for gills should be near the anterior end where no structures for this purpose are found.

c) Colonies of phoronids (?) form on the lower third of the anterior side of the shell but never farther up the apex, indicating the shell is partially buried (Lemche, 1957).

Yonge is in direct conflict with Lemche as to the life position of Neopilina; comparing the feeding apparatus of Neopilina to that of protobranchiate bivalvia, which collect organic debris from the bottom by frilled, ciliated organs located on the margins of the mouth. It is his opinion that the foot, though very weak, would serve to prevent the animal from sinking into the substrate and allow it to creep slowly over the substrate. He cites the scarcity of food supply at depth and the suitability of the fleshy structures around the mouth for collecting bottom deposits as an indication that these monoplacophorans are actually deposit feeders. (Yonge, Treatise on Inv. Paleon. I, Mollusca 1, p. 19; and 1957).

There is no evidence in the trace fauna of the Eau Claire Formation to support or dispute either interpretation. No tracks or trails of a similar size were found that could be related to Palaeacmaea, and the presence of one specimen is hardly enough evidence to base a case for a paleoecological interpretation.

Ichnofauna

Arenicolites Salter 1857

Plate IV, fig. 1, (1626/10)

Description: Thin U-shaped burrow with a thicker, rounded base. Similar to Diplocraterion parallelum but lacking spreite. Walls are generally unlined. May or may not be perpendicular to bedding plane. Dimensions: Outside - 18 mm wide by 18 mm long; 4 mm diameter at top to 7 mm diameter at base of U. Burrows not perpendicular to bedding plane are generally smaller: 1 - 2 mm in diameter by 2 - 3 cm long.

Discussion: While the animal responsible for this burrow is unknown, similar burrow structures have been constructed by annelids. In 1944-45, G. P. Wells studied the habits of the infaunal lugworm, Arenicola marina L.; which burrows in muddy sand on sand flats constructing L or U-shaped burrows. The exact shape of the burrow is apparently a function of the water content of the sediment and degree of packing. The U-shaped burrow has been observed nearer the high tide mark where the sediment tends to dry out more and be more firmly compacted. Where the complete U-tube is present, one arm of the tube is generally filled with a powdered sand. There is a conical depression around this feeding hole constructed as the lugworm comes to the surface to feed from the sediment at high tide. As the worm returns to the bottom of the tube at low tide, it draws fine sand down the shaft. Arenicola is oriented head down in the L-shaped burrow and feeds by drawing a column of softened sand downwards to the bottom of the shaft. The observed presence of weeds and dead leaves at the bottom of the burrow is cited as evidence that the worms actually bring the sediment down to feed, rejecting these particles and leaving them in the tube. Arenicola has been observed in the lab softening the sediment column above by driving water through the burrow and into the sediment by peristalsis-like muscle contractions. At the same time the worm also thrusts its head upwards and then pulls slowly back again forcing the water back through the tube, creating a suction and bringing the softened sediment downward to be ingested by the lugworm (Wells, 1945).

It seems plausible to assume that the Arenicolites traces could have been produced by a marine annelid with life habits similar to those demonstrated by Arenicola marina L.

Cruziana arizonensis

Plate III, fig. 1, (1626/12)

Description: Resembles a resting trace at the end of a furrowing trace. A large bilobate trace, the interior of which contains heavy chevron shaped markings. The lobes are marked with parallel striations and both are bordered on the exterior with sharp endopodal scratches. Toward the posterior end of the trace these markings are replaced with exopodal brush marks.

Dimensions: (1626/12) 4.8 cm wide by 8 cm long, (1626/13) 3 cm wide by 5 cm long.

Discussion: Specimen (1626/13) is adjoined with several superimposed traces resembling Rusophycus or Cruziana irregularis. However, due to their lack of clarity, I will refer to them as traces resulting from triolobite activity.

C. arizonensis was apparently formed as a trilobite stopped furrowing either as a means of protection from an approaching predator or simply as a resting trace (Seilacher, 1970). It is interesting to note that I have not found any molds of trilobites in the *Cedaria* zone that approach the size of this trace. I would suggest however, that since *Cedaria* *woosteri* is the largest trilobite in the faunal zone that the trace is the result of a mature form. The smaller cephalons and pygidiums in the coquinites are representative of molts produced in ontogenetic development.

It is unclear to this author what the exact difference is between C. *arizonensis* and *Rusophycus*. In comparing traces assigned to both, some subtle differences are apparent. *Rusophycus* is generally more distinctly bilobate and lacks the chevron scratchings along the median furrow, regardless of the form types defined by Crimes (1970b). There are also seldom any endopodal markings on the borders of *Rusophycus*, as there are in C. *arizonensis*. However, I suspect that the two classifications are the result of the separate opinions of Crimes and Seilacher. It is my opinion, despite the differences mentioned, that because of the bilobate nature and the fact that *Rusophycus* is also known to be found at the end of furrows, the systematics need revision so that C. *arizonensis* becomes a species of *Rusophycus*, since the life habit that has been assumed responsible for the production of both forms is the same.

Cruziana *semiplicata* Salter 1854

Plate III, fig. 2, (1626/14, 1626/21)

Description: Long even furrows with a median ridge. The furrows are marked with endopodal scratchings and in some instances are bordered by exopodal marked ridges. Some forms appear to be the result of deep procline (cephalon down) ploughing which produces coarser brushings. Dimensions: Vary from 10 mm to 15 mm wide and up to several centimeters long in most instances. Discussion: Seilacher (1970, p. 445), concludes that the variations in depth and form of these furrowing traces are the result of foraging techniques in response to specific food conditions. These procline trails would therefore be classified as pascichnial burrows while similarly shaped C. semiplicata lacking the exopodal borders would be formed by repichnial activity. That is, the cephalon was not contributing to the burrowing activity as in the burrows formed with the cephalon in a procline position. Despite the behavioral differences, the resultant variations in the burrows are all classified within the C. semiplicata group (Seilacher, 1970).

Cruziana cf. jenningsi Fenton and Fenton

Plate III, fig. 3, (1626/15)

Description: Deep excavations: 2 cm wide by 6.5 cm long and 3 cm deep and a smaller: 4.5 cm wide by 5 cm long by 2.5 cm deep. A median furrow is present near the slope but the base of the burrow has a more general U-shape. The walls are almost vertical. The base of the excavation is marked by paired endopodal scratchings.

Discussion: Fenton and Fenton (1937) assigned the construction of this trace to Olenellus in the Lower Cambrian, St. Piran Formation of Alberta and originally defined it as a Lower Cambrian trace. Seilacher (1970), described similar traces from the Upper Cambrian from Bell Island (dated on basis of C. semiplicata), and after comparison of the two traces found in the Eau Claire

Formation, I am also assigning this specific name to these traces despite their original designation as a Lower Cambrian fossil. They are distinctive in relation to the other trilobite related traces found in the Eau Claire and closely match descriptions by Fenton and Fenton (1937) and Seilacher (1970).

According to Fenton and Fenton the trilobites made the excavations as receptacles for eggs rather than in feeding processes:

> "On this hypothesis, a 'ripe' Olenellus dug its burrow in the mud, using its cephalon as a plow, and pushing with its bunched abdominal legs. As the hole deepened, the animal alternately pushed into the mud and passed excavated material out beneath its body; in the latter action the legs may not have been bunched. After the burrow was completed and eggs were deposited the animal crawled or swam, apparently backward from the excavation." (Fenton and Fenton, 1937.)

These burrows were dug in fine grained sand in the Eau Claire Formation. Fenton and Fenton observed that the rhythmic alternations of quartzite and shale throughout the Lake Louise Formation suggests that burrows were constructed in the muds during spring floods and were preserved as sole marks when sand was being deposited in the basin. It is apparent therefore, that the sediment type was not necessarily an influencing factor in nesting.

Fenton and Fenton also concluded from the clarity of the endopodal and exopodal markings on the sand casts that the trilobites did not cover their nests once the eggs had been deposited. This author found two negative molds and one possible sole cast (not figured). This cast however is very globular and lacks any defined appendage markings except for a probable Monomorphichnus trace at one edge.

Diplocraterion parallelum Torell 1870

Plate IV, fig. 2, (1626/11)

Description: U-shaped burrow with protrusive spreite. Burrow is perpendicular to the bedding plane. The walls are parallel and lined. Dimensions: 3 cm wide by 2 cm deep (length incomplete).

Discussion: Diplocraterion is primarily a domichnial burrow. Its occupant was most likely a suspension feeding crustacean or annelid. (Seilacher, 1967, p. 421). The spreite developed as the organism attempted to maintain an optimum distance from the sediment surface. Two recent genera, Corophium volutator and Polydora ciliata are known to construct spreiten burrows similar to those of Diplocraterion (Seilacher, 1967, p. 414). Corophium volutator, an amphipod crustacean, digs its burrow into muddy escarpments on the outer banks of tidal channels. The burrow is dug as a pouch and the spreite are the result of the shifting of the sediment as the pouch is constructed (Schafer, 1972). Polydora however, prefers a hard calcareous shell to sediment and then fills the center of the pouch with grains brought in from the outside. There have been no burrows found in the Eau Claire which would correspond to the type constructed by P. ciliata. The behavior of the animal responsible for D. parallelum apparently would have more closely resembled the activity of Corophium.

Planolites Nicholson 1873

Plate III, fig. 4, (1626/24)

Description: Fillings of burrows of varying widths: 4 mm to 1 cm. Burrows penetrate sediment and appear both on upper and lower bedding surfaces with an irregular pattern and direction of movement. Sediment infilling with both sand and silt.

Discussion: Presumably the result of polychaete annelids, probably sediment ingesters rather than filter feeders. The fodinichnial behavior of the burrowers is responsible for the mixing of the silty shales and sands which dominate Unit One.

Incertae Sedis:

Plate III, fig. 5, (1626/25)

Description: A series of traces 4 to 6 mm in width appearing on rippled surfaces. Most intersect at a central point giving a radiating outward appearance. Some have a bilobate appearance with a median furrow. In some instances this appears to be the result of a collapsed tunnel structure produced by borrowing just under and parallel to the sediment surface. Other trails appear to have a chevron marked surface similar to Cruziana traces, however these traces are epichnial rather than hypichnial traces. While most cross troughs and crests of ripples, some appear to tunnel a little deeper in the crests. One form has been found which meanders down troughs of a series of ripples. (1626/44)

Discussion: This author feels it is important to separate this group of traces as it is a result of a behavioral pattern distinctive of a repichnial habit as opposed to the fodinichnial activities which produced the Planolites traces.

Rusophycus Hall 1852

Plate III, figs. 6, 7, 8, 9, (1626/14, 1626/17, 1626/18, and 1626/19)

Description: Because of the lacks of a consistent division of the ichnogenus into ichnospecies, the following characteristics can be recognized and will be classified according to criteria utilized by Crimes (1970b).

Form A: A bilobate form of varying size with transverse scratches and a deep median groove. The general shape resembles two coffee beans placed side by side, sometimes anteriorly divergent. A ratio of length divided by width consistently approaches 1:5. (Plate III, fig. 6, 1626/14)

Form B: A bilobate form resembling form A, but with the sides generally parallel. The width of these forms is generally greater than type A and overall, these are generally a larger trace. (Plate III, fig. 7, 1626/17)

Form C: Also parallel as in Form B. However, the trace is generally deeper and has a much sharper outline than Forms A and B. According to Crimes, this form is smaller than Forms A and B. However, the specimens found in the Eau Claire that best resemble Form C are as large or larger than either Form A or B. (Plate III, fig. 8, 1626/18)

Form D: Does not have the usual coffee bean appearance but is more cylindrical in shape. Cross markings on some are less well developed. Crimes suggests these more elongate forms are the result of a slow forward movement whereby the trilobite was digging deeply in the sediment. The traces therefore are generally longer than the trilobite itself. (Plate III, fig. 9, 1626/19)

Discussion: These traces are attributed to having been formed by trilobites while resting on the sediment surface (Crimes, 1970b). Crimes places the aforementioned form types of Rusophycus in a stratigraphic sequence, dividing Upper Cambrian from Lower Ordovician on the basis of the presence or absence of the various form types. He also states that even though he can use the various forms of Rusophycus biostratigraphically, he can recognize related Cruziana and Diplichnites (walking traces) of a similar size to the various Rusophycus. Therefore it is his conclusion all traces of a similar size are made by the same trilobite and reflect a behavioral change of the individual in its growth process. This indicates that as the trilobite developed, it changed from a resting to a walking habit, to finally a furrowing habit. The absence of traces smaller than a mean size is explained by the assumption that upon hatching, the larval trilobites had a planktonic habit. The presence of Monomorphichnus would indicate that the trilobites were able to swim throughout their ontogenetic development (Crimes, 1970b).

Since I find specimens throughout the Eau Claire that correspond to all four of the form descriptions given by Crimes, I conclude that use of the four defined forms in a biostratigraphic sense would not necessarily produce reliable results. My observations would however support some of Crimes conclusions relating various traces to ontogenetic development. I feel the four forms are results of various life activities of the trilobites perhaps as a function of the growth of the individual, but more probably reflecting the same activities of various genera since a range of sizes of the four form types has been observed throughout the Cruziana facies in the Eau Claire Formation.

Monomorphichnus

Plate III, fig. 10, (1626/16)

Description: A series of parallel scratchings 12 cm long by 3 cm wide appearing on the upper and lower surface of beds with current marks also present on the samples.

Discussion: Interpreted as swimming, grazing traces as in a trilobite lifting off the sediment surface or being caught in a current and raking the surface intermittently as it is swept along (Crimes, 1970a).

Skolithos Haldeman 1840

Plate IV, fig. 3, (1626/22)

Description: Tubes or tube fillings standing perpendicular to the bedding. Diameter varies from 2 mm to 15 mm. Length is generally 5-7 cm. Some are 15 cm long.

Discussion: Attributed to a filter feeding annelid or phoronid.

Monocraterion Torell 1870

Plate IV, fig. 4, (1626/23)

Description: A conical depression on the bed surface surrounding the top of a vertical tube protruding into the sediment below. Some consisting of concentric rings present around the vertical tube.

Discussion: This feature has been found on the bedding surface of Skolithos burrows and is assumed formed by movements in life processes of the filter feeding annelid or phoronid responsible for the vertical Skolithos burrows.

Microfauna

Samples from the Eau Claire Formation were processed and examined for microfossils as a possible aid in determining the paleoenvironment, but reported negative results. Forty samples averaging 800 grams each were crushed and soaked in detergent for one week. The samples were then rinsed through 2000 and 125 micron sieves, dried and heavies separated with acetylene tetrabromide. Both the light and the heavy fraction were examined. With the exception of a few molds of either larval hyolithids or the apices of the hyolithids and some possible molds of trilobite spines, the search was futile.

The forty processed samples represent an examination of three complete stratigraphic columns of the Eau Claire taken from various localities. Table 2, is a list of the horizons samples.

Localities Sampled	Horizons Sampled
K	1, 2, 3, 5
J	1, 2, 3, 4, 7
G	2, 5, 6
C	1, 4, 5, 7
D	1, 3, 8, 11, 12
E	2, 6, 7, 8, 9, 11, 12, 13, 14, 16, 17, 19, 22, 23
F	1, 4, 5, 6, 7

Table 2: Localities and horizons samples for microfaunal study. Horizons are keyed to illustrated described sections, pages 18 to 48.

Figure 1: *Obolus matinalis* (1626/29) (x 1.5).

2: *Obolus rhea* (1626/30) (x 1.5).

3: *Dicellomus politus* (1626/33) (x 1.5).

4: *Lingulella (Lingulepis) acuminata* (1626/32) (x 2).

5: *Lingulella quadrilateralis* (1626/31) (x 1.5).

6: *Brassicicephalus* (1626/34) (x 1).

7: *Coosia willowensis* (1626/37) (x 1).

8: *Cedaria woosteri* (1626/35)(1626/36) (x 1).

9: *Crepicephalus* cf. *iowensis* (1626/38) (x 1).

10: *Menominia* cf. *calymenoides* (1626/41) (x 2).

11: *Palaeacmaea* cf. *irvingi* (1626/26) (x .8).

12: *Lonchocephalus* cf. *chippewaensis* (1626/39) (1626/40) (x 1)

13: Operculum (*Welleraspis* ?) (1626/42) (x 1.5).

14: *Welleraspis* (1626/42) (x 2).

15: *Hyolithes primordialis* (1626/27) (1626/28) (x 1).

Explanation of Plate II.

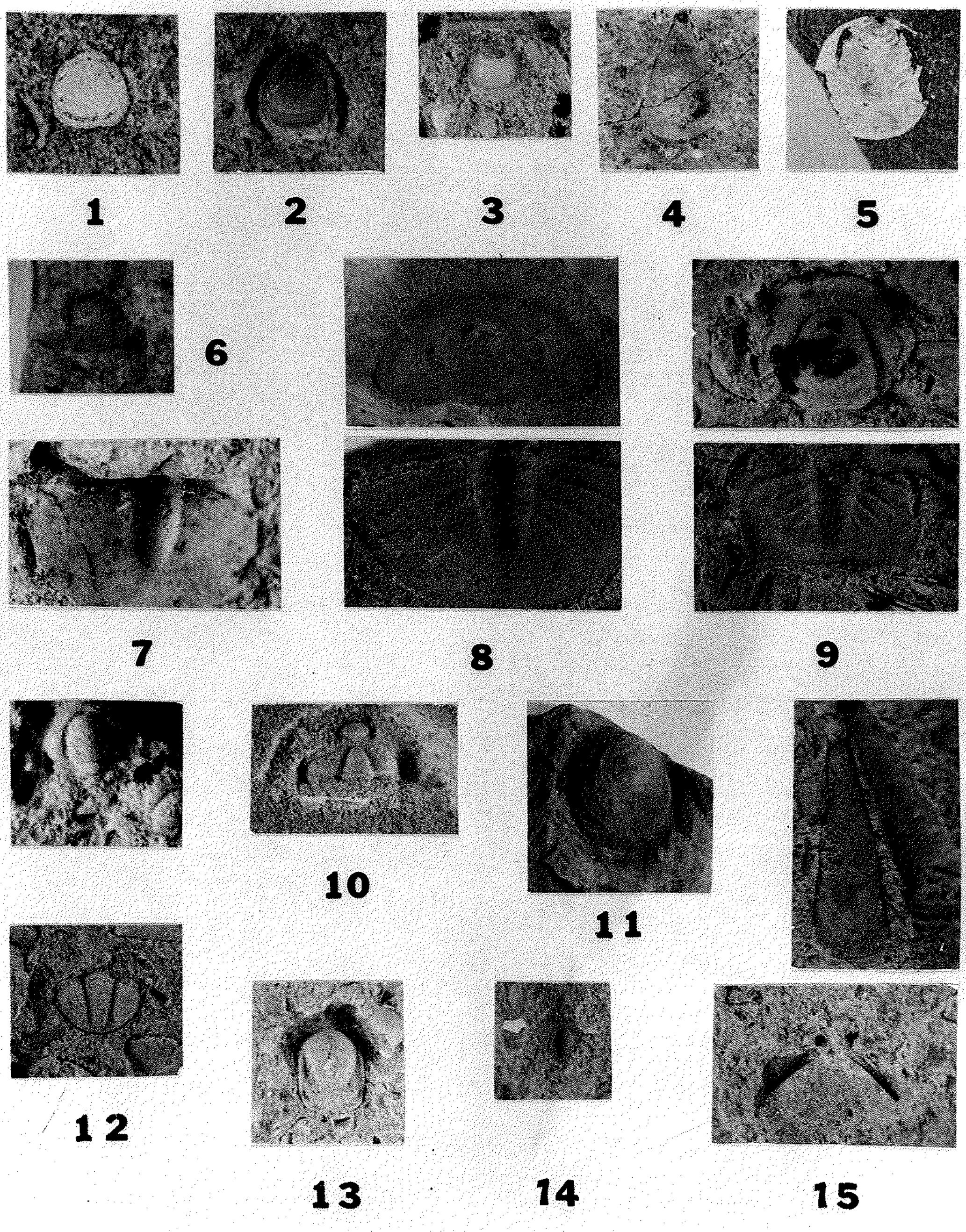


Plate II. Skeletal fauna of the Eau Claire Formation.

Figure 1: *Cruziana arizonensis* (1626/12) (x .3).
2: *Cruziana semiplicata* (1626/14) (x .5).
3: *Cruziana* cf. *jenningsi* (1626/15) (x . 2)
4: *Planolites* (1626/24) (x .3).
5: *Incertae Sedis* (1625) (x .3).

Explanation of Plate IIIa.

Figure 6: *Rusophycus* Form A (1626/14) (x 2).
7: *Rusophycus* Form B (1626/17) (x . 5).
8: *Rusophycus* Form C (1626/18) (x . 2).
9: *Rusophycus* Form D (1626/19) (x . 3).
10: *Monomorphichnus* (1626/16) (x . 5).

Explanation of Plate IIIb.

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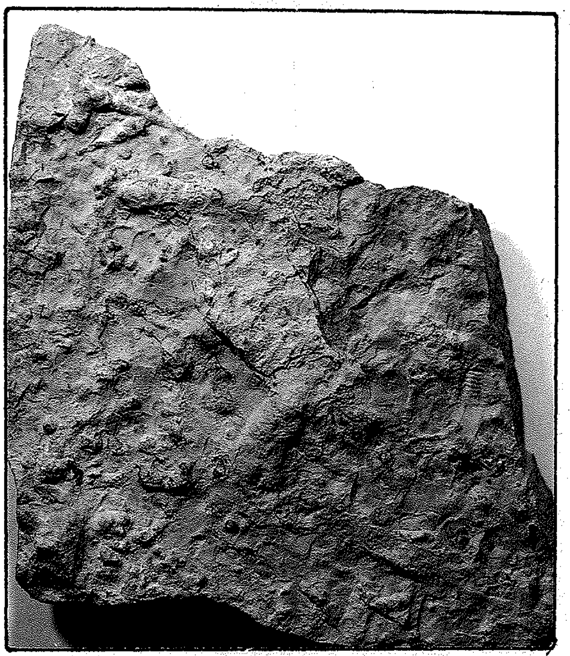

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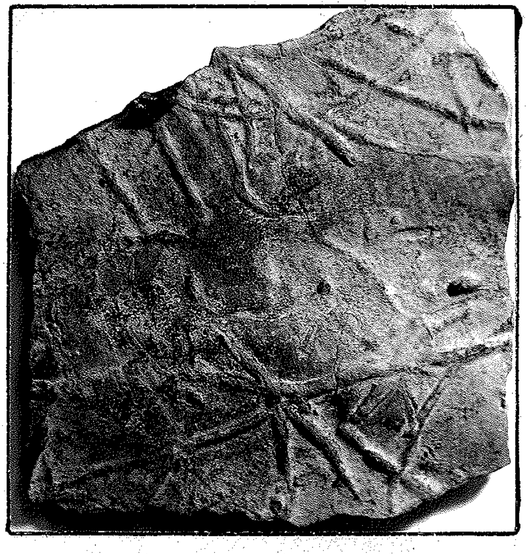

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Plate IIIa: Cruziana Facies.

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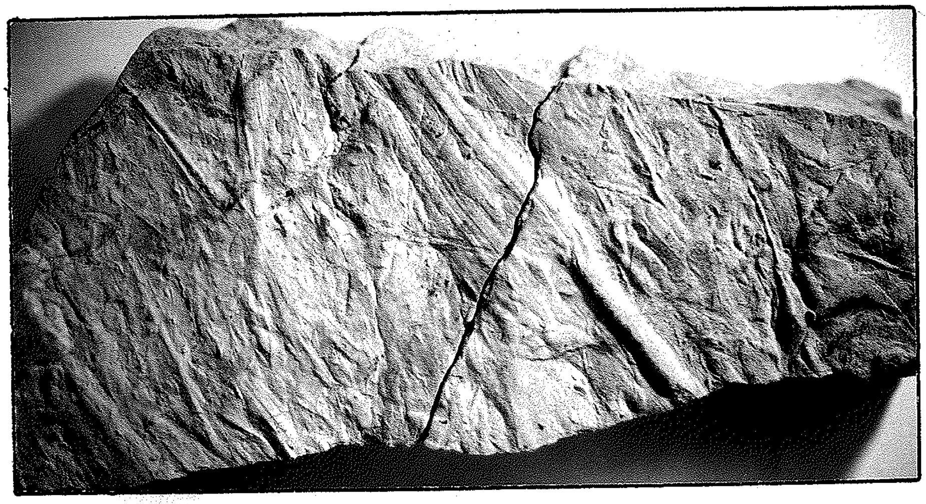

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Plate IIIb: *Cruziana* Facies

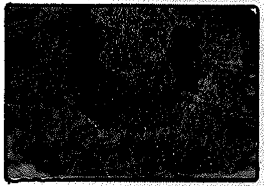
Figure 1: Arenicolites (1626/10) (x 1).

2: Diplocraterion parallelum (1626/11) (x .5).

3: Skolithos (1626/22) (x .5).

4: Monocraterion (1626/23) (x .3).

Explanation of Plate IV.



I

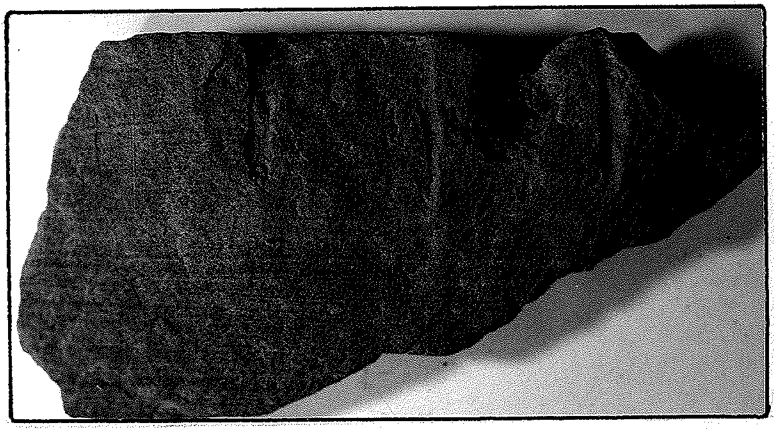


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Plate IV: <u>Skolithos</u> Facies.

Explanation of Plate Va:

Figure 1: Ripple marks with mud cracks superimposed (1626/8). (x .2)

Figure 2: Example of horizontal laminae (1626/6). (x .3)

Figure 3: Example of cross-laminae (1626/2). (x .3)

Explanation of Plate Vb:

Figure 4: Megaripple (Unit Two).

Figure 5: Mud pebble conglomerate (1626/9). (x .1)

Figure 6: Tool mark (1626/7) (x .5).

Explanation of Plate VI:

Figures 1 - 3: Three stages of biogenic destruction of bedding. (1626/3) (1626/4) (1626/5) (x .3)

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2

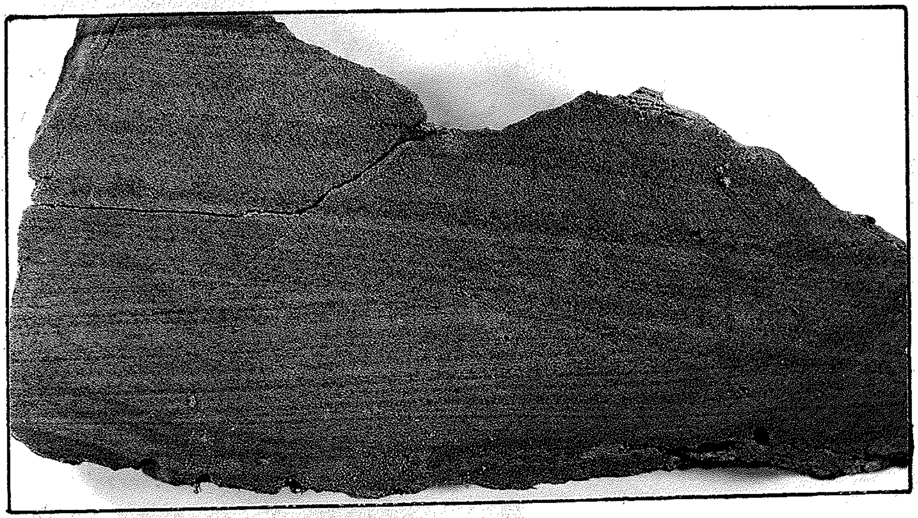

Plate Va: Sedimentary Structures.

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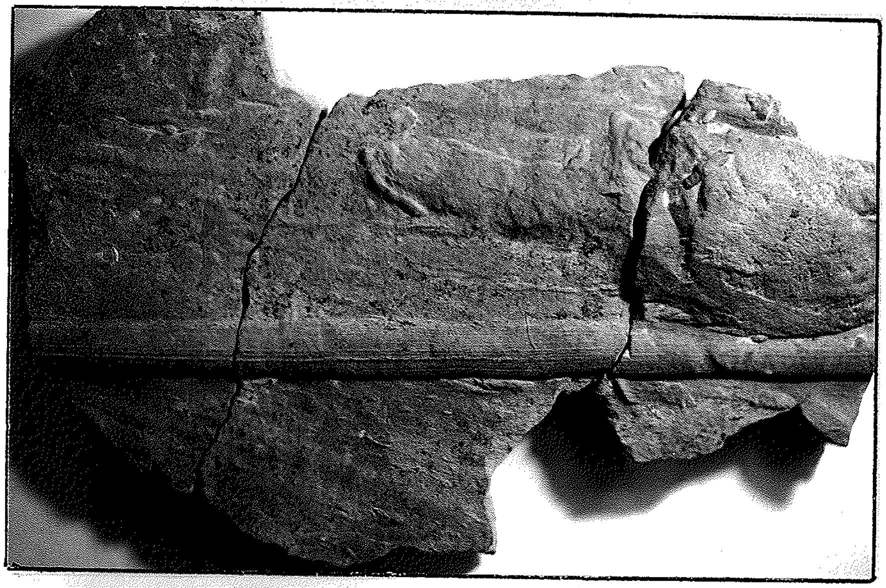

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Plate Vb: Sedimentary Structures.

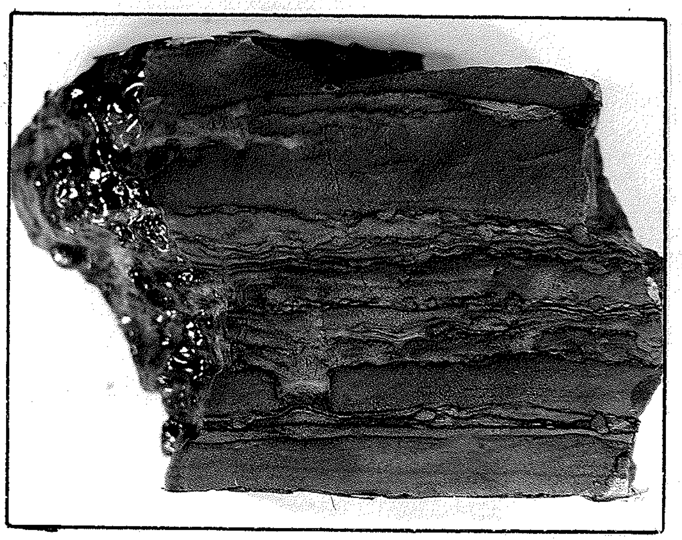

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Plate VI: Biogenic Structures.

PALEOENVIRONMENTAL SYNTHESIS

Ichnofacies:

The ichnofauna found in the Eau Claire Formation represent two distinct and separate ichnofacies; a Cruziana Facies, defined in approximately the lower two-thirds of the formation; and a Skolithos Facies represented by the assemblage of trace fossils in the upper one-third of the formation. (Seilacher, 1967) (See figure 3 for stratigraphic column illustrating Ichnofacies in Eau Claire Formation.)

The previously described ichnogenera representing both the Cruziana and Skolithos facies are as follows:

1. Cruziana Facies: (Plate III)

   Cruziana (all species described in this thesis)

   Rusophycus (Forms A thru D of Crimes 1970)

   Monomorphichnus

   Arenicolites

   Planolites

   Unnamed repichnial traces-Incertae Sedis

   Skolithos

   Monocraterion

2. Skolithos Facies: (Plate IV)

   Skolithos

   Monocraterion

Diplocraterion parallelum

Arenicolites

Communities represented within these ichnofacies:

1. The Cruziana Community:

The variety of genera of trilobites and the abundance of their related traces would indicate their dominance of the community. The Cruziana, Rusophycus and Monomorphichnus traces are evidence of the various life activities of the trilobite. While there are great concentrations of skeletal fragments of trilobites, the best evidence of their life activity is from these traces. Traces believed to relate to nesting (Fenton and Fenton, 1937), swimming (Crimes, 1970[a]), burrowing and resting (Seilacher, 1970; Crimes, 1970[b]) are abundant evidence indicating a total range of life activity (Crimes, 1970[b]). Trilobites, being arthropods, molted at various growth stages, and the variation of size in skeletal remains of the various genera is further evidence of life and growth in this environment.

The hyolithids, inarticulate brachiopods, and the monoplacophoran which comprise the rest of the body fauna are not necessarily representative of any life assemblage. This is a common faunal assemblage in Upper Cambrian sediments (Yochelson, 1961) and would apparently be compatible with the inferred shallow water environment. However, there is no direct evidence this fauna represents a living assemblage as is the case with the trilobites and soft-bodied non-preserved members of the community. Since both detritus and suspension feeders are present there must have been currents sufficient in strength to bring in a food supply, yet not disturb the muddy sediments periodically being deposited. The rate of deposition was slow enough to allow a thorough reworking of the sediment by the infaunal members, yet the energy level was high enough at times for development of ripple surfaces, finely laminated, fine grained sandstone beds and accompanying suspension feeding burrowers. The variable current energy and the changes in current direction brought in silt and clay allowing resumption of the activities of the sediment ingesting members of the community.

2. The Skolithos Community:

While the complete body fauna is consistently present throughout the formation, the trace fauna changes markedly. The Skolithos community gradually develops with the decrease in shale content and an accompanying decrease in the sediment ingesting members of the Cruziana Community. The numbers of Skolithos burrows increases and U-shaped burrows inhabited by filter feeding crustacians and phoronids are developed. A community dependent upon currents for its food supply dominates. The fragmental and current oriented remains of the skeletal fauna, including the trilobites, and the lack of any trilobite related traces are an indication that these remains are solely the result of current deposition and the only life assemblage present is represented by the traces of the soft-bodied polychaetes and phoronids.

Sedimentary Structures as bathymetric indicators present within the ichnofacies of the Eau Claire Formation: (Plate V)

1. Mud cracks (1626/8): Both complete and incomplete sets of mud

cracks are present and repetitious throughout the Cruziana Facies. In the shalier, thin bedded units the mud cracks develop both as complete polygons and incomplete cracks and are usually sand filled. The width and depth of the cracks vary throughout the stratigraphic column. Cracks developed on ripple surfaces of sand are generally small but complete polygons; while those on the shale surfaces are larger, whether complete or incomplete. In all instances where it is visible, the base of the massive sand units of the lower massive beds is marked with well developed, generally wide (1-2 cm.) and deep (2-3 cm.) mud cracks. Many of the interbedded thin sand and shale beds of this unit are also marked by well developed mud cracks. In some instances the mud cracks appear to be biologically induced especially where they are less angular and less well developed, i. e. not good polygonal development throughout the surface of the slab. Some wedges appear to be marked with scratches similar to endopodal markings in the Cruziana traces while the more sinuous cracks appear related to an animal with a pascichnial behavior pattern. It has been proven experimentally that the development of mud crack patterns can be controlled by small surface-living invertebrates (Baldwin, 1974), therefore it is feasible, given the quantity and variety of infaunal burrowers and epifaunal grazers present in the Eau Claire Formation that some of the mud crack patterns could have been biologically influenced (1626/44, 1626/45).

The problem also arises as to the conditions under which the mud cracks developed. Subaqueous shrinkage cracks have been documented (Moore, 1914; Twenhofel, 1923; Donovan and Foster, 1972) and have been experimentally produced in the laboratory (White, 1961; Burst, 1965; Donovan and Foster, 1972). Van Straaten (1954) also approached this problem when comparing a Devonian sequence to the recent tidal flat deposits of the Wadden Sea. It was his conclusion, based on personal observations of Wadden Sea sediments that the large complete crack patterns were found only in the high tide level sediments. The smaller (3-4 mm. wide by few mm. to few cm. deep), generally incomplete cracks could occur subaqueously as well as subaerially since he observed them in the bottoms of tidal channels (approximately 9 m. water depth) which were never exposed to air. However, he states that once these cracks become sand filled they are generally preserved during subsequent tidal inundations. Because of this feature of preservability, it has occurred to this author that these crack patterns observed at the bottom of tidal channels could have developed during exposure produced by spring tides and thus be preserved and visible for prolonged periods of time, since the sedimentation rate in these channels is much lower than on other areas of the tidal flat. The experimentally produced synaeresis cracks of Donovan and Foster were developed at a depth of 12 cm. in a 2.5 mm. layer of clay. (White, 1961; and Burst, 1965, do not mention water depths or clay thicknesses of experimentally produced subaqueous cracks). While there appears to be no depth limit to the formation of synaeresis cracks, a necessary condition for their formation is a change in salinity (Coneybeare and Crook, 1968). Burst, citing this condition as necessary suggested that this transition "could result from seasonal salinity changes in lagoonal, tidal channel and nearshore marine areas where the salinity is highly affected by surface runoff" (Burst, 1965, p. 353). The results of investigations by Donovan and Foster in the Caithness Flagstone of Northeast Scotland also suggests shallow water situations for synaeresis crack development. They also cite a polygonal or rectangular plan and a greater depth of penetration in vertical section as two criteria for distinguishing subaerial mud cracks from those formed subaqueously by synaeresis (Donovan and Foster, 1972, p. 313).

Therefore, the water depth inferred by mud cracks is very shallow regardless of their mode of origin (Burst, 1965; Van Straaten, 1954). Since the majority of the crack patterns within the Eau Claire are well developed polygons regardless of the dimensions, it would appear that the majority of these patterns were due to subaerial exposure. Blatt, Middleton and Murray are somewhat skeptical about the occurrence of synaeresis cracks in the ancient record. They suggest that while "it has been demonstrated that mud may crack underwater in the laboratory, ...in nature, mudcracks appear to be a relatively reliable indicator of emergence." (Blatt, Middleton, and Murray, 1972, p. 193).

2. Mud chips (1626/9):

Mud chips, intraformational conglomerates and coquinites chips are present at the base of some of the very thick beds within the lower massive unit. In most instances the chips and pebbles are scattered throughout the well developed coquinites which are characteristic of these thick to very thick bedded sandstone units. The intraformational conglomerates have been observed at two localities; H and J. At locality J, the intraformational conglomerate is present as thinly laminated sandstone pebbles somewhat imbricate at the transition from unit one to unit two. At locality H, the intraformational conglomerate occurs as a sandstone pebble conglomerate present in the shalier zones of the interbeds in the lower massive unit. Van Straaten (1954a) and Klein (1967) noted similar concentrations of clay chips and pebbles along with concentrations of shell material as lag deposits on the bottom of gullies, creeks and channels on the tidal flats of the Dutch Wadden Sea.

3. Current Formed Sedimentary Structures:

a. Fine laminae composed of brachiopod fragments, glauconite and/or micaceous clay layers are present in the thin sandstone beds of Unit 1 and Unit 2 (1626/6). The laminae are horizontal in some beds but demonstrate cross bedding in other beds, especially the highly glauconitic beds of unit two (Locality Ha). The laminated beds are not graded beds, whether horizontal or cross laminated. The strength of the currents necessary to produce the horizontal laminae is not well defined. (Pettijohn, Potter and Siever, 1972). While plane beds normally develop in the upper flow regime, for fine sand they can exist over a wide range of Froude number (.3 to .8) (Simons et al. 1965).

The cross laminae are of varying types (1626/2). Large scale, low angle cross bed sets are common to the thickly bedded sandstone beds of Unit 2 and thick beds of Units 3. Smaller scaled more angular sets are characteristic of the thin bedded units and the Skolithos Facies of Unit 2. The type of cross-bedding present in the Eau Claire is characteristic of those described as occurring in tidal flat deposits (Reineck, 1967, Boersma, 1969; Goodwin and Anderson, 1974; Simons et al., 1965).

b. Irregular, lenticular flaser beds. Irregular, wavy bedding, often lenticular predominates throughout Unit 1, and in the interbedded silts of Unit 2. According to a classification of primary sedimentary structures by Pettijohn and Potter in 1964, the beds are described as unequal in thickness; laterally variable in thickness; discontinuous (Pettijohn, Potter, and Siever, 1973). Similar bedding style is developed in North Sea sediments by sands migrating across rippled muddy deposits or layers of mud coating rippled sand. (See Plate I for illustration of this bedding style.)

c. Ripple Marks (1626/8): The presence of both asymmetrical and symmetrical ripple marks as well as interference ripples indicate the possibility of both a current and wave origin. Evans (1949) and Allen (1968) point out the difficulties in relating symmetry of ripples to current or wave origin but current formed mega-ripples (Boersma, 1969) are present in the thick bedded sandstone beds of Unit 2. This author feels it is not useful to distinguish between current and wave originated ripples since both occur in shallow water sediments and apparently do not define a particular environment of deposition. Boersma however has defined megaripple structures and related those structures to sand flat areas of tidal flats on the North Sea.

Variations of Sedimentary Features found in the Skolithos facies:

1. Mud cracks:

Mud cracks present in the Skolithos Facies are similar to those in the

Cruziana Facies but are encountered less often.

2. Fine Laminae:

Both horizontal and cross laminae occur in the upper approximate 25 ft. of unit two but are mostly lacking in Unit Three. Low angle cross bed sets are present in Unit Three, but do not develop characteristic laminae of Unit Two. Cross bedded laminae predominate in the Skolithos facies of Unit 2, similar to the type described on recent tidal flats in the Netherlands. (Boersma, 1969).

The general absence of silt and mud, characteristic of the Skolithos facies hindered the weathering of rippled surfaces and prohibited the development of the wavy, lenticular bedding in this facies.

BATHYMETRIC INTERPRETATIONS

The lack of any observed microfauna in the Eau Claire Formation may also be further indication of the shallowness of the depositional environment. Two studies conducted by Laurel C. Babcock (1971, 1974) here at the University of Wisconsin also indicated that shallow water environments are generally barren of any micro-fauna, especially the usually abundant conodonts.

Her investigation of an interpreted shallow water stromatolite sequence in the Prairie du Chien group in Wisconsin produced minimal material while her work in the Permian reef complex of West Texas produced no conodont specimens in the back reef lagoonal area. Conodont material was found however, in the fore reef area and into the basin deposits. Personal communication (March, 1975) with Dr. David L. Clark also supports the concept of a general lack of conodont material in shallow water areas.

While the negative results of my investigation can not be an indisputable indication of the shallow water environment of deposition for the Eau Claire, these results are consistent with other micropaleontological studies conducted on determined shallow water depositional environments and coincide with other observed bathymetric indicators found in the Eau Claire Formation.

Seilacher does not assign fixed depth ranges for each of his ichnofacies when relating bathymetric controls for the trace fossil communities. He does define the Skolithos facies as being the shallowest, intertidal or most shoreward. The Cruziana Facies is the next deeper facies but still intertidal to slightly below wave base. (Seilacher, 1967). The energy level is also very important as a facies control and with respect to the ichnofacies present in the Eau Claire Formation, perhaps more important as a control than depth. The mud cracks and other related sedimentary features present throughout the 120 foot section of the Eau Claire Formation indicate a very shallow situation. Yet a supposed deeper Cruziana assemblage is present in the siltier, shalier portions of the formation while the inferred shallower Skolithos Facies is limited to the fine grained, purer cross-bedded sandstones. The decrease in the frequency of zones of mud cracks in this upper Skolithos facies is related to a greater water depth and a higher energy environment since the relationship of water depth to energy level on tidal flats is opposite that of a normal beach zone. (A more complete explanation of current action on tidal flats follows on p. 97.) The most important factor influencing the distribution of this paleocommunity appears to have been the energy level. The higher energy of this somewhat deeper environment restricted the sediment being deposited to the coarser size fraction, removed the silts and shales but more importantly held in suspension the food supply of these filter feeding organisms.

The shallower and quieter lower energy environment permitted the deposition of the fine silts and shales along with the food supply supporting the establishment of a detritus feeding *Cruziana* community. Further evidence of of the influence of the energy level on these ichnofacies occurs in the *Cruziana* Facies. *Skolithos* and *Monocraterion* traces are developed in the thinner bedded sandstone units present in the lower shaly thin beds and lower massive beds. *Cruziana* and *Rusophycus* traces are developed on the upper surfaces of those beds which contain shale coatings and biogenically mixed sandstone/shale units above. This would indicate fluctuations in the energy level in this area allowing the establishment of a predominantly filter feeding community before the currents shifted permitting re-establishment of the detritus feeding community. Evidence is totally lacking to delineate the magnitude of fluctuations in sea level necessary for the establishment of these two differing communities in such short periods of time as indicated by the alternating sequences present in the lower unit of the Eau Claire.

The characteristic sedimentary features relating to water depth indicate an increase in the energy level upward in section which is also evident by the ichnofacies developed and it is this writer's opinion that these sequences indicate a general raising of the sea level throughout Eau Claire time.

ENVIRONMENT OF DEPOSITION

The lithofacies, biofacies and accompanying sedimentary structures of the Eau Claire Formation indicate a shallow depositional environment. Similar lithofacies, biofacies and sedimentary structures have been observed in investigations of recent tidal flats (Reineck, 1967; Klein, 1967; Hantzschel, 1968; Van Straaten, 1954, 1961, 1972; Heckel, 1972) and have also been recognized and documented in the ancient record (Van Straaten, 1954; Potter and Glass, 1958; Allen and Tarlo, 1963; Klein, 1970; Goodwin and Anderson, 1974).

Tidal flats are unique in that tidal action moves fine sediment on shore, developing a sequence of sediment in reverse of observed beach deposits. The incoming tide brings the muddy sediment in, keeping it in suspension until the tide begins to slacken before retreating. As the tide ebbs, the mud settles out and the currents of the outgoing tide are not strong enough to erode the silt and mud (Van Straaten, 1961).

The three recognizable lithofacies: silty, sandy mud (Unit One), silty sands with shell coquinite deposits (Unit Two) and the cross-bedded sands (Unit Three); and the two ichnofacies: Cruziana and Skolithos with their accompanying ichno and skeletal fauna, are characteristic of tidal flat sub-environments recognized both in the recent and the ancient record. The three lithofacies of the Eau Claire Formation closely parallel three sub-environments delineated by Reineck, Van Straaten and Hantzschell in the Dutch Wadden Sea and North Sea of the Netherlands and Germany.

These three sub-environments are (from high tide line to low tide line):

1. Mud Flat: Non-homogeneous mud with inclusion of sand grains is deposited near the high water line and in varying thicknesses. Frequently these thick mud deposits are intensely burrowed due to a high infaunal population. Accompanying sedimentary structures include subaerial dessication cracks, lenticular and flaser bedding and rhythmically laminated bedding.

2. Mud-sand environment: The mud-sand (Misch) environment is characterized by rhythmically laminated bedding, fine and coarse sandy mud banks, lenticular and flaser bedding, short wave ripple bedding, and bioturbate structures. Meandering tidal channels with concentrations of shell material and mud pebble conglomerates as lag deposits at the bottom are present.

3. Sand flat: Laminated sand, flaser bedding with some lenticular bedding, short wave and mega rippled bedding, and some bioturbate structure resulting from the activities of bivalvia and _Arenicola_ are sedimentary and biogenic features characteristic of sand flat environments. (Reineck, 1967, p. 201.) (The presence of dessication cracks is quoted from Van Straaten, 1954b, 1961.)

While the three lithofacies of the Eau Claire Formation do not match exactly the three sub-environments of recent tidal flats, important and distinctive similarities are present.

Unit One of the Eau Claire Formation has characteristics of both the mud flats and the Misch. The abundance of dessication cracks, the presence of both laminated and non-laminated sands and intense bioturbate structure of the mostly infaunal _Cruziana_ facies are most characteristic of mud flats.

However, the generally irregular, wavy or lenticular bedding pattern of the finely laminated sandstone beds in these shaly thin beds of the Eau Claire are more indicative of the Misch sub-environment on modern tidal flats (Reineck, 1967). Because of the presence of features representing both sub-environments, I feel Unit One is indicative more of a transitional area between a true mud flat and the Misch flats. The presence of Arenicolites and Skolithos type burrowing structures which are more characteristic of the Misch or sand flat zones is further evidence of the transitional nature of this unit.

Unit Two is characteristic of a true Misch flat with meandering tidal channels (indicated by the very thick bedded sand units with basal lag deposits of shell hash and mud chips). Each of these units-grades upward to thinner bedded sands and silty shale beds with both a Cruziana and Skolithos ichnofauna. This type of bedding style has been recognized by both Van Straaten (1954, 1961) and Reineck (1967) as characteristic of a vertical sequence produced by tidal channel migration. The gradual decrease and final absence of the Cruziana facies paralleled by the increased abundance and diversification of the Skolithos facies in the 25 feet of unit two would indicate a general increase in the energy level of the tidal flat due to a raising of the sea level and the development of a true sand flat sub-environment, which is characterized by ripple bedding and a general decrease in bioturbate structure. However, the presence of some silts and shales and finely laminated sands on a stratigraphic horizon equal to these thicker sand units would indicate areas of topographic highs resulting in zones of transition and a mixing of these sub-environments. (Refer to upper portions of unit two, localities E, F, J.)

The predominant lack of any trace fauna and the large scale cross-bedded nature of Unit Three fits most closely the foreshore or beach wall profile of Reineck's North Sea sediments. However, the lack of laminated sands and short wave ripple bedding, and the presence of some dessication cracks (locality F) would indicate that Unit Three was deposited close to a dune bar or island rather than being a longshore bar or beach wall (Reineck, 1967, p. 203). (See comparative charts of features of the Eau Claire and Recent Tidal Flats, pages 103 and 104).

Two types of tidal flats have been defined; one typified by the Bay of Fundy, occurs along rocky coasts and is characterized by wave cut benches, estuaries, clay flats, tidal marshes and the tidal flats which developed in the lee of barrier islands. The second type occurs as wide or narrow flats along a soft sediment coast of low relief, such as the Wadden sea of the Netherlands (Klein, 1967). The Eau Claire Formation represents a similar tidal flat environment. While the Wadden Sea is a large lagoon separated from the Atlantic Ocean by the Frisian Islands, there is no known evidence that similar barrier islands were present during the deposition of the Eau Claire Formation. Tidal Flats are known to occur along coats with no barrier islands for protection, e. g. Surinam coast; and sediments grade gradually into normal open sea deposit (Van Straaten, 1961). It is also possible that the hypothetical Eau Claire barrier islands are present in the subsurface in Minnesota, Iowa and Illinois and have not been defined from well logs.

The vertical progression from a high-water level mud flat environment to a lower water level sand flat and possible forewhore zone is indicative of a transgressive sequence. A similar sequence has been defined by Reineck as occurring on recent tidal flats and being indicative of a transgressive sequence (Reineck, 1969). Several tidal flat environments have been recognized in the ancient record and are well documented (Klein, 1970; Goodwin and Anderson, 1974; Swett et al., 1971; Van Straaten, 1954; Evan and Tarlo, 1963; Potter and Glass, 1958). The recognized sedimentary structures, lithofacies and biofacies of the Eau Claire Formation compare favorably with these studies as well as those of the Recent. While each of the investigated tidal flat areas has unique features, the repeated interbedding of mud and rippled sand develop varying but distinctive facies is perhaps the most characteristic feature of tidal flat deposits. Climate, tidal range, sediment supply and transport, amounts and types of biological activity are factors affecting facies development. The unique combination of each in various geographic settings produce the variability recognized in investigations of these recent and ancient tidal flat areas (Blatt, Middleton, and Murray, 1972).

SUMMARY

The Eau Claire Formation represents a tidal flat environment with three distinct subenvironments defining a transgressive sequence. A high tide level mud flat is overlain by meandering tidal channels of Misch flats which grade upward to sand flats and finally, at or below low tide level, foreshore sands. The biofacies and biogenic structures present support this conclusion of a gradual increase in sea level. A *Cruziana* facies characteristic of the mud flats gradually alters to a higher energy *Skolithos* facies as the mud flats become sandier and meandering channels invade the mud flats. The *Skolithos* facies becomes dominant on the sand flats and diminishes with the appearance of the foreshore sands. Sedimentary structures also support this premise. The decrease in the occurrence of mud cracks with an increase in horizontal and cross-laminated sands and mega ripples accompanies an increase in the energy level, characteristic of a transgressing sea. This author recognized the unconformity between the Eau Claire Formation and the Wonewoc Formation described by Morrison (1968) and Ostrom (1970). The evidence of possible further transgression during Eau Claire time has been removed by erosion which accompanied the regression and exposure prior to Galesville deposition.

EAU CLAIRE FORMATION	NORTH SEA TIDAL DEPOSITS (RECENT)
Lithofacies 3:	Low Water Mark:
Sandstone, fine gr., generally clean. Low angle X-bed sets. Brachiopod fragments. A few *Skolithos* burrows.	Offshore shoals and banks. Flanking tidal ebb and flow channels. Clean sands with shells and shell beds. Strong currents.
Lithofacies 2:	Lower Flats (Sand flats, Misch)
Sandstone, fine gr., thick to very thick bedded. Alternates with fine gr. sandstone/siltstone beds with variable clay content. Thick beds generally X-bedded with skeletal coquinites at base. Basal surface often marked with mud cracks. Ripple marks present. Interbeds thin, wavy, lenticular. Generally contain biogenic structure. Upper 30 ft. of this unit has little clay. Very thick bedded sandstone with low angle X-laminae. *Skolithos* facies upper 30 ft. *Cruziana* facies lower 50 ft.	Chiefly clean and some muddy sands. Wave action, tidal run-off channels.
Lithofacies 1:	High Water Mark (upper mud flats)
Sandstone, fine gr., thin to thick bedded interbedded with a sittstone unit with a high clay content. Wavy, lenticular bedding. Very bioturbate. Sandstone beds horizontally or cross laminated. Ripple marks mud cracks. Entire units contains a *Cruziana* facies.	Muddy sands and silts with sand lenticles and laminae. Abundant burrowing animals. Alternate submergence and emergence. (Allen and Tarlo, 1963, p. 139)

Table 3: A comparison of the lithofacies of the Eau Claire Formation with Recent North Sea tidal flat sub-environments.

EAU CLAIRE FORMATION	DUTCH WADDEN SEA TIDAL DEPOSITS
Lithofacies 1 and 2	Lamination of tidal flat and channel deposits.
Not present	Marsh laminations Beach laminations Brackish water laminations
Lithofacies 1 and 2	Current ripple structures
Lithofacies 1 and 2	Wave ripple structures
Lithofacies 2	Mud pebble beds
Lithofacies 1 and 2	Shell beds
Lithofacies 2	Load casts
Not observed	Slump structure
Lithofacies 1, 2 and 3	Normal dessication cracks
Lithofacies 2 (possible)	Mud cracks of subaqueous origin
Not observed	Structures due to escaping or entrapment of air.
Lithofacies 1 and 2 *Cruziana* Facies	Burrows by skeletal fauna
Lithofacies 1, 2, and 3 *Skolithos* Facies	Burrows of (marine) worms & crustaceans.
Not present	Structures due to burrowing land animals or due to plant roots. (Van Straaten, 1954b, p. 67-85.)

Table 4: A comparison of the biologic and sedimentary features of the Eau Claire Formation with Recent Dutch Wadden Sea tidal deposits.

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