PROPOSED REFERENCE SECTIONS AND CORRELATION OF UPPER SILURIAN AND DEVONIAN STRATA, EASTERN WISCONSIN

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ABSTRACT

Three new rock cores are designated as reference sections for the Upper Silurian Waubakee and the Devonian Lake Church and Thiensville Formations. They were taken near each respective type section in Ozaukee County, each of which is now virtually obscured. Based on the cores, correlation to strata in Milwaukee County is now more certain. The type Waubakee, and strata assigned with some uncertainty to the Waubakee in Milwaukee County, have virtually identical stratigraphic sequences, namely an upward gradational change over several meters from the fossiliferous open-marine Racine Formation to a barren, laminated, tidal flat deposit. Therefore, the two deposits appear to be properly correlated.

The Lake Church Formation is absent in Milwaukee County where the Waubakee Formation is directly overlain by the Thiensville Formation. Strata assigned to the basal Thiensville in Milwaukee County contain lithologies generally dissimilar to previous descriptions of the type Thiensville, but the new cores are proof that the same lithologic sequence is also present at the Thiensville type section.

In Ozaukee County member subdivisions previously established within the Lake Church Formation were poorly defined and are unrecognizable within the new reference section core, taken less than a kilometer from the type section. Therefore, the member subdivisions are abandoned.

INTRODUCTION

The western-most Upper Silurian and Devonian strata of the Michigan basin are present along a narrow band parallel to the Lake Michigan Shoreline in Milwaukee and Ozaukee Counties, Wisconsin (figs. 1, 2). However, these strata are largely covered with glacial drift, and the few existing quarry and natural exposures are not sufficient for detailed stratigraphic analysis. Recently, the Milwaukee Metropolitan Sewerage District (MMSD) constructed over 50 km of deep tunnels to store and convey overflows from combined sewers. For their geotechnical data base over 100 rock cores were taken within or through the Silurian/Devonian strata.

Data from the cores are sufficient to interpret depositional environments and confirm general stratigraphic relationships for the Upper Silurian and Devonian formations in Milwaukee County (Mikulic and Kluessendorf, 1988; Kluessendorf and others, 1988), but additional questions were raised concerning correlation to their type areas in Ozaukee County (fig. 1). Specifically, the MMSD cores contain strata assigned to the Thiensville Formation (MMSD, 1981; fig. 2) which were not previously described at the type section or in any other exposure. They do, however, contain limited strata with a lithology and fauna similar to a distinctive part of the upper (type) Lake Church Formation. The general Lake Church lithology, however, is absent in the cores, raising the possibility that a complex facies relationship exists between the two formations.

The final question pertains to strata assigned to the Waubakee Formation. Although the strata are lithologically similar to the type-Waubakee, they pinch out in northern Milwaukee County (fig. 3). Hence, the two rock bodies are not continuous, raising the question of whether they are truly correlative or not.

These questions could not be addressed with existing data. Not only are the type sections of all three formations largely or totally obscured, but a complete published description, including upper and lower contacts, did not exist for any specific location, including the type sections. Therefore, cores were taken through the Upper Silurian/Devonian as close as possible to each type section to address these questions and serve as permanent reference sections.

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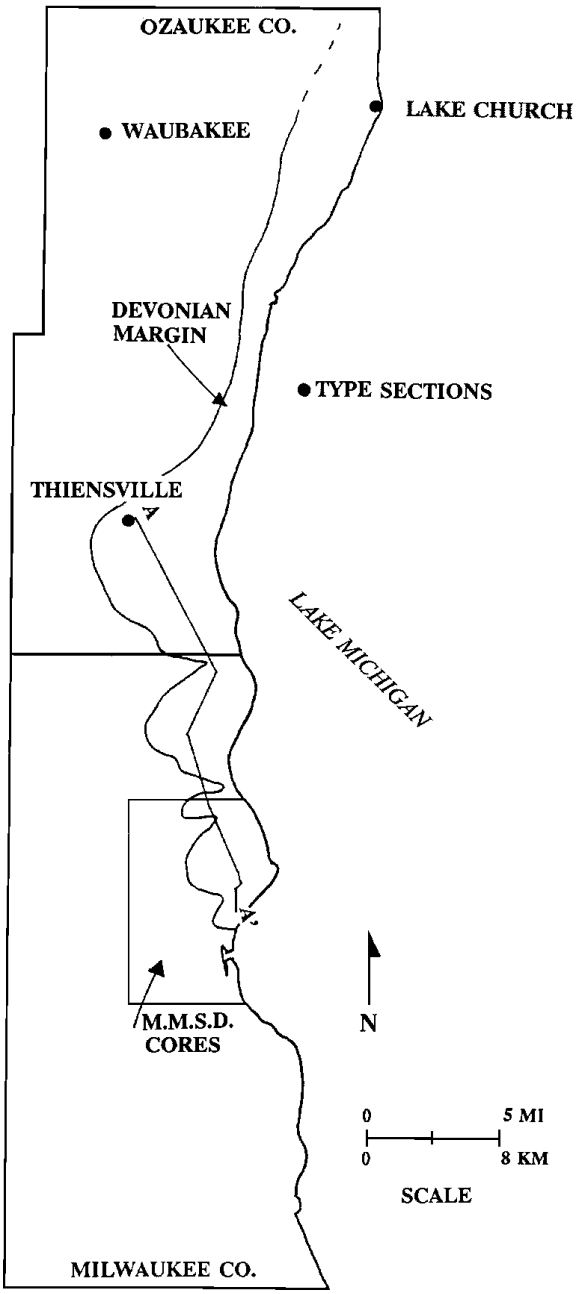

Figure 1. *Location map, southeastern Wisconsin. Devonian margin taken from Rovey (1990).*

HISTORY AND TYPE SECTION DESCRIPTIONS

Waubakee Formation

The Lake Church and Thiensville Formations were once included within the Waubakee Formation. Chamberlin (1883) first described a laminated dolomite in Milwaukee County between (today's) Racine and Milwaukee Formations. He described the lower part (today's Waubakee) as thin-bedded, hard, brittle, light gray and laminated. Elsewhere in Milwaukee County he described a variably-bedded, brown, porous, laminated dolomite (Thiensville) directly below the Milwaukee Formation, but he considered the different beds parts of the same unit.

Chamberlin (1877, 1883) also described two small quarries on opposite banks of the Milwaukee River approximately 1.5 km west of the Village of Waubeka and correlated those rocks to the exposures in Milwaukee County based on lithologic similarity. Alden (1906) later introduced the name Waubakee for the entire sequence, designating the northern quarry at Waubeka as the type section. Today, no trace of the north quarry remains, but the nearby south quarry still exposes 2 m of rock.

The sequence was subdivided into the current formations by Raasch (1935). He restricted the term Waubakee to the lower gray dolomite by placing the upper brown beds into the Thiensville Formation. He

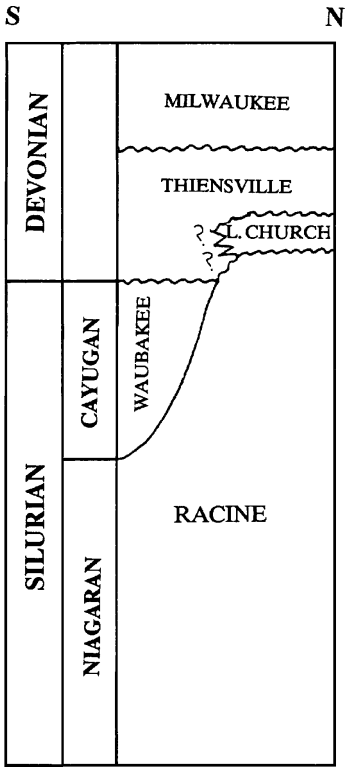

Figure 2. *Upper Silurian and Devonian stratigraphy, southeastern Wisconsin. Lithostratigraphic names are at the formation level.*

also designated fossiliferous strata between the Thiensville and Waubakee as the Lake Church Formation.

Lake Church Formation

Currently there are only two known exposures of the Lake Church Formation; both are in quarries now mostly flooded. Several meters of the upper type section are exposed in Harrington Beach State Park. The second exposure is the upper meter of an abandoned quarry approximately 240 m west of the Thiensville type section (fig. 1). Raasch (1935) stated that the Lake Church disappears south of the Milwaukee/Ozaukee County line, but the reasons for the disappearance are not clear.

Belgium Member

Raasch (1935) subdivided the Lake Church into two members and described the lower Belgium Member as being present only in the extreme north, presumably meaning the extreme north of Ozaukee County. By inference a basal conglomerate above the Silurian/Devonian contact is included in the Belgium Member, but his wording is ambiguous; it could also mean the strata immediately above and exclusive of the conglomerate.

He described the Belgium Member as thin-bedded "chocolate brown" dolomite. The brachiopod *Chonetes* dominates the fauna, with common bivalves and other brachiopods. He did not describe an upper contact.

Ozaukee Member

Raasch (1935) described the Ozaukee Member of the Lake Church Formation as thick-bedded, brown to dark gray, pyrite-rich dolomite. The fauna is more limited than the Belgium Member, but locally includes coral, bivalves, high-spired gastropods, and crinoids. Specific genus and species names were not given, however. He placed the upper Ozaukee contact at an erosional unconformity and conglomerate at the base of the overlying Thiensville Formation. However, the contact was not exposed at the type section, nor were any specific locations described.

Thiensville Formation

Raasch (1935) designated a road cut along Highway 57 in Thiensville as the Thiensville type section. The cut remained partially exposed until 1989 when it was covered with fill. Currently there are only two additional known exposures of the Thiensville. Several meters of the upper Thiensville are exposed along the Milwaukee River in Estabrook Park at Shorewood, and less than 1 m of (apparently) basal Thiensville is periodically exposed along the Lake Michigan shoreline approximately 2 km south of Port Washington.

Raasch (1935) characterized the Thiensville as variably-bedded with a succession of lithologies. Beds of brown, bituminous, porous, laminated dolomite alternate with lighter-colored, less-porous beds. He found only a limited fauna, and that from beds described as being near the bottom of the formation. A fossiliferous bed was formerly exposed along the base of the roadcut, but there is an approximate 6-m gap in exposure between the base of the cut and the top of the adjacent quarry where the Lake Church Formation is present. Therefore, it is difficult to judge whether or not the fossiliferous beds are actually at the base of the formation, since the lower contact was never exposed, nor reported from any other locality.

Based on the discussion above, the stratigraphic units in question are vaguely defined and characterized, and the type section designations do not meet the modern requirements of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). There is an obvious need to re-visit the type sections and establish permanent reference sections to characterize each formation.

MILWAUKEE METROPOLITAN SEWERAGE DISTRICT CORES

Waubakee Formation

Strata assigned to the Waubakee Formation in the MMSD cores are approximately 25 m thick and are hard, brittle, well-laminated dolomite mudstone with a distinct petroliferous odor when broken. Laminae range from less than 1 mm to approximately 1 cm in thickness and alternate between dark and light gray. They are parallel to sub-parallel, sometimes wavy, and sometimes discontinuous. Rarely, the laminae are crenulated with a minute fenestrate porosity, and mudcracks and gypsum pseudomorphs are present at multiple horizons. The lower contact generally is gradational over 1.5 to 3 m with the Racine Formation, but Racine reefs, where present, may protrude into or through the Waubakee (fig. 3).

The upper Waubakee contact is sharp and erosional, as proven by reworked Waubakee clasts in the basal Thiensville. The upper 1 m interval directly beneath the basal Thiensville contact is typically discolored to a very dark gray. Locally, however, a weathering profile originating in the overlying

Thiensville extends into the upper Waubakee, obscuring the contact.

In Ozaukee County, the Waubakee has never been found outside the type area. Even where the younger Lake Church Formation is preserved, the Racine Formation, not Waubakee, is present directly beneath the Lake Church (Mikulic, 1979). Based on figure 3, the Waubakee in Milwaukee County abuts a thickened wedge of Racine Formation and, therefore, was probably never continuous with the type Waubakee. Whether the two were deposited contemporaneously, however, remains unanswered.

Thiensville Formation

In Milwaukee County, strata assigned to the Thiensville Formation are divisible into three informal subunits (fig. 4).

Lower unit

The lower unit is 6 to 7.5 m thick. Core recovery was poor within this interval because it is soft and highly weathered. The dominant lithology is a semi-consolidated dolomitic mud containing irregularly-shaped nodules and clasts of chalky dolomite. In some cores the entire interval appears relatively uniform, but in others two to three specific horizons of more intense weathering are detectable. Where the beds are relatively unweathered, they appear to be brown, granular, laminated dolomite.

This lithology was not previously reported within the Thiensville Formation. It was included because of the similarity with the upper Thiensville and the obvious lithologic contrast and erosional unconformity between it and the underlying Waubakee.

Middle unit

The middle unit is approximately 3 m thick. The lowermost lithology is brown, fine-grained, granular, friable, parallel-laminated dolomite. At the top of this interval a distinct marker bed 1 m or less thick is delineated by abundant bivalves, gastropods and silt-size quartz grains. This bed grades upward into a dark brown, highly-organic dolomite containing zones of interlaced carbonaceous laminae and thin (1 to 3 cm) interbeds of nearly black, extremely carbonaceous material.

The lithology of the middle unit also was not specifically described for the Thiensville, but may correlate to the base of the type section exposure, based on the common occurrence of fossiliferous beds, which elsewhere are extremely rare in the Thiensville. Alternatively, Mikulic and Kluessendorf (1988) and Kluessendorf and others (1988) noted the resemblance between these beds and the upper fossiliferous beds at the Lake Church type section, raising the possibility that the lower "Thiensville," as mapped in Milwaukee County, actually correlates in some manner to the Lake Church Formation. Unfortunately, specific

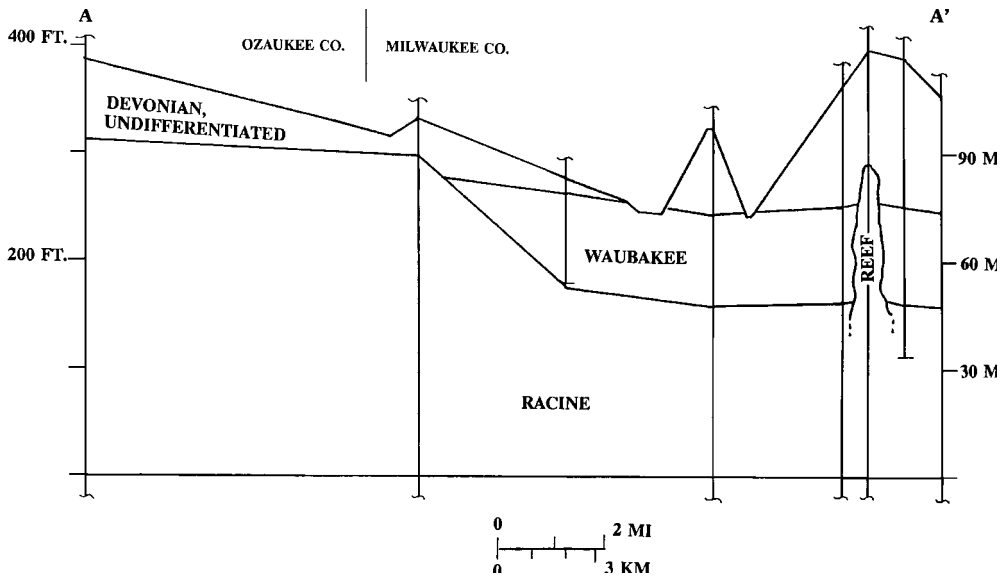

Figure 3. *Geologic cross section A-A'. Modified from Rovey (1990). Line A-A' is shown on figure 1.*

paleontologic data relevant to the problem are still lacking.

Upper unit

Only the upper Thiensville definitely corresponds to previous descriptions in Ozaukee County. It is generally 9 to 11 m thick and is strikingly rhythmic, consisting of brown, porous, laminated beds alternating with gray, dense, unlaminated beds. The gray beds are locally vuggy and commonly brecciated. The transition between the two lithologies is frequently an erosive, scoured contact, particularly at the top of brown intervals, and the bottom few centimeters of overlying gray beds may contain reworked clasts from the brown beds below.

Rhythmic bedding is less developed in the lowest 3 m, marking a transition to increasing dominance of weathering effects which increasingly obscure the original lithology.

The upper Thiensville contact was observed *in situ* in a dropshaft being blasted into an MMSD tunnel (see Rovey, 1990). It is marked by iron sulfide mineralization along an undulatory surface with approximately 15 cm of local relief. Large clasts (up to 0.5 m in diameter) of Thiensville are reworked into the base of the overlying Milwaukee Formation.

NEW CORES

Relevant parts of three new rock cores are described below. All are now stored at the Wisconsin Geological and Natural History Survey (WGNHS) core repository. The first core, UWM-WB is assigned the WGNHS identification number CJ-294-OZ-521-X. It was taken approximately 1000 m southwest of the Waubakee type section at the small quarry on the south bank of the Milwaukee River, approximately 1.5 km west of the Village of Waubeka (SW 1/4, NW 1/4, SE 1/4, S. 29, T 12N, R 21E, Fredonia 7.5 Minute Quadrangle). It is designated as a supplementary reference section for the Waubakee Formation.

The second core, UWM-LC (identification number CJ-295-OZ-522-X) was taken in the parking lot of the boat ramp at the dead end intersection of Ozaukee County Highway D with Lake Michigan (NW 1/4, NE 1/4, NW 1/4, S. 19, T 12N, R 23E, Port Washington East 7.5 Minute Quadrangle). This location is approximately 640 m north of Quarry Lake in Harrington Beach State Park, the Lake Church type section. The core is designated as part of the composite Lake Church primary reference section.

The third core, UWM-FF (identification number CJ-296-OZ-523-X) was taken in the truck turn-around area northwest of the loading docks at the Federal Foods plant, Thiensville, Wisconsin (NW 1/4, NE 1,4, SE 1,4, S. 10, T 9N, R 21E, Cedarburg 7.5 Minute Quadrangle). This location is approximately 300 m east of the Thiensville type section. The core is designated as a primary reference section for the Thiensville, and part of the composite reference section for the Lake Church.

Waubakee Formation

Because the Waubakee in Milwaukee County is not continuous to the type area, it may be impossible to prove beyond doubt that the two occurrences are strictly correlative. However, if most diagnostic features are common to both sites, confidence in the traditional correlation is increased. The core at Waubeka was, therefore, taken to determine whether the type Waubakee is similar in stratigraphic sequence with underlying strata, whether it is lithologically similar over its entire thickness and whether the bottom con-

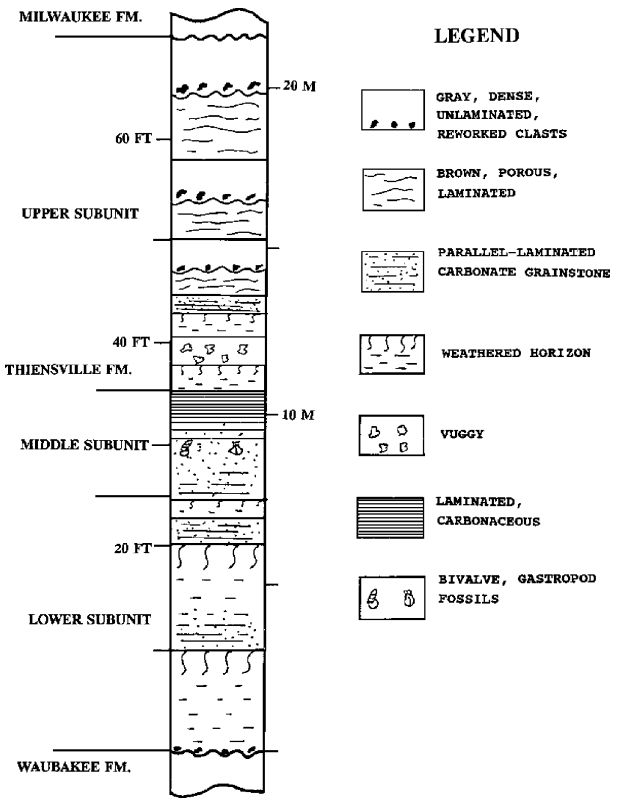

Figure 4. *Generalized stratigraphic sequence with the Thiensville Formation, Milwaukee County. All lithologies are dolomite.*

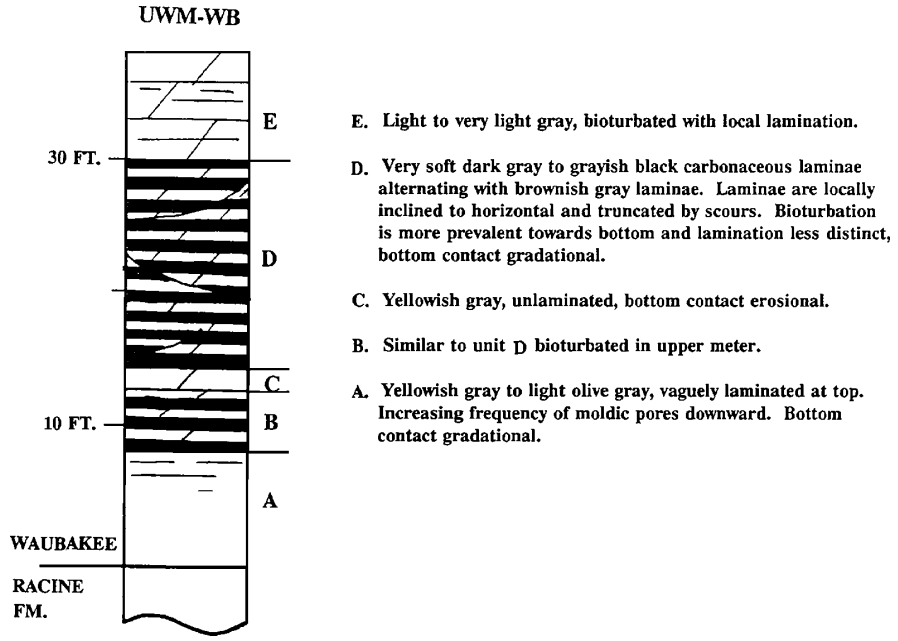

Figure 5. *Graphic log and description of Waubakee reference section, core UWM-WB. All lithologies are dolomite.*

tact is also gradational.

Figure 5 is a graphic log and description of relevant portions of core UWM-WB. The upper beds, still exposed in the adjacent quarry, can be confidently correlated to the former type exposure, based on both Chamberlin's (1877, 1883) and Alden's (1906) descriptions. The core, however, begins at the quarry floor, and consists of lithologies not specifically described at the type section. Therefore, it is not designated as a primary reference section for the Waubakee Formation, but as a secondary or supplementary reference section to fulfill criteria stated in the stratigraphic code (North American Committee on Stratigraphic Nomenclature, 1983, p. 853): "To illustrate the diversity or heterogeneity of a defined unit or some critical feature not evident or exposed in the stratotype."

The upper 1.5 m (exposed in the quarry) is virtually identical lithologically with the Waubakee in Milwaukee County, so the description is not repeated. The underlying strata (recovered from the core), however, vary significantly. As in Milwaukee County the contact between the upper Racine and the lower Waubakee is gradational over 2.5 m from massive fossiliferous to laminated barren dolomite. However, at Waubeka the lamination in the lower beds is distinct from that in Milwaukee County. Instead of hard, brittle, gray and dark gray laminae, the lithology is very dark and organic-rich, with alternating soft, carbonaceous and brownish-gray laminae. At Waubeka numerous laminae are also inclined to the horizontal and truncated by scour surfaces.

Although neither Chamberlin (1877, 1883) nor Alden (1906) described the carbonaceous beds at the actual type section, Chamberlin (1883, p.197) included them within the same unit and described them from nearby exposures as: "a softer dark dolomite, colored by carbonaceous matter, sometimes disposed in frequent black, or dark brown laminae, which give to the rock an appearance quite peculiar." His description leaves little doubt that these lower beds are properly considered part of the type Waubakee Formation.

The similar stratigraphic sequences in the two locations is evidence supporting use of the term "Waubakee" for strata in Milwaukee County. At Waubeka the fossiliferous upper Racine Formation grades over approximately 2.5 m into the Waubakee, similar to the transition in Milwaukee County. Although carbonaceous laminae are not present in the MMSD cores, the predominance of lamination at both sites is evidence that the gradational contact marks a major episode of increased restriction, from open marine to tidal-flat conditions. Because such a drastic restriction is only known at one stratigraphic position in the Upper Silurian of the Michigan basin (Niagaran

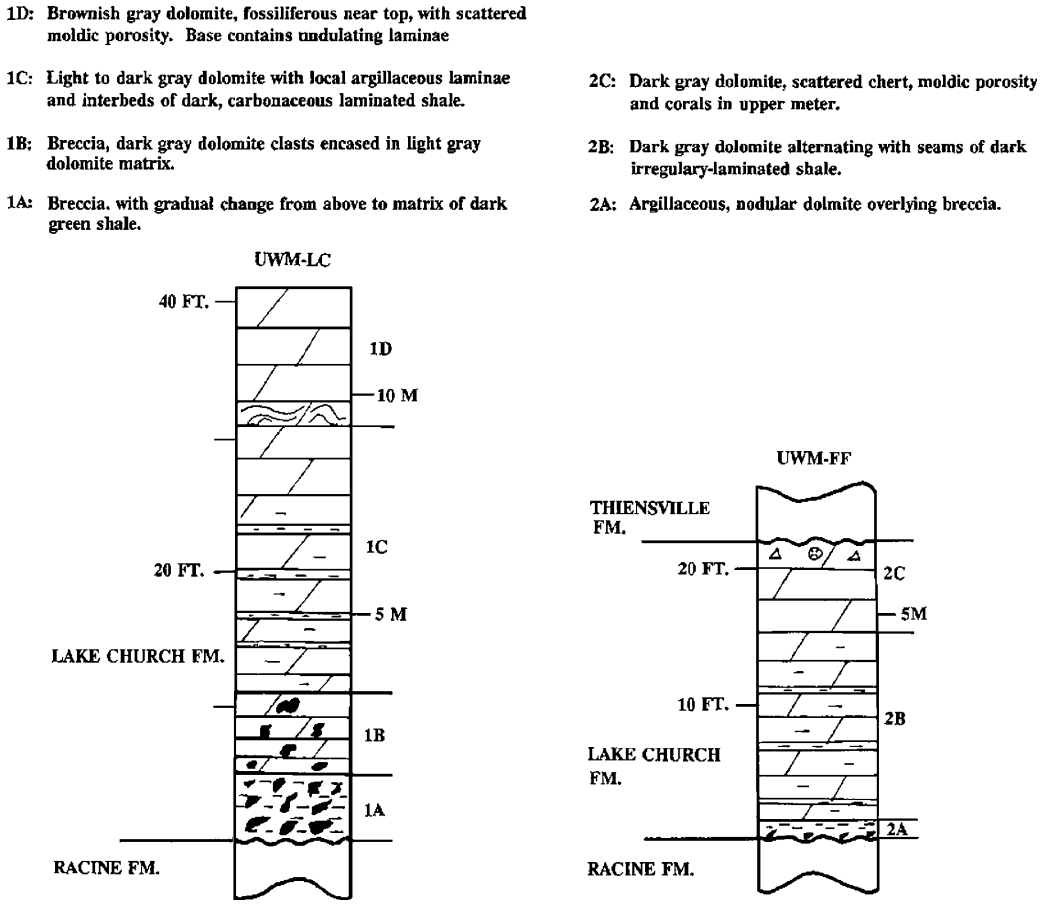

Figure 6. *Graphic log and description of composite Lake Church reference section, cores UWM-LC and UWM-FF. All lithologies are dolomite.*

to Cayugan transition, fig. 2), the two deposits appear generally synchronous, although paleontologic evidence is lacking.

Lake Church Formation

Figure 6 is a graphic log and description of relevant portions of cores UWM-LC and UWM-FF. Both cores are designated as a composite (primary) reference section for the Lake Church Formation, to include both upper and lower contacts.

In UWM-LC the most striking feature is the breccia in the lowest 4 m of the Devonian. The beds correspond to the basal conglomerate described by Raasch (1935), but, as mentioned, his description was unclear as to whether they should be included in the Belgium Member. The strata above the conglomerate are generally dark gray argillaceous dolomite mudstone containing pyrite and a limited fauna. They match Raasch's description for the Ozaukee Member and have none of the characteristics of the Belgium Member. Therefore, the member subdivisions cannot be recognized in the reference section.

Besides the problem of member recognition, there is currently a conflict in nomenclature as well. The lowest member of the Quaternary-age Kewaunee Formation was recently designated as the Ozaukee Member (Mickelson and others, 1984) in the same geographic area and locally may directly overlie the Devonian-age Ozaukee Member. Although the latter usage conflicts with the priority of the original, it has become entrenched and far more widespread. Considering that the Devonian members are vaguely defined, and that the distinction between members cannot be recognized less than one kilometer from the type section, the best solution is to abandon member subdivisions within the Lake Church Formation.

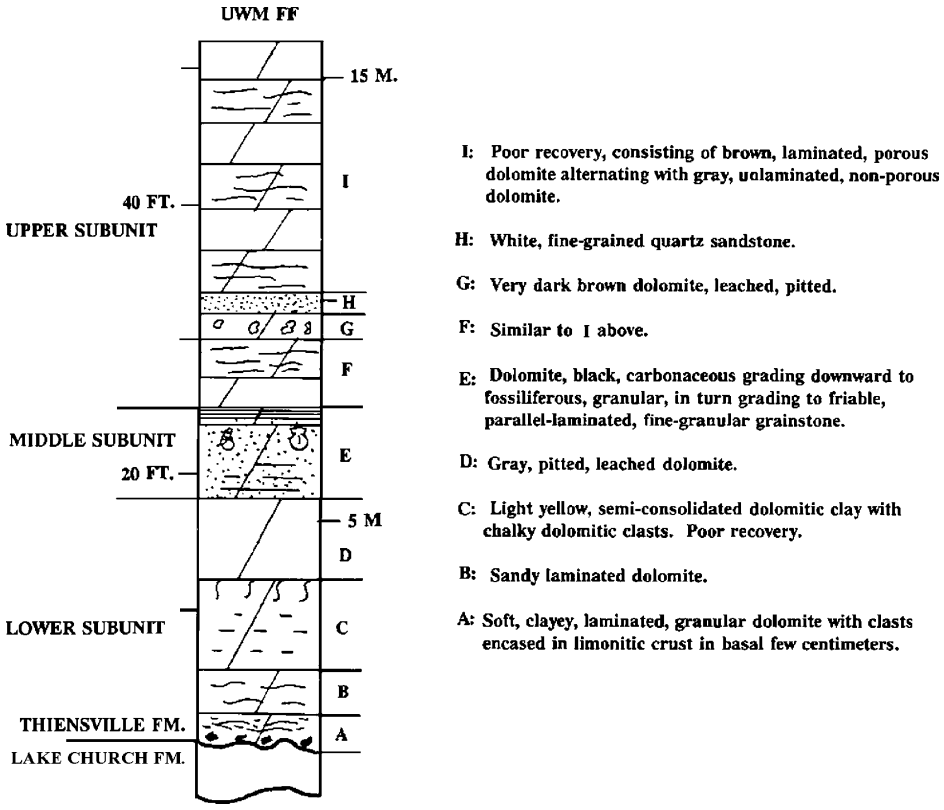

Figure 7. *Graphic log and description of Thiensville reference section, core UWM-FF.*

Thiensville Formation

Figure 7 is a graphic log and description of relevant portions from core UWM-FF, designated as a primary reference section for the Thiensville Formation, and part of the composite Lake Church reference section. Although core recovery was poor, enough detail is present to divide the Thiensville into three main units, correlative to the three subunits in Milwaukee County.

The lowest Thiensville is a highly-weathered, poorly-consolidated, clay-rich interval overlying a conglomeritic erosional base. The middle division has a brown, finely-laminated, fine-granular lithology grading upward through a highly fossiliferous intermediate into a dark brown to black carbonaceous bed. The upper Thiensville is dominantly a coarse-grained, brown, porous, laminated lithology alternating with a denser, unlaminated, gray lithology. The upper Thiensville contact unfortunately is not present.

The lower subunit is problematic, because its elevation is below road level, but above the top of the adjacent quarry which exposes Lake Church strata. Therefore, it was not exposed along the roadcut and not originally defined as part of either the Thiensville or the Lake Church. The lithology, however, is clearly similar to the overlying Thiensville and contrasts strongly with the underlying Lake Church. The unconformable contact at the base of the subunit also marks an abrupt break in sedimentation and change in sediment character. Therefore, these beds are now designated as part of the Thiensville.

The organic-rich bed in the middle unit is greatly reduced in thickness from the MMSD cores and probably was not exposed during Raasch's visits, but the underlying fossiliferous bed apparently is the bottom fossiliferous zone; its elevation in the core is the same as the base of the cut. The upper subunit corresponds to the general type section description by Raasch (1935).

Is the question of Thiensville - Lake Church equivalency settled? The answer can only be given conditionally. It is now clear that the middle and lower Thiensville subunits from the MMSD cores are present at the Thiensville type section *and* that they are properly part of the type Thiensville. However, this does not preclude the possibility of a facies relationship between the type Thiensville and Lake Church, unless the upper fossiliferous beds at the

Lake Church type section correlate exactly with the (somewhat fossiliferous) Lake Church beds beneath the type Thiensville. Future research should address this issue of correlation between the two type sites.

SUMMARY AND CONCLUSIONS

The Upper Silurian Waubakee and Devonian Lake Church and Thiensville Formations were vaguely defined and characterized at their respective type areas in Ozaukee County. Lack of information on lithologic variation, internal subdivision and bounding contacts, caused uncertainty regarding correlation to their possibly - equivalent units in Milwaukee County. Data from new rock cores near the type sections are defined as reference sections for each respective formation, and clarify much of the previous uncertainty, generally confirming previous correlations.

Although the type Waubakee includes 9 m of highly carbonaceous basal strata not present in Milwaukee County, a similar stratigraphic sequence in both cases is evidence supporting correlation. Both deposits grade upward over several meters from the fossiliferous Racine Formation into a barren, laminated, deposit. The transition, therefore, marks an upward change from open, normal marine to shallow, restricted, tidal flat sedimentation. Because such a drastic restriction is known only at the Niagaran/Cayugan transition for Michigan basin strata, the two deposits appear generally correlative.

The Lake Church Formation is not present in Milwaukee County. Reasons for its disappearance are not yet clear, however. Formal member subdivisions within the Lake Church are unrecognizable in the new reference section, and are, therefore, abandoned.

Three informal lithologic subdivisions within the Thiensville Formation are present at both the type area and in Milwaukee County. Research on these subdivisions should continue to determine if their elevation to formal member status is warranted. Because of their common occurrence, fossiliferous strata near the middle of the Thiensville in Milwaukee County are properly assigned to the Thiensville Formation in spite of lithologic and faunal similarity with portions of the type Lake Church. However, the possibility of a facies relationship between the fossiliferous beds, also present at the type section, and the type Lake Church cannot be ruled out without further research.

ACKNOWLEDGMENTS

This research was funded by the University of Wisconsin Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and from the State of Wisconsin Federal Grant NA 90AA-D-SG469, project R/NI-14.

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