STRATIGRAPHY OF THE EAU CLAIRE FORMATION OF WEST-CENTRAL WISCONSIN

BY

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ABSTRACT

The Upper Cambrian Eau Claire Formation is primarily a fine to very fine grained quartzitic sandstone interbedded with greenish-grey shale beds. Within the Dresbachian Stage it is situated above the Mt. Simon Sandstone and below the Galesville Member of the Wonewoc Formation. The Eau Claire's generally thin bedded, fine grained nature distinguish it readily from the much more massive bedded, coarser grained sandstones of the underlying and overlying units.

The Eau Claire Formation can be subdivided into five distinct lithologic zones, largely on the basis of bedding style and shale content. These are from the base upward: the "shaly beds", the "lower thin beds", the "lower massive beds", the "upper thin beds", and the "upper massive beds". These lithologic zones are traceable over the extent of the outcrop, although they are not all present at any single exposure.

The Eau Claire Formation grades downward into the Shawtown Formation (upper Mt. Simon). The lower contact is placed at the top of the uppermost medium or coarse grained sandstone bed in the Shawtown Formation, a bed which, because of its characteristically dark, iron staining, is informally called the "rusty foot". The upper contact with the Galesville is unconformable as is demonstrated by the basal conglomerate, considerable relief within a small area on the upper surface of the Eau

Claire, and other evidences found over the extent of the Eau Claire outcrops. There is also a distinct lithologic break marked by a sudden increase in grain size, decrease in feldspar content, and increase in purity within the Galesville.

Several detailed described sections demonstrate lateral persistency of units within the Eau Claire Formation. Heavy liquid separations of light minerals from the heavies produced little of significance with respect to the heavies. The Eau Claire has less than one percent by weight heavy minerals and does have a somewhat higher garnet content than the Shawtown or Galesville. The Eau Claire is usually quite glauconitic. The light minerals consisted of quartz and a relatively high percentage of potassium feldspar (average 30%) which is believed to be largely authigenic. Euhedral orthoclase over-growths around microcline cores are not uncommon. X-ray diffraction methods support the idea of authigenic crystallization of the orthoclase.

The Eau Claire Formation was deposited farther offshore than either the Shawtown or the Mt. Simon formation as part of the same cycle and derived its sediment largely from the Precambrian crystalline complex to the north and east. The Eau Claire exhibits evidence of both a transgressive phase for the most part and also a regressive phase near the very top. Uplift of the area and/or withdrawal of the sea after the deposition of the Eau Claire subjected the area to erosion. The seas readvanced a short time later to deposit the Galesville Sandstone over the eroded surface.

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INTRODUCTION AND PURPOSE

The primary purpose of this study is to define and describe the Eau Claire Formation where it is exposed in and near the type section in Eau Claire, Wisconsin. Because there is a need to assign definite, workable limits to the Eau Claire, detailed stratigraphic descriptions were made to determine if the succession is laterally persistent.

Secondary objectives included a study of the Eau Claire's relationship to related Upper Cambrian units, particularly the overlying Galesville Member of the Wonewoc Formation, and a determination of the sedimentological history of the area covered by the Eau Claire Formation.

The Eau Claire Formation is of the Upper Cambrian (Croixan) Series. It is underlain by the Shawtown Formation (Raasch and Unfer, 1964) and overlain by the Galesville Member of the Wonewoc Formation. (See Ostrom, 1967 for a discussion of the nomenclature as is used in this paper; see figure 3).

The detailed stratigraphy of the Eau Claire Formation has not been worked out previously. Earlier workers like Twenhofel, Raasch, and Thwaites (1935) made good general studies of the Eau Claire in their work in the upper Mississippi Valley. The detailed studies that have been made are in the realm of paleontology, and again Raasch (1935) as well as Lochman (1958) are responsible.

Lack of detailed work in the Eau Claire has led to uncertainty in interpreting the Cambrian geology of the area, even to the inability of different writers to agree on just what constitutes the Eau Claire Formation. In addition, subsurface correlation is necessary in an economic as well as an academic sense, and an accurate, detailed study of the surface outcrops should facilitate such correlation.

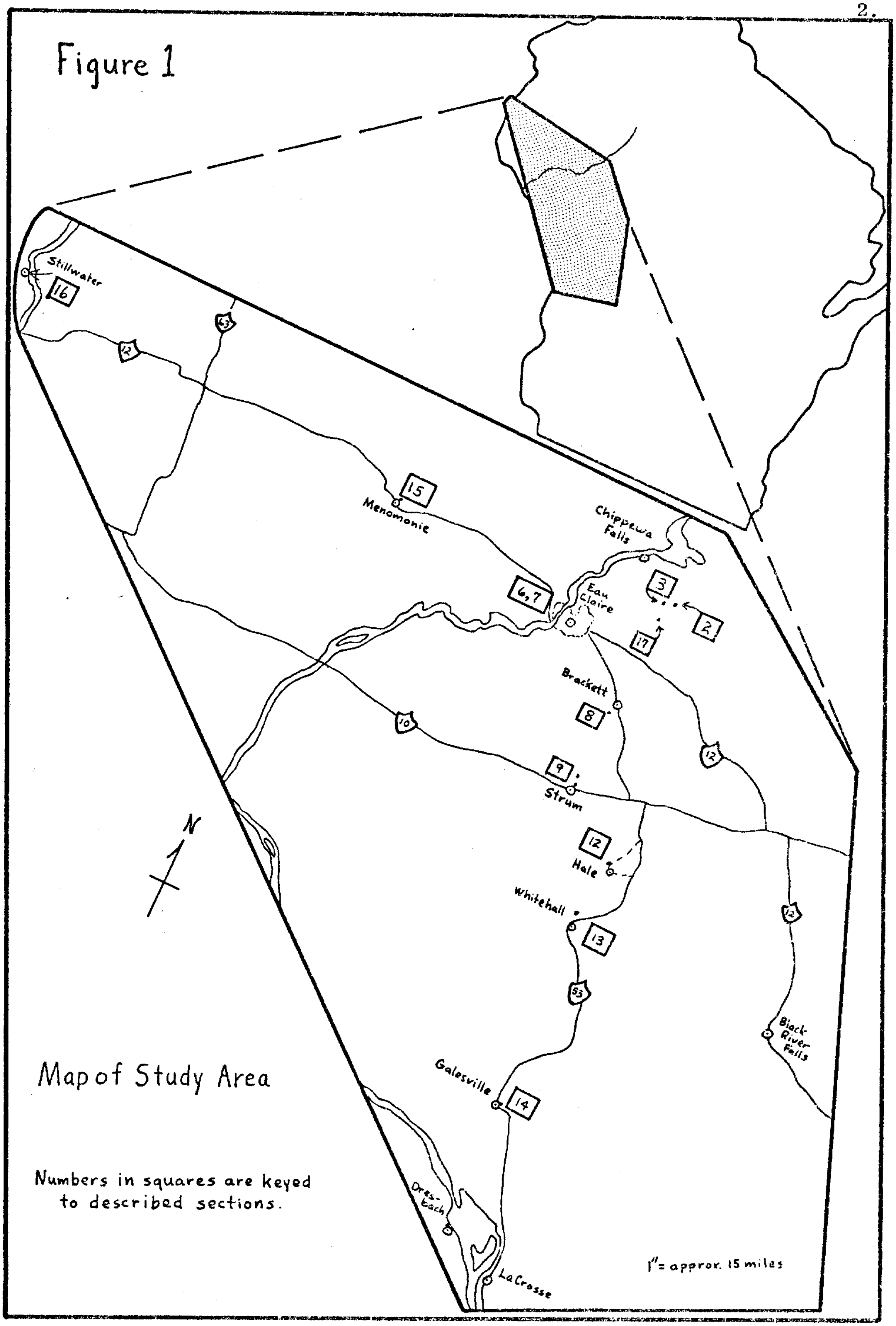

Figure 1

Map of Study Area

Numbers in squares are keyed to described sections.

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Acknowledgements. -- The idea for the study came from Dr. M. E. Ostrom of the Wisconsin State Geological and Natural History Survey. The Survey furnished financial and material support for the field work. The thesis was written under the direction of Dr. L. M. Cline of the University of Wisconsin.

Previous Studies

Since the first stratigraphic studies of the Croixan rocks of the upper Mississippi Valley were made, the nomenclature referring to the lowermost of these, the present Mt. Simon, Eau Claire, and Galesville Formations, has been changed repeatedly. A brief discussion of the changes will supplement the outline seen in figure 2 and will summarize the evolution of the classification of the Eau Claire Formation.

Wooster's (1882) early descriptions of the Potsdam Sandstone included the first mention of the term "Eau Claire" in a lithologic and paleontologic context, namely the "Eau Claire trilobite beds." Winchell (1886) formally separated the "shale" from the enclosing sandstones. Formational status was given to the Eau Claire beds by Ulrich (in Walcott, 1914, p.354). Ulrich's classification was perhaps the earliest to rely so strongly on paleontology. His original description of the Eau Claire Formation as "Usually a coarse white friable sandstone with *Dicellomus* and *Lingulella* at the base..." has left room for confusion in the literature regarding the nature of the Eau Claire. Perhaps Ulrich was referring only to the basal beds, as this description would fit those near the base of the exposure at Mt. Washington. By far the bulk of the Eau Claire Formation consists of fine to very fine grained sandstone with some clay. The writer does not include the coarse sandstones at the base of the lower

	Winchell 1873	Winchell 1886	Berkey 1897	Walcott 1914	Twenhofel and Raasch in Wilgus, 1933	Trowbridge and Atwater, 1934 Twenhofel, Raasch and Thwaites, 1935	Howell, et al. 1944	Berg, Bell and Nelson, 1956	Emrich, 1962 Outcrop	Emrich, 1962 Subsurface	Ostrom 1967
CAMBRIAN SYSTEM	St. Croix Sds.	Shale (St. Croix Formation)	Franconia Sds.	Franconia Sds.	Mazomania; Franconia (sensu stricto) (Franconia Formation)	Franconia Sds.	Franconia Sds.	Franconia Sds.	Franconia Sds.		Lone Rock; Mazomanie
	Potsdam Sds.	Dresbach Sds. (St. Croix Formation)			Ironton (Franconia Formation)	Ironton Mbr.	Ironton Mbr.	Woodhill Mbr.	Ironton Fm.	Ironton-Galesville Fm.	Ironton Mbr. (Wonewoc Fm.)
		Dresbach Sds. (St. Croix Formation)	---?---	Dresbach Sds.	Dresbach Mbr. (Eau Claire Formation)	Galesville Mbr. (Dresbach Formation)	Galesville Mbr. (Dresbach Formation)	Galesville Mbr. (Dresbach Formation)	Galesville Fm.		Galesville Mbr. (Wonewoc Fm.)
		Shale	Dresbach Shales	Eau Claire	"Fossiliferous mbr. generally known as Eau Claire" (Eau Claire Formation)	Eau Claire Mbr. (Dresbach Formation)	Eau Claire Mbr. (Dresbach Formation)	Eau Claire Mbr. (Dresbach Formation)	Eau Claire Fm.		Eau Claire Fm.
		Hinkley Sandrock		Mt. Simon	Mt. Simon Mbr. (Eau Claire Formation)	Mt. Simon Mbr. (Dresbach Formation)	Mt. Simon Mbr. (Dresbach Formation)	Mt. Simon Mbr. (Dresbach Formation)	Mt. Simon Fm.		Shawtown Fm.*; Mt. Simon Fm.

Figure 2

* see Raasch and Unfer, 1964.
The Shawtown Fm. has been inserted into Ostrom's column by this writer.

Modified from Emrich, 1962.

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quarry on Mt. Washington within the Eau Claire Formation.

Trowbridge and Atwater (1934) reduced the Eau Claire to member status within the Dresbach Formation. Twenhofel, Raasch, and Thwaites (1935), using the Trowbridge classification, did some of the first published detailed work on the Eau Claire unit and re-emphasised the paleontological zonation. Berg, Nelson, and Bell (1956) retained the Trowbridge classification but modified the member slightly shifting the emphasis on classification from paleontologic to lithologic by including within the Eau Claire only fine grained sandstones and shales. They noted a sharp lithologic break between the Eau Claire and Galesville members at Dresbach, Minnesota, and commented that their classification would add considerably to the thickness of the Galesville of Twenhofel, Raasch, and Thwaites.

In addition to the above writers, Englund (1950), Perko (1940), Krumholz (1940), and Benish (1940) have worked within the area under study within this report. However, because of changes in Cambrian terminology and classification, I have found that, for the most part, what was called Eau Claire in their areal studies is considered a fossiliferous part of the Shawtown Formation in this paper.

In accord with the Wisconsin Geological and Natural History Survey the writer believes the Eau Claire unit as defined on the following pages is deserving of formational rank and will refer to it in such a manner as figure 3 indicates.

Stratigraphic Nomenclature Used in This Paper

Figure 3

Ostrom, 1967

System	Group	Formation	Member	Stage
Ordovician	Prairie du Chien	Oneota		
Cambrian		Jordan	Sunset Point	Trempealeauan
	Tunnel City	St. Lawrence	Lodi	
			Black Earth	
		Mazomanie / Lone Rock	Reno	Franconian
			Tomah	
			Birkmose	
	Elk Mound	Wonewoc	Ironton	
			Galesville	Dresbachian
		Eau Claire		
		Shawtown		
		Mt. Simon		
Precambrian				

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STRUCTURAL SETTING

The Eau Claire study area is situated on the western side of the Wisconsin arch, a southeast trending extension of the Wisconsin dome of northern Wisconsin. To the east of the arch the strata dip into the Michigan basin. Immediately south of the Wisconsin arch lies the Illinois basin which is separated from the Michigan basin by the Kankakee arch, a southeastward extension of the Wisconsin arch. South of the study area and west of the Illinois basin is the Forest City basin. The Mississippi River arch separates the two basins. West of the study area lies the Mid-Continent gravity high and somewhat farther west through central Minnesota runs the Transcontinental arch.

Within the study area the dip is generally to the southwest and at angles seldom exceeding five degrees. Because of the low dip and relatively non-resistant nature of the Eau Claire Formation the exposures are few and seldom over twenty feet thick when found.

STRATIGRAPHY

Described Stratigraphic Sections

Sections were described and measured wherever more than ten feet of the Eau Claire Formation was found. In addition, special attention was given to both the upper and lower contacts whenever they were exposed, regardless of whether there was enough of a section to warrant descriptions. The detailed descriptions on the following pages were made by the writer unless otherwise stated.

Well defined boundaries for the Eau Claire Formation have not been recorded in the literature. Such lithic limits are highly desirable, both in an academic sense, and in a practical one. This is borne out in particular in subsurface work. Fossils characteristic of the Eau Claire are not as abundant as they might be for purposes of identification, and those that are found are poorly preserved and very fragmental. Because well cuttings are generally quite small, whole trilobites cannot be obtained from the cuttings. Subsurface correlation of the Eau Claire Formation is necessary, however, and with this in mind the writer has set out to describe the Eau Claire Formation with an emphasis on the lithologic approach, and then to determine if at least a general persistency of the individual units exists over a broad area.

Careful study of all contact exposures has shown that the upper contact of the Eau Claire Formation with the Wonewoc is easily identified. The lower contact, though part of a transitional sequence from the Mt. Simon, is not as arbitrary as it seems at first glance.

The Shawtown Formation (Raasch and Unfer, 1964) is characterized by alternating beds of Eau Claire and Mt. Simon types of lithologies. The contact between each thin bed is generally very sharp. At the top of this sequence, which may exceed fifty feet in thickness, is a bed of medium to coarse grained, well rounded quartz-arenite (typical Mt. Simon lithology). This bed is usually from five inches to a foot or so thick, very strongly iron-stained, and is commonly referred to in the text and described sections as the "rusty foot". Immediately above the "rusty foot" the Eau Claire Formation begins.

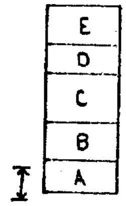
With only two very minor exceptions ** the "rusty foot" is the last medium grained sandstone to appear in the section upward to the base of the Wonewoc Formation. The Eau Claire Formation, then, has no medium or coarse grained sandstone beds, but consists of interbedded clays, shales, siltstones, and very fine grained sandstones which are often rich in glauconite.

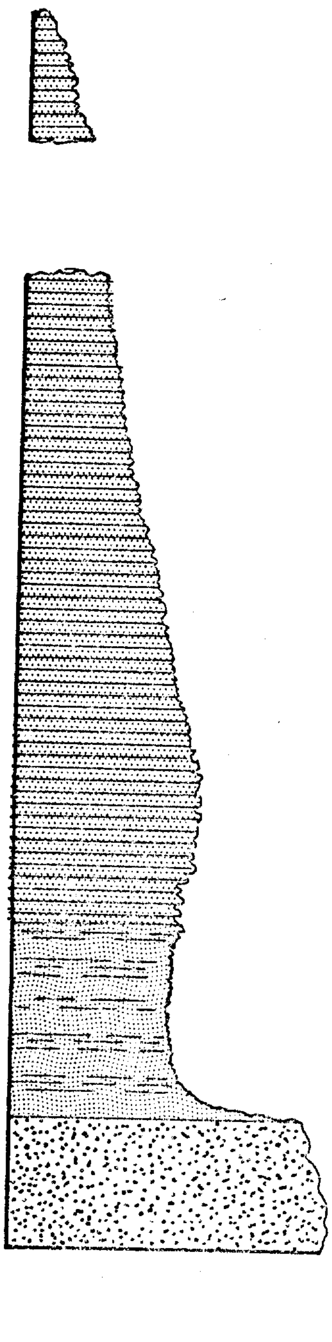
There is a sharp lithologic break at the top of the Eau Claire. The Eau Claire is a fine or very fine grained, highly glauconitic sandstone, while the overlying Galesville is coarser, cleaner, and often cross bedded. (See section subtitled "Contact Relations".)

** At the type section of the Eau Claire two 1" - 2" lensoid beds of medium grained sandstone may be seen about ten to fifteen feet above the base of the Eau Claire.

3 Chippewa Co. T.28N., R.8W., Sec.33, SW 1/4, SE 1/4

Scale: 1" = 3'





Same as unit 3; darker color.

Covered

3. Sandstone: gray-grayish tan; fine gr., sub-angular to sub-rounded; rather well-sorted; vy. little glauconite; abundant Hyolithes; thin bedded, poorly resistant; few clay interbeds near bottom; much mica near base.

10.0'+

2. Sandstone - Clay: gray to lt. olive green; irregular bedding; fine to vy. fine gr., poorly sorted; vy. non-resistant; few brachiopods.

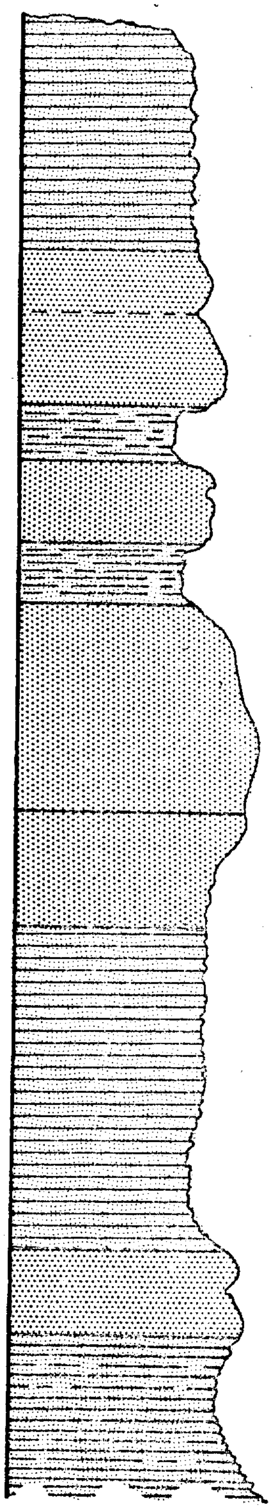
3.0'

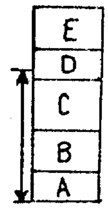
1. Sandstone: gray-tan to red-brown; med. to vy. coarse gr.; well-rounded, med. sorting; clean; vy. abundant brachiopods; "Rusty Foot"

3'

6 Eau Claire Co. T.27N., R.10W., Sec.25, NW 1/4, NE 1/4

Scale: 1" = 5'





12. Sandstone: tan, mostly fine gr., some clay, very glauconitic, thin-bedded. 6.0'

11. Sandstone: tan to red-tan; fine gr., sub-rounded to rounded, angular to sub-angular; medium sorting; vy. glauconitic, thick bedded–massive, ripple marks, few thin clay interbeds 4.0'

10. Sandstone-Clay: similar to unit # 8 1.5'

9. Sandstone: like unit # 7; has delicate laminations in the glauconite; abundant brachiopods and <u>Crepicephalus</u>. 2.0'

8. Sandstone-Clay: red-tan, fine gr., thin-bedded or irregular bedded; often vy. glauconitic, non-resistant, especially near top 1.6'

7. Sandstone: tan, fine to vy. fine gr., angular, glauconitic, well-indurated, massive bedding 5.3'

Upper Quarry Floor

6. Sandstone: dk. buff, fine gr., well-sorted, sub-rounded thick-bedded; Cedaria near bottom in thinner beds 3.0'

5. Sandstone: similar to unit # 4, but thin-bedded, many clay partings; vy. few fossils; non-resistant 8.2'

4. Sandstone: buff; fine gr., well-sorted, glauconitic, thick-bedded; few clay interbeds 2.3'

3. Sandstone-Shale: interbedded; sandstone is gray-buff, fine gr., glauconitic, thin-bedded; clay partings, bottom marks; generally "dirty" appearance in upper 5'; definite bedding. 9.0'

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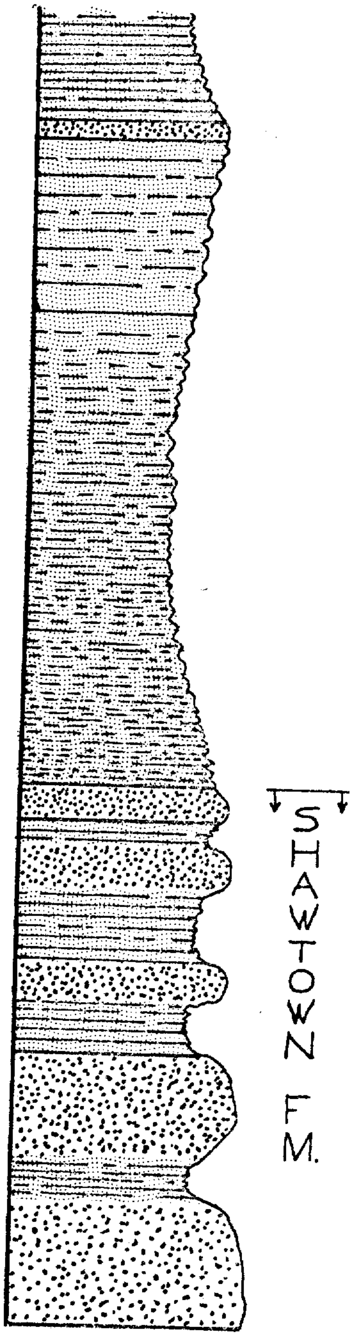
6 continued



3. Sandstone-Shale: continued from above.

2. Sandstone: medium grained, well-rounded, well-sorted, iron-stained 0.5'

1. Sandstone-Clay: sandstone is tan to purplish tan, fine gr., well-sorted, angular to subangular, slightly glauconitic; inter bedded, irregular bedding; sands become slightly thicker bedded going up the section 18.0'

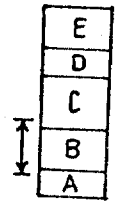
Z Sandstone: type similar to unit X ; "Rusty Foot". 1.0'

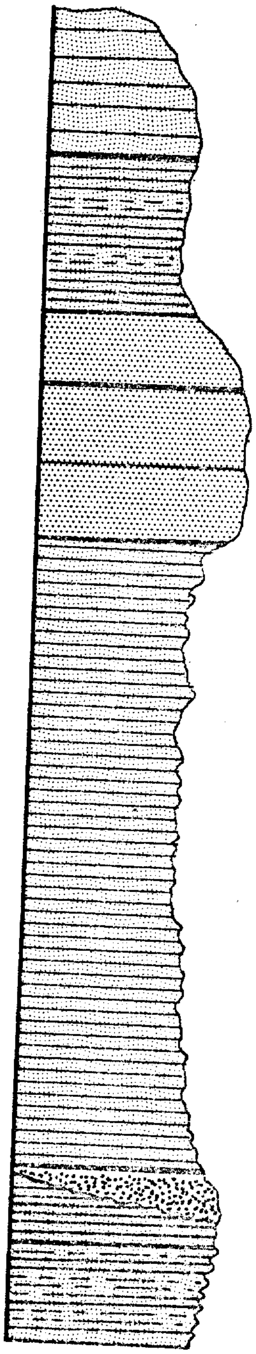
Y Sandstone: light-tan to buff; fine to vy. fine gr., medium sorting; subangular, slightly glauconitic, numerous greenish-gray clay partings; bottom marks (trace fossils?) and Oboloid brachiopods abundant. 6.0'

X Sandstone: lt. tan to red-brown; medium gr., well-rounded, well-sorted, iron concentrations in bands; fairly massive, but interbedded with thin beds of sandstone type Y. 7.0+'

7 Eau Claire Co. T.27N., R.10W., Sec. 26, SW 1/4, center

Scale: 1" = 4'





7. Sandstone: lt. tan; vy. fine gr., medium sorting; glauconitic, good Cedaria; thicker bedded here than in unit #6 2.5'

6. Sandstone: lt. tan; thin-bedded, interbedded with green clay; vy. fine gr., medium to poor sorting; brachiopod fragments 3.2'

5. Sandstone: yellow-brown; vy. fine gr., sub-angular, well-sorted, glauconitic; massive bedding 4.7'

4. Sandstone: vy. fine gr., thin-bedded; beds become thicker 3' from top then thin and clayey again; there is a "spongy" textured rock 4' from top; glauconitic; few fossils 12.9'

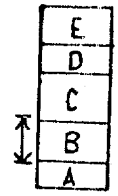
3. Sandstone: dark ochre; poor sorting; up to medium gr., cross bedded, well-rounded, slightly glauconitic. 0.9'–0.1'

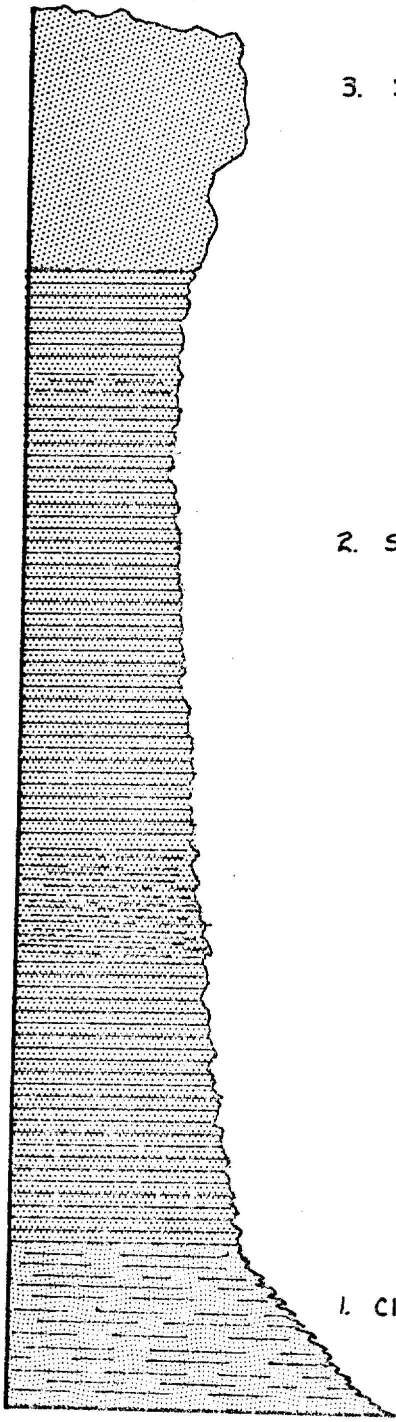
2. Sandstone: red ochre; fine to vy. fine gr., well-sorted, poorly rounded; slightly glauconitic; cut out by unit #3. 0.6 – 1.3

1. Sandstone + Clay: red-tan sandstone, green-gray clay; thin to irregular bedding. 2.0'

8 Eau Claire Co. T. 25 N., R. 8 W., Sec. 5, SE 1/4, NE 1/4

Scale: 1" = 3'





3. Sandstone: dk. tan, fine gr.; <u>Cedaria</u> present, thick to massive bedding; mostly inaccessible
4.0'+

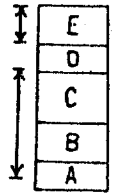
2. Sandstone-Clay: interbedded; lt. tan, irregular bedding common with thin sandstone beds occasionally; quite non-resistant
15.0'

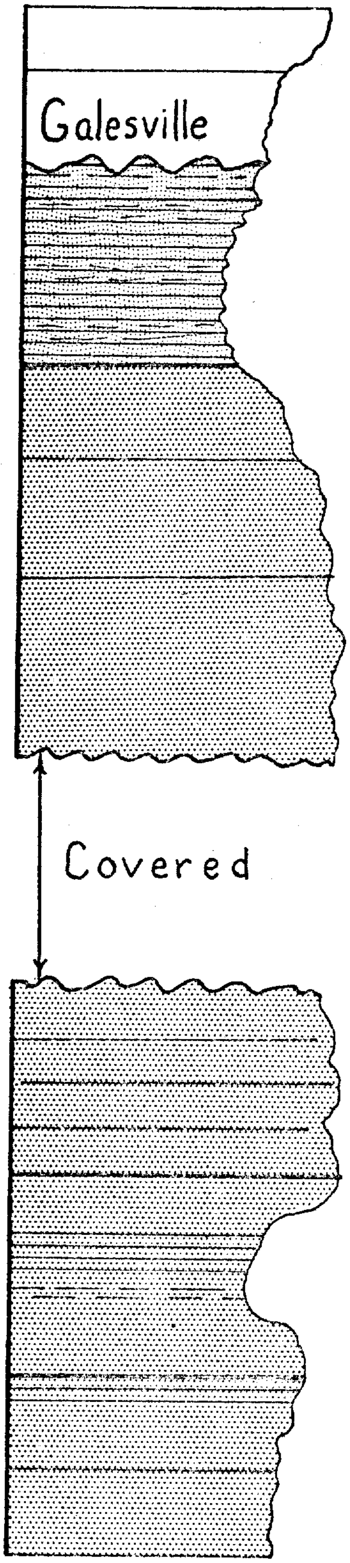
1. Clay-Sandstone: dk. green shale; quarry floor
2.0'+

9

Trempealeau Co.: above "Covered"; T.24N., R.8W., Sec.5, SW 1/4, SW 1/4
below " ; T.24N., R.8W., Sec.18, SE 1/4, NE 1/4

Scale: 1" = 6'





18. Sandstone: med. gr., massive, cross-bedded 17.0'

17. Sandstone: red-brown; vy. fine to med. gr., poor sorting; non-resistant; basal 2" strongly re-cemented with iron just below which is a 1" white siltstone, irregularly bedded.

16. Sandstone: yellow-brown; fine to vy. fine gr.; often well rounded, moderate sorting, definite bedding, well-indurated, worm burrows? 1.1'

15. Sandstone: similar to # 14, but cleaner; little or no glauconite; thin to irregular bedding, less resistant, grains often rounded, not so well-sorted 5.0'

14. Sandstone: yellow-tan to green-tan; fine gr., sub-angular, well-sorted; vy. glauconitic, quite thick bedded; abundant shell fragments 12.2'

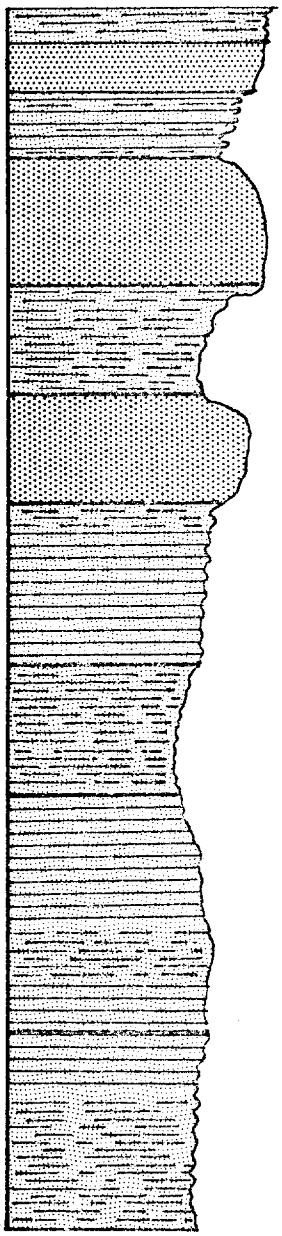
Exposure above separated
from one below by approx. 2 miles;
missing section = about 22'

13. Sandstone: fine gr., well sorted, vy. glauconitic; fossil fragments, weathers as thick-bedded but is thin to medium bedded. 6.0'+

12. Sandstone: similar to # 11 but, more glauconite; thin to thick-bedded; abundant *Crepicephalus*, bands of darker fossil material, few green clay partings; gradational from # 11. 6.3'

11. Sandstone: yellow-brown, fine gr., sub-rounded, very little glauconite; *Cedaria*; mostly thick bedded; *Crepicephalus* near top where thinner bedding becomes apparent 5.5'

9 continued



10. Clay-Siltstone: gray-green claystone with sandstone similar to # 7 interbedded; predominantly clay. 1.0'

9. Sandstone: similar to # 7. 1.5'

8. Sandstone: similar to # 7 but thinner and more irregularly bedded; clay partings; abund. trilobites 2.0'

7. Sandstone: tan, fine gr., moderately well sorted, glauconitic; trilobite fragments; quite thick-bedded but may weather to thin-bedded near top; resistant; (actual beds are about 0.5'-1.0' near base, thinner above) 3.9'

6. Sandstone-Clay: mixed; yellow-brown, mottled, very poorly indurated; little more than sediment; irregular bedding; vy. weak; thin clay at bottom. 3.4'

5. Sandstone: yellow-gray, fine-gr., well-sorted, glauconitic, thick-bedded, vy. resistant; thickens and thins to less than 2'. 3.3'

4. Sandstone: gray-tan, fine to vy. fine gr., sub-rounded to angular, slightly glauconitic; thin-bedded, micaceous, irregular bedding in top 1' 5.0'

3. Claystone: dk. gray, micaceous, thin-bedded; interbedded with a few vy. fine gr. sandstones; silty, totally non-resistant. 4.0'

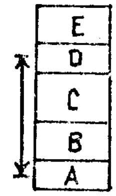
2. Sandstone: similar to #1, but much less clay and more resistant; still thin-bedded with thicker beds near top 7.3'

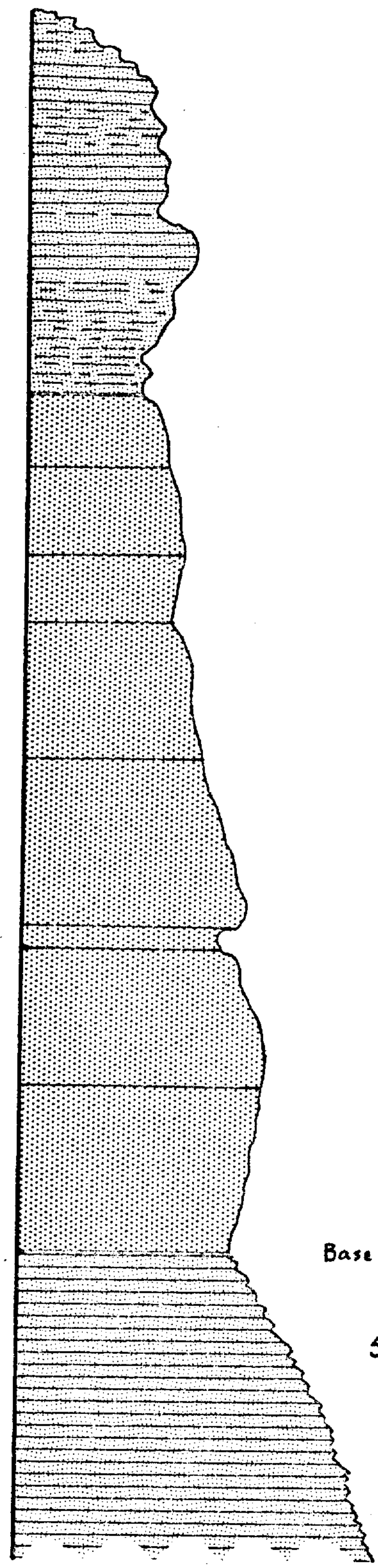
1. Sandstone: gray-tan, fine to vy. fine gr., moderately well-sorted; thin-bedded, slightly glauconitic; trace of Cedaria throughout; micaceous, numerous bottom marks; clay partings 6.0'

Base of Exposure

12 Trempealeau Co. T.23N., R.7W., Sec.17, SW¼, NW¼

Scale: 1" = 5'





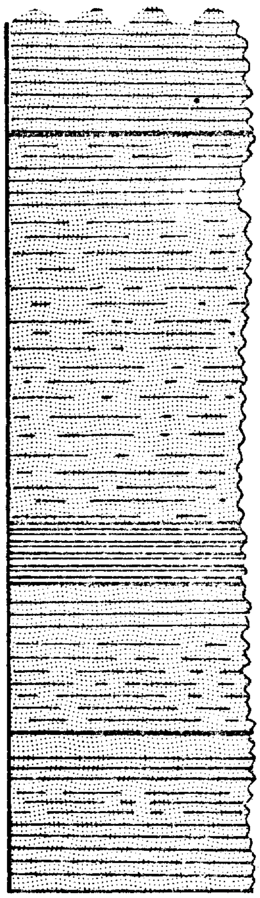
7. Sandstone-shale: interbedded, mostly sandstone; thin-bedded, quite glauconitic; mostly inaccessible 10.0'

6. Sandstone: brown-yellow, fine grained, quite glauconitic; moderate sorting, thick-bedded to massive; few coarser and more rounded sandstone beds; fossil-rich bed (non-resistant) about 7' above base of unit 22.0'

Base of steep face.

5. Sandstone: light tan, fine grained, med. sorting, very little glauconite; abundant *Cedaria* "hash"; thin-bedded, very shaly at bottom. 10.5'

12 continued



5. Continued from previous page.

4. Sandstone: yellow-brown, medium to vy. poorly sorted; thin to irregular bedding; vy. weak; has few good, definite beds interbedded near top 10.0'

3. Shale: green-gray, fissile with weathering; quite pure, some brachiopod fragments; interbeds gradationally into unit #4. 1.5'

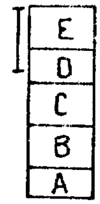
2. Sandstone: lt. tan, mostly fine gr., vy. poor sorting; some well-rounded, medium sand grains; thin to vy. irregular bedding; few brachiopods; vy. weak bedding more distinct toward top. 3.8'

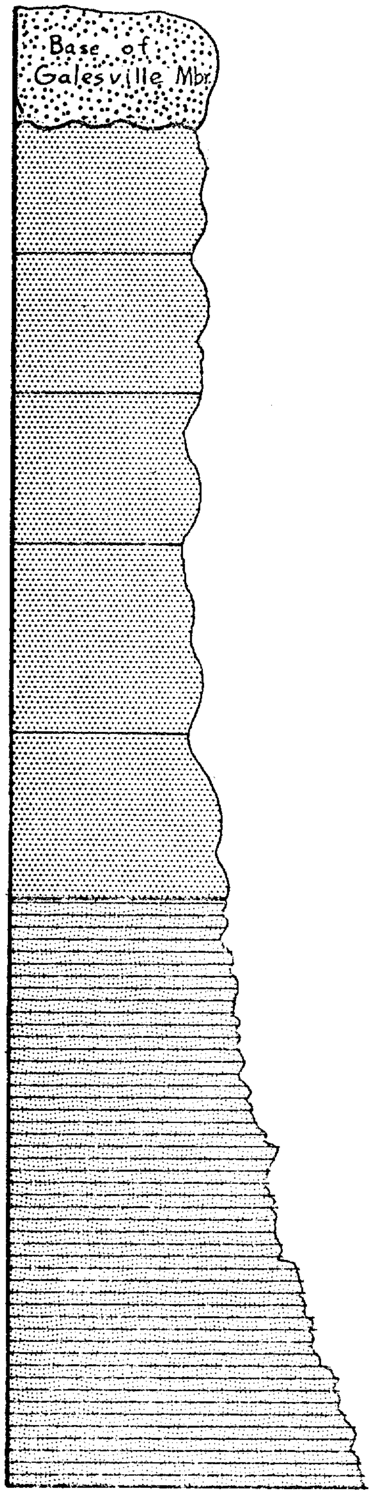
1. Sandstone: yellow-tan or gray; vy. fine gr., interbedded with green claystone; _Cedaria_? medium sorting; slightly glauconitic, often micaceous, thin-bedded. 4.0'

13 Trempealeau Co. T. 22 N., R. 8 W., Sec. 14, NE 1/4, NE 1/4

Description modified from that of G.O. Raasch in Twenhofel, Raasch, and Thwaites, 1935, p. 1738.

Scale: 1" = 5'





Sandstone: lt. yellow gray, mottled; streaked yellow and brown; predominantly coarse grain with poor sorting near base which is irregular and overlain by bed consisting of sand and pebbles from below; contact is sharp.

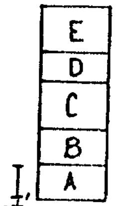
2. Sandstone: lt. yellow-gray to lt. green-gray; fine-grained, argillaceous, little glauconite; some cross-bedding; abundant oboloid brachiopods, moderately well-sorted; sub-massive appearance at top 20.0'

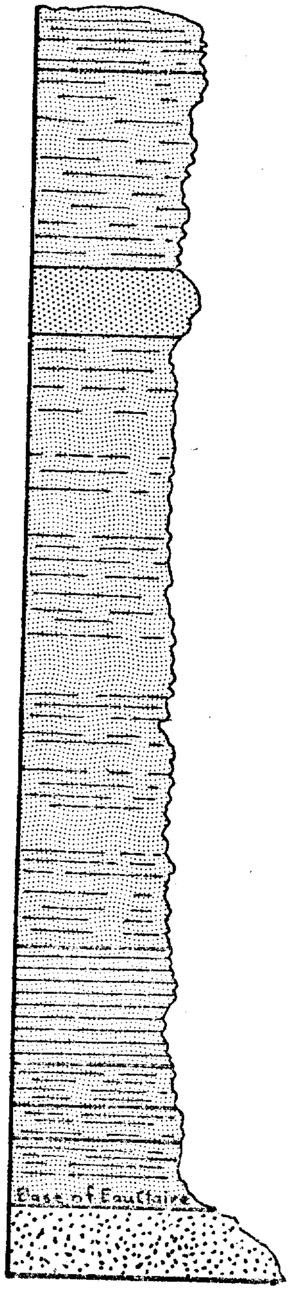
1. Sandstone: green-gray, fine grained, thin-bedded, glauconite, thin green clay seams. 15.0'

BCM

17 Eau Claire Co. T.27N., R.8W., Sec.9, SE 1/4, NW 1/4

Scale: 1" = 3'





9. Sandstone: yellow-brown, fine gr., non-resistant 1.0'+

8. Sandstone: similar to #6; mottled, irregular bedding, non-resistant; cleaner near top 3.0'

7. Sandstone: gray-tan, fine to vy. fine gr.; well-sorted, angular, well-indurated, slightly glauconitic, thicker-bedded than other units. 1.0'

6. Sandstone: dk. tan, fine to vy. fine gr., thin-bedded, usually much clay, but varying greatly; few thin beds of cleaner sand; mostly irregular bedding with green clay filling in irregularities 9.5'

5. Sandstone: gray-tan, vy. fine gr., thin-bedded, micaceous, first sign of <u>Cedaria</u> 1.8'

4. Sandstone: yellow-gray, vy. fine gr., irregular bedding, almost shaly weathered appearance 0.6'

3. Sandstone: purplish-tan; vy. fine gr., well-sorted, vy. slightly glauconitic; abundant <u>Hyolithes</u> 0.5'

2. Sandstone-clay: sub-mottled (dk. green and white); vy. poorly sorted, mostly fine to vy. fine gr., 1.0'

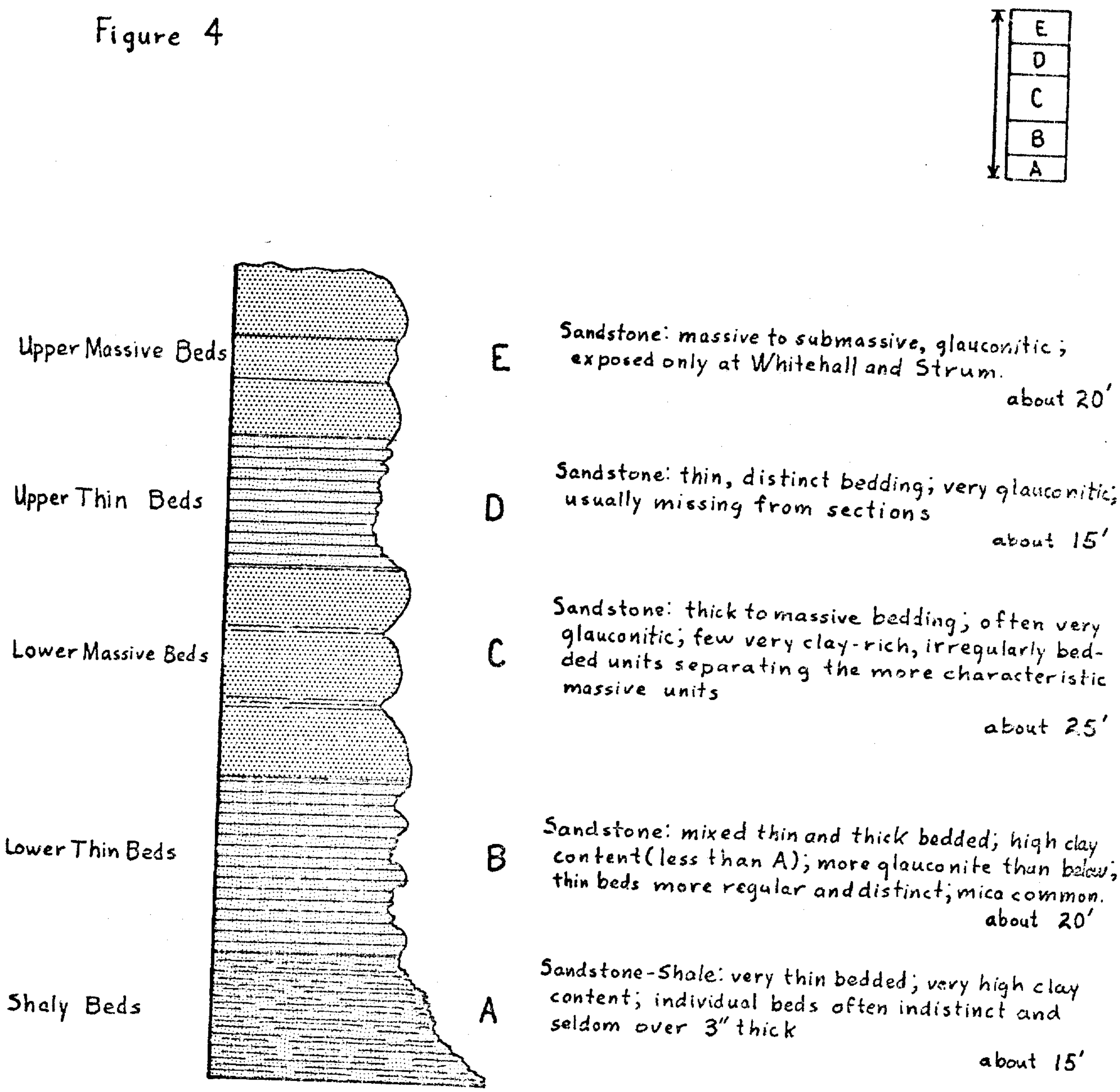
1. Sandstone: rust-red; med. to coarse gr.; "Rustyfoot."

BCM

Composite Section

A general composite stratigraphic section (figure 4) of the Eau Claire Formation has been compiled from all the outcrops visited by the writer. Because the type section is incomplete, the uppermost units were taken from other sections, principally the Whitehall and Galesville exposures, The correlations between exposures are solely those of the writer.

Figure 4



BCM

Plate I

Picture taken at Strum, Wisconsin which illustrates the typical outcrop appearance of the Eau Claire Formation.

Plate I

Picture taken at Strum, Wisconsin which illustrates the typical outcrop appearance of the Eau Claire Formation.

The Eau Claire Formation may be subdivided into five definite units which are, with the exception of unit E, traceable over the extent of the outcrop of the Eau Claire. Bedding style and clay content are the primary criteria for the unit breakdown as illustrated above, while such factors as glauconite and mica content are subordinate. (An increase in glauconite content from bottom to top is consistent.) The faunal break between the <u>Cedaria</u> and <u>Crepicephalus</u> zones occurs rather consistently near the base of the more massive "C" zone.

The basal unit of the Eau Claire, the "shaly beds," rests on the "rusty foot" of the Mt. Simon with marked contrast in lithology as is typified by the type section. The "shaly beds" appear to have a higher clay content than the other units and the bedding therein is commonly quite irregular. For this reason the unit is easily weathered. The "shaly beds" average from ten to fifteen feet in thickness.

In unit B the bedding, although still quite thin, becomes much more distinct and a few thicker beds (3" - 5") are dispersed throughout forming minor ledges. Mica is commonly seen on the bedding planes and glauconite is much more abundant here than below. This, the "lower thin beds" zone, averages about twenty feet in thickness, and weathers nearly as fast as the "shaly beds" below.

Above unit B the bedding style becomes much thicker, massive in comparison to the lower units, and glauconite becomes a very prominent feature of these sandstones. There are a few occasional clay-rich, almost mottled beds separating the more prominent and characteristic massive appearing beds for which the unit is named, the "lower massive beds".

Unit D, the "upper thin beds, are not everywhere present. They may be seen in part at Mt. Washington, Galesville, Whitehall, and possibly Hale exposures. At Galesville it is very evident that erosion has removed these beds at one end of the exposure while less than a hundred yards away up to two and one-half feet remain (see plate 5). This unit has thin, distinct beds which are very rich in glauconite, and ranges from zero to over fifteen feet thick.

The highest unit in the Eau Claire, the "upper massive beds", is found only at Whitehall and consists of rather thick bedded, somewhat cross-bedded sandstones. It is about twenty feet thick there and is overlain unconformably by medium grained, heavily iron stained Galesville Sandstone.

METHODS OF STUDY

The writer made several detailed stratigraphic sections of the Eau Claire Formation. Also, several samples were taken for heavy mineral, light mineral, and clay mineral analyses.

The study area comprised approximately 5300 square miles in west-central Wisconsin. The field work was done primarily in June, July, and August of 1967. Figure 1 is a map of the area with the locations of the described sections and exposures.

MINERALOGY

Five-hundred gram samples of the Shawtown, Eau Claire, and Galesville were collected in the field. From these the writer analyzed their mineralogy by using a petrographic microscope, heavy liquids, and X-ray diffraction methods.

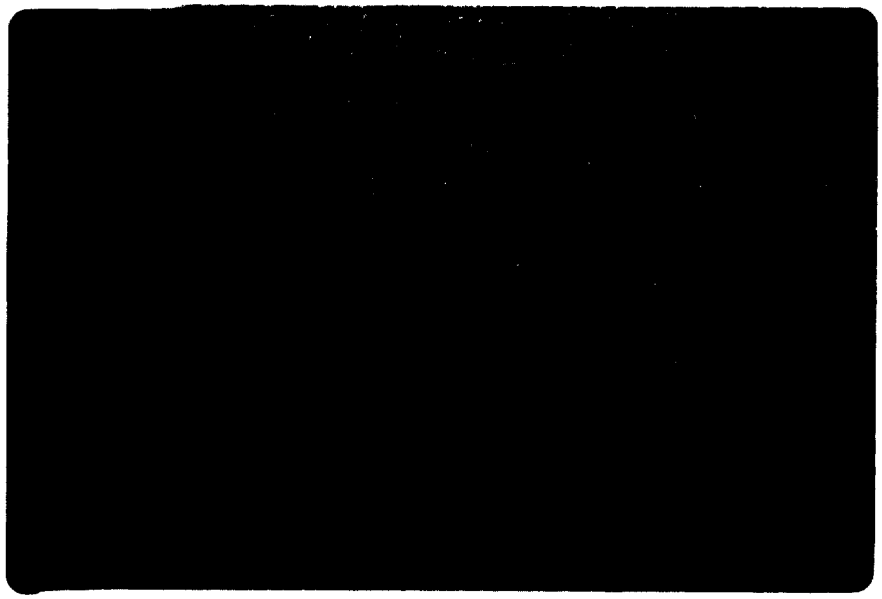
The Eau Claire Formation consists mainly of feldspathic sandstone. Its light mineral make-up is of detrital quartz grains amounting to from 40 to 100 percent of the total and averaging about 66 percent. The quartz grains vary from rounded to sub-angular, and frequently exhibit etched boundaries where in contact with either a potassium feldspar or some of the finely crystalline "matrix" material which is also rich in potassium. The potassium feldspars are of two types. Detrital microcline is usually rather rare, although it increases considerably in a few units. The principle feldspar is a monoclinic form of orthoclase as indicated by X-ray diffraction methods. Euhedral orthoclase crystals which have grown around microcline cores are not uncommon is some strata. This, together with the evidence for a monoclinic form of orthoclase, is quite conclusive evidence that a very large part of the feldspar in the Eau Claire Formation is of authigenic origin. As indicated in table 5 the potassium feldspar content is as high as sixty percent in one example, and as low as zero percent in a few others. It averages about thirty-three percent of the light fraction.

Included in the light fraction is material that might best be called "matrix" due to its very finely crystalline nature, so fine as to make definite identification of individual grains very difficult. Mainly they consist of feldspar laths (probably authigenic) and quartz grains. In addition, there is an occasional grain of zircon sometimes found trapped within one of these little pellets. There is an even finer grained "mud" around the crystallites. Because the laths in the pellets often have long, crystalline forms, and because the clearly authigenic overgrowths are found intimately associated with the matrix of the mudballs, it is believed that these feldspars are all likely to be authigenic. Perhaps some of the laths are albite, as not all of them stained yellow although the pellet as a whole was tinted yellow by the stain. It is the writer's belief that these rounded pellets are minute balls of silty clay or mud that were ripped up

Plates 2 and 3

Microphotographs of typical sandstone from the Eau Claire Formation. Note the orthoclase (stained yellow) on plate 2; plate three shows an overgrowth on the crystal as revealed by crossing the nichols.

Plane Polarized Light



Crossed Nichols

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Microphotographs of typical sandstone from the Eau Claire Formation. Note the orthoclase (stained yellow) on plate 2; plate three shows an overgrowth on the crystal as revealed by crossing the nichols.

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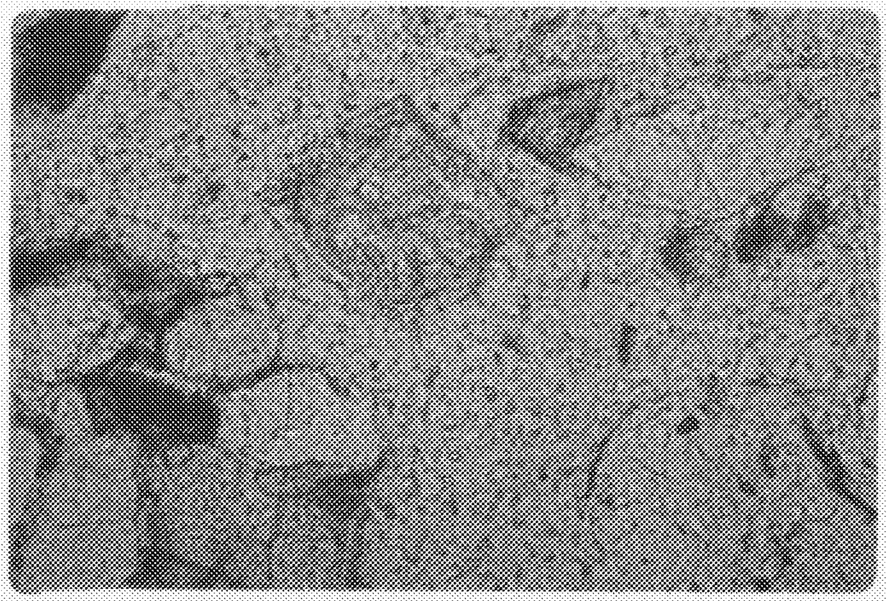

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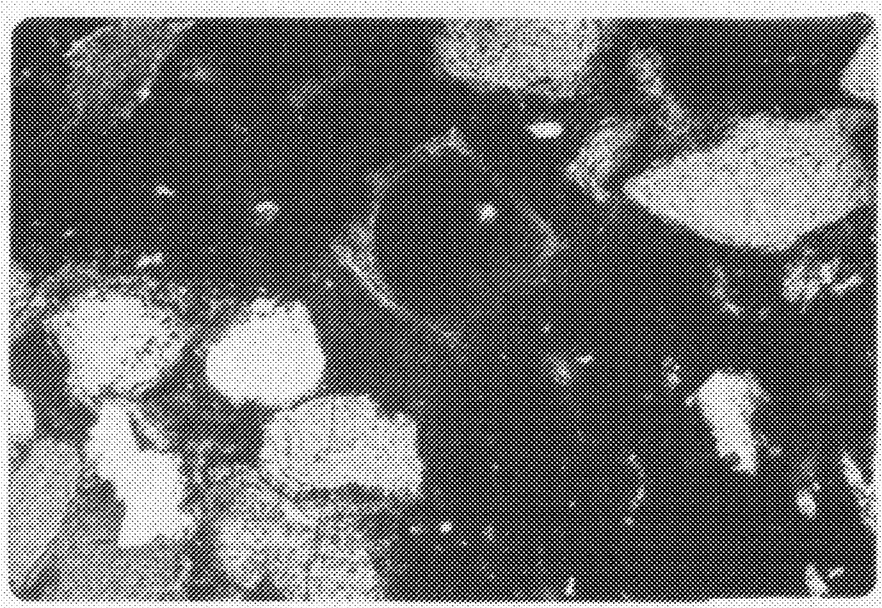

Figure 5

Results of Heavy Liquid Separation and Point Counting of Heavy and Light Minerals from Mt. Washington

unit number	grains counted	% Garnet	% Zircon	% Tourmaline	% Opaque		Feldspar (% of lights)
12	100	17	25	14	44		30
11	300	29.7	24.7	10.3	35.0		33
10	200	47.5	31.0	9.0	12.5		36.7
9	50	26	38	4	32		30
8	50	30	18	14	38		35
7	200	6.5	19.0	16.0	58.5		
6	400	16.25	13.25	6.5	64.0		21
6	300	4.0	10.7	7.3	78.0		
5	300	34.67	13.67	7.3	44.3		35.7
5	300	47.0	21.3	3.7	28.0		
4	300	24.0	19.7	5.0	51.3		
3	100	23	23	15	39		37.7
3	300	22.0	21.0	1.3	55.7		

← Top of Section

unit number	grains counted	% Garnet	% Zircon	% Tourmaline	% Opaque		Feldspar (% of lights)
3	300	34.0	28.7	4.0	33.3		42.3
2	100	52	23	8	17		0
1	300	7.7	24.3	7.3	60.7		42
1	0						
1	300	36.0	20.3	5.0	38.7		38.3
1	0						trace
1	300	29.3	26.0	3.6	41.0		60.7
1	300	26.0	15.7	6.0	52.3		
6' above contact	0						
Z	200	24.0	36.5	39.5	0		fine 13.3 coarse 0.0
Y	300	22.3	18.0	8.0	51.6		42
X	300	26.7	21.7	4.0	47.7		

Shawtown Fm. (units Z, Y, X)

BCM

from the bottom, rolled into shape, and dropped. The abundance of glauconite in many of these sandstones indicates the presence of abundant potassium in the oceans, some of which may have been incorporated into the clay minerals of the mud and is now responsible for the mud's stainability. It is very possible that the feldspar laths grew after the pellets were formed, for if they had crystallized earlier, it is unlikely that they would have maintained their long, prismatic shapes in all the tumbling that followed and caused the shaping of the balls.

Heavy minerals comprise considerably less than one percent of the Eau Claire Sandstone. The most prominent of the non-opaques are garnet, tourmaline, and zircon, with very few grains of hornblende. The tourmaline grains are well rounded as are the zircons. In most cases the garnets were extremely etched, a feature also found in the Galesville and Ironton and attributed in that formation (the Wonewoc of this paper) to solution by Andrews (1965, p.148). Dryden and Dryden (1946) attribute the etching to weathering at the surface in the source area. There seemed to be no noticeable concentration of certain heavy minerals in certain levels as might be useful for correlation purposes. If anything, the lack of heavies in certain zones might be useful. There also seemed to be a high feldspar and opaque content associated with a low content of tourmaline.

The opaque grains were largely glauconite, but hematite and probably magnetite were also present in considerable quantities. Opaques commonly accounted for the majority of heavy minerals

PALEONTOLOGY

The fauna of the Eau Claire Formation has been studied in detail by previous writers. Excellent summaries may be found in Twenhofel, Raasch, and Thwaites (1935, p.1694), in Lochman-Balk and Wilson (1958), and in Berg, Nelson, and Bell (1956, p.14).

Fossils in the Eau Claire are of three main types; trilobites, brachiopods, and "pteropods". The Eau Claire has been zoned with trilobites (see Raasch and Unfer, 1964, p.430). The two major faunal zones are the Cedaria Zone in the lower part, followed by the Crepicephalus Zone in the upper part. A third, the Aphelaspis Zone, had been added above the Crepicephalus Zone. Aphelaspis has been found in exposures at only two localities near Hudson, Wisconsin (Nelson, 1951, p.770). Lochman-Balk and Wilson (1958) however, point out that there is a major biostratigraphic break between the Crepicephalus Zone and the Aphelaspis Zone, and they conclude that this is a criterion for the upper boundary of the Dresbachian stage. If this is so, the Aphelaspis Zone should probably not be considered a part of the Eau Claire Formation.

The brachiopods are all of the phosphatic shelled, inarticulate type and are usually very abundant, particularly in the lower half of the Eau Claire Formation. The oboloid and linguloid shells are found in zones that are otherwise quite devoid of fauna. These brachiopods are the only fossils that are found within both the Eau Claire and Shawtown Formations, sometimes extending over forty feet below the base of the Eau Claire.

Another genus, Hyolithes, is abundant in certain beds of the Eau Claire Formation. Sometimes called "pteropods", these animals are commonly found in the same beds as those abundant in trilobite remains, although Hyolithes is also found without other genera.

All fossils are preserved as molds and casts of the living animal. The trilobites are always fragmental while the other genera are commonly found whole. As trilobites are believed to have molted much the same as the modern locust, and because their sutures were certainly lines of weakness in the shell, the broken up remains that are found in the Eau Claire do not necessarily represent a death assemblage that has been washed in from elsewhere. The molted shells were undoubtedly light enough to be moved by the slightest current. Perhaps as the exoskeletons accumulated on the bottom, they were concentrated in the slight depressions of the sea floor. This method of origin would also explain their present occurrance in lensoid pockets.

In addition to the molds and casts of Obolus, fossils of this brachiopod made up of original shell material are very common, and occasional shells with some original coloration have been found by the writer.

To one untrained in the specialty of trilobite paleontology the faunal zonation of the Eau Claire and any correlations dependent on such a zonation are quite impossible. The writer suspects that even with an adequate knowledge of that specialty, the scarcity of fossils and total lack of good specimens would render field and even laboratory work very difficult.

CONTACT RELATIONS

The relationship that the Eau Claire has with its neighboring units, the Shawtown and the Galesville, is perhaps best illustrated by a study of their contact relations with one another.

The massive, poorly sorted, coarse and medium grained sandstones of the Shawtown are found interbedded near the top of the formation with thin beds of fine grained sandstone identical to that found in the Eau Claire Formation. The invading fine grained beds become more numerous upwards in the section as the coarser sands decrease in quantity. The upper limit of the Shawtown is placed at the top of the last medium to coarse grained

Plate 4

Contact of the Galesville with thin-bedded Eau Claire showing basal conglomerate.
Galesville, Wisconsin

Plate 5

Picture from same locality as above showing the thin bedded nature of the Eau Claire just below the contact. Good conglomerate is found only where thin beds are so present. Contrast with plate 6.

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Contact of the Galesville with thin-bedded Eau Claire showing basal conglomerate.
Galesville, Wisconsin

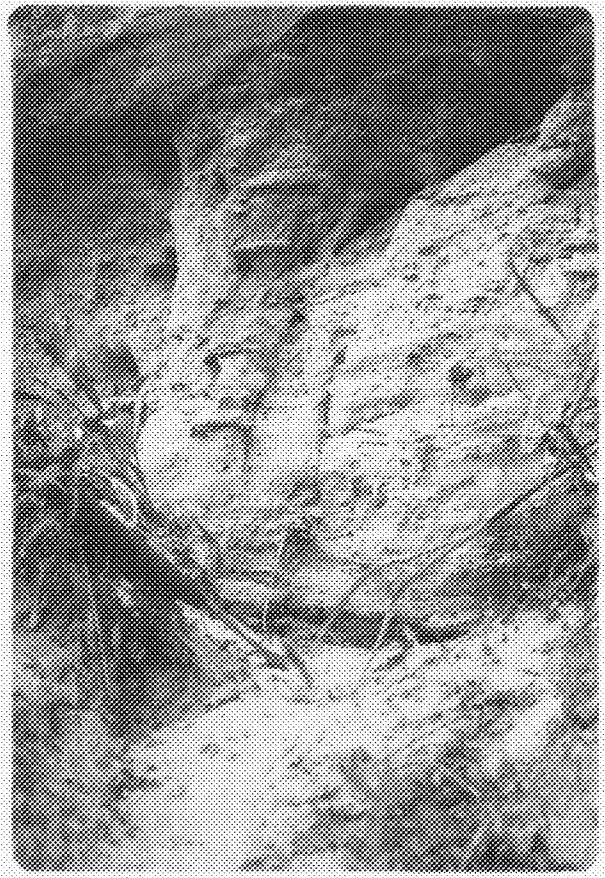

Plate 5

Picture from same locality as above showing the thin bedded nature of the Eau Claire just below the contact. Good conglomerate is found only where thin beds are so present. Contrast with plate 6.

sandstone bed to appear below the very shaly lower Eau Claire. That bed is usually about six inches to a foot in thickness, and although it may not be the very same bed at all localities, the "rusty foot" as so described is always present just below the base of the Eau Claire "shaly beds". The writer believes that this is a transitional change in environments from the Mt. Simon, through the Shawtown Formation, and into the Eau Claire Formation, and records a transgressing sea.

The uppermost beds of the Eau Claire are always fine grained and rich in glauconite. The Eau Claire Formation as a whole is quite rich in feldspar as is the Mt. Simon and Shawtown Formations. The Galesville is a fine to medium grained sandstone which is almost invariably thick or massive bedded. It is very clean compared to the Eau Claire and contains less than two per cent feldspar on the average (Emrich, 1962, p.47). Emrich has pointed out that the heavy minerals of the two formations do not very enough in any way to distinguish one from the other. At the top of the Eau Claire the break between the Eau Claire and the Galesville is always sharp and may be picked almost to the grain.

In some localities, notably where the "upper thin beds" are present immediately beneath the contact, a good basal conglomerate may be seen in the lower Galesville. The ripclasts and other evidences of erosion may be seen over a very broad area. Where the basal conglomerate is not present, relief on the Eau Claire surface and absence of the "upper thin beds" might be considered evidence for erosion. The best example of both the conglomerate and the relief may be seen at Galesville, Wisconsin (plates 4 and 5) where relief exceeds ten feet in less than one-hundred yards, and the "upper thin beds" present at one end of the exposure have been removed at the other end, presumably by erosion. Also, Twenhofel, Raasch, and Thwaites (1935, p.1695) point out that the upper faunal zone, the Crepicephalus Zone, is the first to disappear in a traverse from west to east up onto the Wisconsin dome.

CORRELATION

Rocks of the Eau Claire Formation are recognized in Michigan (Cohee, 1948), Minnesota (Stauffer and Thiel, 1941), Iowa (Steinhilber, et al, 1961), Indiana (Workman and Bell, 1948), and Illinois as well as Wisconsin. Howell (1944) has correlated the Eau Claire with the Reagan Sandstone of Oklahoma, the Nolichuky Shale, and Potsdam Formation of the Appalachians, the Weeks Formation of the Great Basin, and the Maurice Formation of the Rocky Mountains. To the near south in the Ozark region, the Eau Claire correlates with the Bonneterre Dolomite (Ulrich, 1911; and Workman and Bell, 1948).

CYCLIC NATURE OF THE DEPOSITIONAL ENVIRONMENT

The sandstone to shale to carbonate facies relationships have long been regarded as evidence of a transgressing marine environment. The possibility of general cyclicity in the Croixan rocks has also been investigated for many years, and most writers would agree that at least in the broadest sense of the term, there is a degree of cyclicity present.

Bell, Berg, and Nelson regarded the Mt. Simon as the transgressive beach facies, the Eau Claire as an offshore facies, and the overlying Galesville as the regressive beach facies, and postulated an unconformity at the top of the Galesville over which their Woodhill Member of the Franconia Formation transgressed starting a second cycle. This interpretation is concurrent with that of Twenhofel, Raasch, and Thwaites, at least in so far as to point out a "gradational" change of the Eau Claire upward into the Galesville and eastward into Mt. Simon - Galesville lithologies.

Ostrom (1964, 1966) concluded that, although the Mt. Simon was transgressive and that the Eau Claire had both a transgressive and regressive phase separated to the south by the Bonneterre Dolomite, there is an unconformity at the top of the Eau Claire, and the Galesville deposition initiated a second cycle.

This study has confirmed the presence of a widespread unconformity at the top of the Eau Claire as presented above (under "Contact Relations"). Rocks identical to those in the Eau Claire have been found in the Franconia (Berg, 1952; and Ostrom, 1964). Strong similarities in bedding style and mineralogy can also be seen. These rocks are invariably underlain by the worm-bored, widely variable lithologies as found in the Shawtown and Ironton Formations. Carbonates, the Bonneterre Formation and Black Earth Member of the Trempealeau Formation respectively, represent possible reef environments farther offshore and stratigraphically above the Eau Claire and Franconia in some places.

Although some may still question the exact beginnings and endings of each cycle, there can be no doubt that the Eau Claire Formation and the other Croixan formations represent seas that transgressed and regressed with some regularity.

PROVENANCE

The source of the sediments in the Eau Claire Formation is largely the

Precambrian crystalline complex to the north, hence the abundance of quartz and the heavy mineral suite present. The garnet content presents a problem as Emrich (p.181) points out. No good source rock has been found, even in southernmost Canada. Garnetiferous schists are found farther north in Canada.

Occasional grains of detrital microcline might have come from either the shield area or the Mt. Simon. The larger amounts of authigenic feldspars were introduced later, perhaps by the same fluids that etched the garnets.

SEDIMENTATION AND DEPOSITIONAL HISTORY

The Eau Claire Formation varies widely in reported thickness. As definite boundaries for the Eau Claire have never been agreed upon, the thickness at a given outcrop may range considerably depending on the author writing the article. Thwaites (1923) gives a minimum thickness of 70 feet near Rockford, Illinois and a maximum of 410 feet at St. Charles, Illinois from his subsurface data. Again from well data Buschbach increases the maximum figure to 575 feet in Kankakee County, Illinois. Generally speaking, the Eau Claire Formation is thinnest nearest the Wisconsin dome and thickens to the west and south as it becomes finer grained. Buschbach (1964) notes the gradual change from mostly sandstone in the north through a progressively shalier and more dolomitic formation to the south.

The relationship that the Eau Claire Formation has with the underlying and overlying units is open to debate. The basal contact picked by the writer was somewhat arbitrary, although the "rusty foot" does seem to turn up consistently wherever the base of the Eau Claire is seen. The beds of the Shawtown Formation alternate from coarse to fine grained with increasing numbers of the fine-grained variety upward. This seems to be a transitional phase from the predominantly coarse and medium grained Mt. Simon to the fine grained Eau Claire.

The upper contact of the Eau Claire with the Wonewoc has been called everything from conformable (Twenhofel, Raasch, and Thwaites, 1935) to unconformable (Ostrom, 1966). The writer believes that the rip-ups found wherever thin-bedded Eau Claire underlies the contact, the relief found along the contact, and the consistantly sharp break and change in lithologies are evidence for an unconformity. This evidence was present in all parts of the study area. In addition, the presence of a high feldspar content in the Eau Claire (35 percent average) while the Galesville has a very low percentage (1 - 2 percent average) indicates a break between the two.

Ulrich (1911) and Howell (1944) have correlated the Eau Claire with the Bonneterre Dolomite to the south, a tongue of which extends up into northern Illinois and southern-most Wisconsin. The Eau Claire seems to be an offshore facies of the Mt. Simon, at least in part. The writer believes that the upper parts of the Eau Claire are regressive. The Lombard Dolomite Member of the Eau Claire Formation in Illinois separates two sandstones there just as its correlative, the Bonneterre does to the south. It is not unreasonable to assume that the uppermost beds of the Eau Claire where they have not been removed by erosion are representative of a regressive phase.

A transgressing sea moved up onto the Wisconsin arch and dome depositing the Mt. Simon as a broad sheet of sand. The Shawtown was being deposited just offshore in very shallow water, while in a zone just beyond the Eau Claire was being deposited. Van Andel and Curray (1960) have pointed out an environment in the Gulf of Mexico that might be similar to that which was present during the deposition of the Eau Claire Formation. It is an environment that is seaward of the beach zone and receives its sediment from a number of directions depending on the currents' direction at a given time. Thus, the lithologies of succeeding beds may vary as they do with rapidity in the Eau Claire. The shallow water conditions that prevailed are attested to by the presence of ripple marks in the Eau Claire, especially near the top which might also indicate the shallowing of a regressive sea at that time. Into the depositional shelf environment, which must have had little in the way of fauna due to its ever-changing nature, broken-up assemblages of trilobites were brought and deposited. The more adaptable brachiopods might actually have lived there, but they too were probably brought in from elsewhere as is suggested by their concentrations and extremely comminuted nature in some beds.

Uplift on the Wisconsin arch or Wisconsin dome apparently caused a retreat of the seas at the end of Dresbachian time. Lochman-Balk and Wilson (1958, p.333) state that normal marine deposition stopped in this area near the end of the Dresbachian, and that there is a very distinct faunal break between the Crepicephalus and Aphelaspis zones separating two stages. This is indicative of an environmental change at that time.

It was during regression that the uppermost beds of the Eau Claire were laid down only to be removed for the most part by the erosion that followed. Readvancing seas brought the deposition of the Galesville Sandstone on the truncated edges of the Eau Claire. Although outcrops are rare, thinning of the Eau Claire northward and eastward onto the arch is suggested. At Galesville remnants of the "upper thin beds" remain, whereas to the north at Strum and Eau Claire they are absent. At Friendship Mound there is a bed less than a foot thick that is of Eau Claire lithology and rests between the Mt. Simon and Galesville Sandstones. At the Wisconsin Dells no Eau Claire was detected.

Plate 6

Typical contact of the Eau Claire Formation with the Galesville where the upper-most Eau Claire present is massive rather than thin bedded. Menomonie, Wisc.

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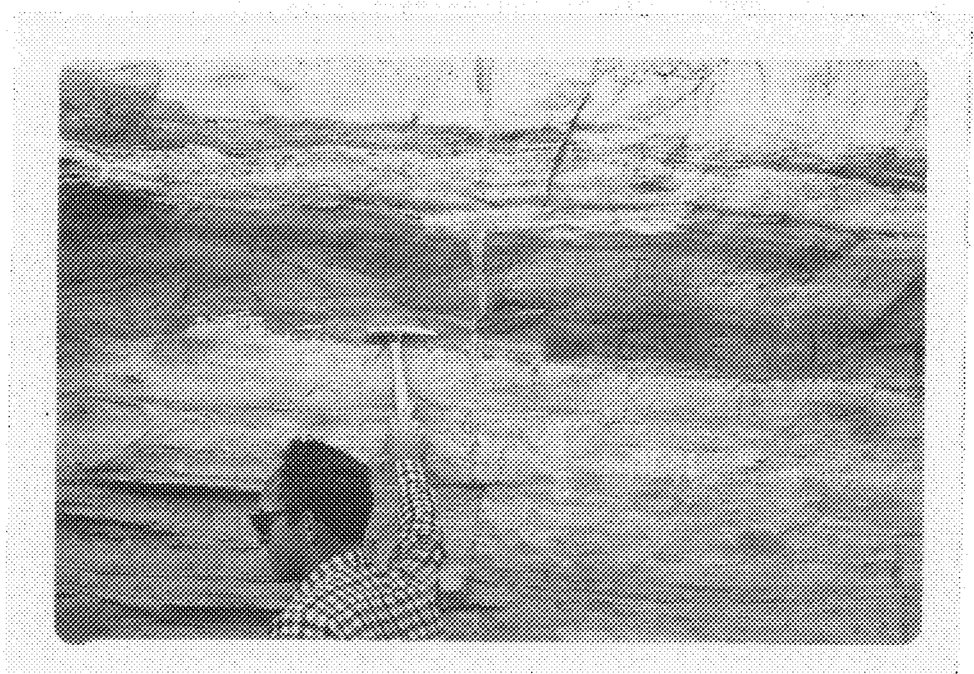

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