The Southern Limit of Red Till Deposition in Eastern Wisconsin

Charles W. Rovey II[1] *and Mark K. Borucki*[2]

ABSTRACT

Accelerated bluff erosion along Lake Michigan's Wisconsin shoreline exposed several features not previously noted at the St. Francis Power Plant exposure south of Milwaukee. Reddish rhythmites in the upper bluff grade northward into a massive red diamicton over a distance of 90 m. Based on stratigraphic sequence, lithologic similarity and re-mapping of the Ozaukee terminal moraine, the red diamicton is correlated with the Ozaukee Member of the Kewaunee Formation, the oldest of Wisconsin's red till units.

The absence of Ozaukee till south of this exposure proves that it is the southern limit of Wisconsin's red till. The gradation from till to rhythmites suggests that the terminal ice front was in standing water of glacial Lake Chicago.

INTRODUCTION

The record of Pleistocene glaciation exposed in the Lake Michigan bluffs at and around the St. Francis Power Plant exposure (named for the now largely-demolished Wisconsin Electric Power Plant and called the St. Francis exposure here, fig. 1) has intrigued geologists for years. The bluff profile south of the plant was described by Mickelson and others (1977), Lasca (1983), Christensen and Schneider (1983), Schneider and Need (1985) and Monaghan (1990) and was visited during the 1983 Northeast Section Geological Society of America meeting. The general stratigraphic sequence described in these reports is till of the New Berlin Formation at the base of the bluff overlain successively by lake sediment, water-laid diamicton and till of the Oak Creek Formation (fig. 2). A boulder lag progressively truncates the Oak Creek Formation and defines the base of a channel which was successively infilled by sandy sediment and then reddish rhythmites deposited in Glacial Lake Chicago. The bluff is planed by a wave-cut terrace slightly below the Glenwood (195 m) level of Lake Chicago.

These deposits represent significant events in the Late Woodfordian deglaciation history of the Lake Michigan basin (Hansel and others, 1985). After deposition of the New Berlin Formation during the later Cary ice advances, the basin was intermittently free of ice and occupied by a series of glacial lakes. The Oak Creek Formation was deposited during the latest Carry advances which successively left the prominent Valparaiso, Tinley and Lake Border morainic systems around the southern half of Lake Michigan. During retreat, phases of Glacial Lake Chicago formed at the Glenwood stage in the southern portion of the basin and expanded northward as the ice retreated

The site is notable for two reasons: it is the southernmost bluff exposure of the New Berlin Formation, and lake sediment overlying the New Berlin Formation as instrumental in recognizing and defining proglacial Lake Milwaukee as a separate predecessor to proglacial Lake Chicago (Schneider and Need, 1985). The stratigraphic record at the St. Francis exposure is more complete and important than previous authors thought. The importance was recognized during this investigation primarily because (1) the record-high lake levels of 1987 accelerated erosion and produced a fresh, uncovered bluff face, and (2) a stabilization project initiated by the City of St. Francis to combat that erosion progressively covered the entire bluff exposure from base to top with fill. Because the fill was emplaced in terraces, detailed inspection of the upper bluff was facilitated during the final stages of the project. The fill now completely covers the exposure, making further observations impossible without large-scale excavation.

[1] Geoscience Department, Southwest Missouri State University, 901 S. National Ave., Springfield, MO 65805

[2] Layne Geosciences, Inc, N. 4140 Duplainville Road, Pewaukee, WI 53072

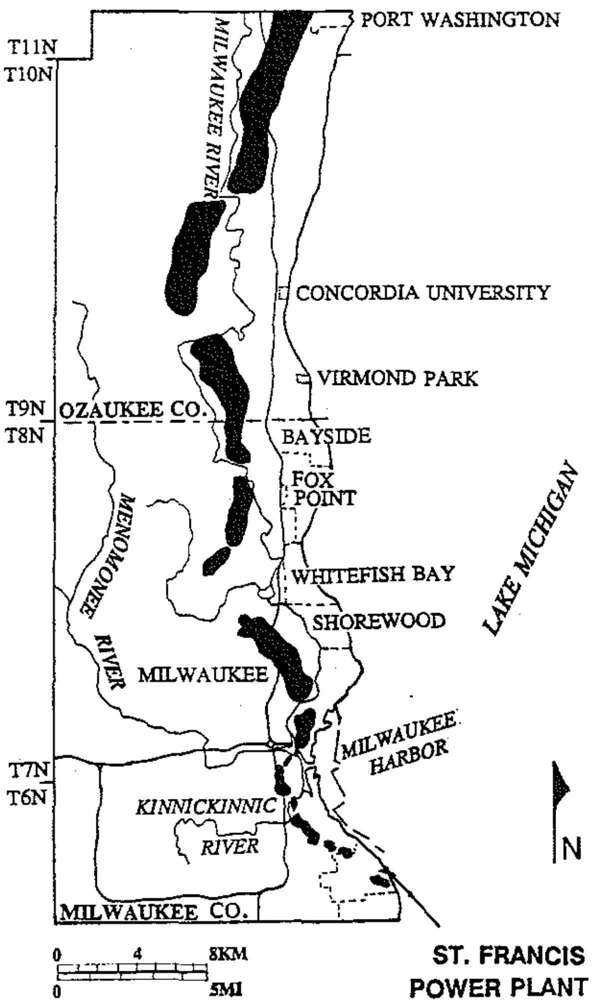

Figure 1. Location map, southeast Wisconsin. Darkened areas show the Ozaukee terminal moraine, as mapped in this study. Ridges in the Menomonee and Kinnickinnic River valleys are from Need (1983).

NEW DESCRIPTION

Boulder Lag

Several features not previously mentioned were noted during this study. There is not a single boulder lag, but two, defining two superposed erosion surfaces (fig. 3). The lower surface slopes gently to the south, and is present between the water-laid diamicton of the basal Oak Creek Formation and the overlying Oak Creek till. The middle part of the diamicton has a silty clay matrix and resembles till in many respects, but is crudely stratified, suggesting deposition of sedimentation in standing water instead of direct deposition from ice. The diamicton overlies the cobbly New Berlin Formation and grades into laminated silt and sand at both contacts. Thus, the diamicton unit as used here includes the lake sediment which Schneider and Need (1985) proposed as evidence for Glacial Lake Milwaukee.

The upper lag defines the previously described channel, originating between the Oak Creek till (above the lower lag) and a separate overlying massive, reddish diamicton, not previously reported. The upper lag drops steeply to the top of the New Berlin Formation where it merges with the lower lag. At the north end of the exposure the upper lag is not as pronounced, and up to 0.3 m of bedded sand (not depicted in fig. 3) are locally present between the Oak Creek Formation and the red diamicton.

Channel Sand

The lower sandy sediment confined within the channel consists of alternating cross bedded and rippled sets. The occurrence is unusual and possibly diagnostic because it is the only bluff exposure of such an infilled channel known from south of Port Washington (Mickelson and others, 1977; Rovey and Borucki, 1995). It is similar geometrically and sedimentologically to channels and infilled sediment described by Rust (1976), who interpreted them as sub-aqueous channels cut by streams emanating from the margin of a nearby grounded ice mass into a proglacial lake. If such an interpretation is correct for the channel at St. Francis, it was cut and partially filled while a glacial ice front was within several hundred meters of the exposure.

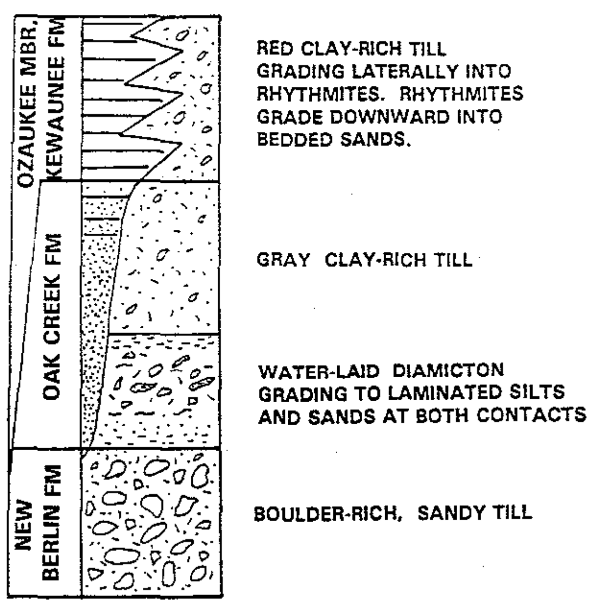

Figure 2. Late Woodfordian stratigraphy at the St. Francis Power Plant exposure.

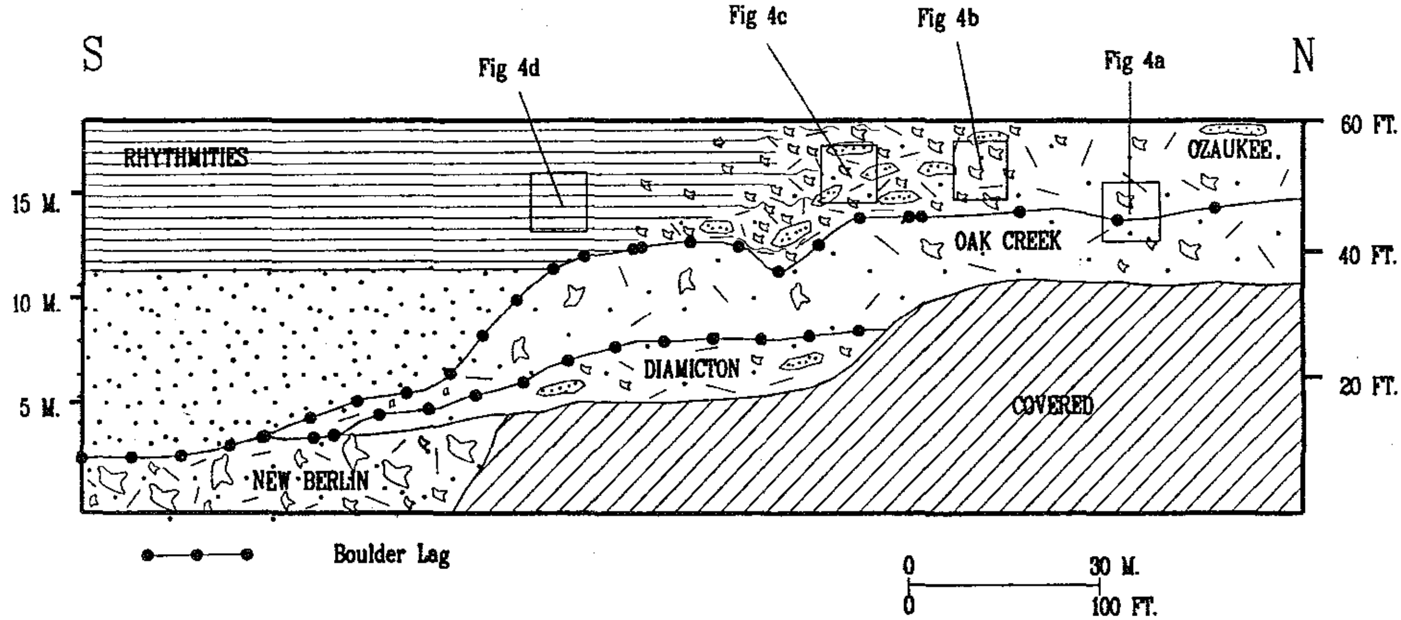

Figure 3. Schematic section of stratigraphic relationships formerly exposed at the St. Francis Power Plant Site. See Figure 2 for a description of the units and formal stratigraphy.

The channel sand grades upward into rhythmite. Within the upper meter of the sand are two thin (approximately 8 cm) layers of sandy red clay. These layers contain evidence of deposition from density currents, including scoured, erosional bases and normally graded bedding with a rippled sandy base grading upward to laminated clay. The clay is similar to that comprising the fine-grained part of each couplet in the overlying rhythmites. The color of the clay is distinct, and throughout the Lake Michigan basin it marks the initial appearance of a new sediment source generally associated with the Port Huron ice advances (Hansel and others, 1985). Apparently a connection was established between the Lake Michigan and Superior basins during the Cary-Port Huron retreat, and red clay from the Lake Superior region was transported and deposited in the Lake Michigan basin. Subsequent ice advances entrained the red clay, accounting for the distinct color of the Port Huron and Greatlakean red till.

Because density flows in glacial sediments are particularly diagnostic of a nearby ice margin in contact with a proglacial lake (Ashley and others, 1985; Gustavson, 1975 a,b), the interbedded flows in the channel are further evidence that the sands were deposited subaqueously near a glacial margin. We conclude that the ice front was the earliest Port Huron ice advance.

Rhythmites

The cross bedded and rippled sands are overlain by distinct rhythmites consisting of red clay alternating with lighter-colored, coarser-grained sediment. The rhythmites overlap the channel sand at the channel margins and beyond rest directly on the upper boulder lag and Oak Creek till. The sand layers are generally rippled and, except near the base where they are normally graded and contain features consistent with density flow origins, contain internal laminae of silt and fine sand. The vertical change is evidence of an upward transition from slump-generated surge rhythmites to suspension-settling rhythmites (Ashley and others, 1985). The rhythmites are discussed in more detail in the following section.

Red Till

The most important new observation is that the rhythmites grade northward almost imperceptibly into a massive red diamicton present at the top of the bluff. The continuous transition is proof that the red diamicton and the reddish rhythmites were deposited contemporaneously; they are facies equivalents.

Starting from the red diamicton (Fig. 4a), the transition to rhythmites occurs over a relatively short distance, scarcely more than 90 m. The transition begins where the diamicton's pebble and cobble con-

Figure 4a. Contact between the Ozaukee (upper) and Oak Creek (lower) till units. Contact is marked by approximately 8 cm of bedded sand (at shovel). See figure 3 for photo location.

Figure 4b. Cobbly Ozaukee diamicton. Note increase in pebble and cobble content from figure 4. See figure 3 for photo location.

tent increases abruptly (Fig. 4b). Traces of stratification are initially defined by clasts at the same elevation over horizontal distances of several meters, and then by concentrations of clasts and sand pods in elongate lens-shaped patterns. Over the following 30 m the deposit develops a definite, but discontinuous, stratification (Fig. 4c) with rudiments of rhythmites defined by a segregation into contorted layers of clay-rich and sand-rich sediment. The clay layers, in particular, contain evidence of flowage, including sharply erosional bases and rip up clasts of unconsolidated clay. Individual layers are folded, overturned, highly deformed, and are discontinuous. The clay units are interstratified with unsorted coarse, cobbly sand, variable in thickness, with distinct fining and sorting trends away from the diamicton and toward the rhythmites. Boulders and lens-shaped bodies of cobbles, interpreted as dropstone accumulations, are locally present within a finer-grained sand matrix. Pebbles and cobbles within the sand layers continue with decreasing frequency over another 30 m past the point where distinct stratification develops. Beyond that distance clasts and other evidence for ice-rafted debris are rare and rhythmites are fully developed (Fig. 4d).

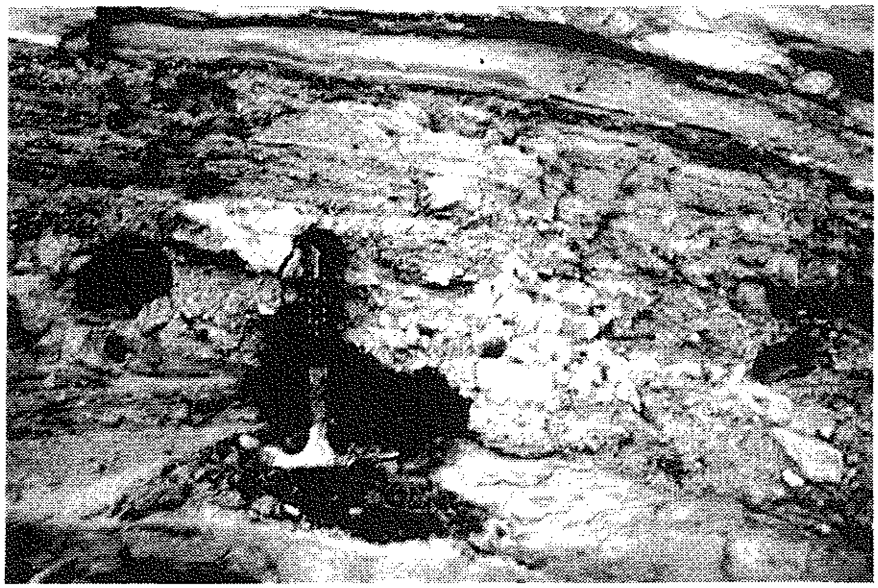

Figure 4c. Poorly stratified Ozaukee sediments. See figure 3 for photo location.

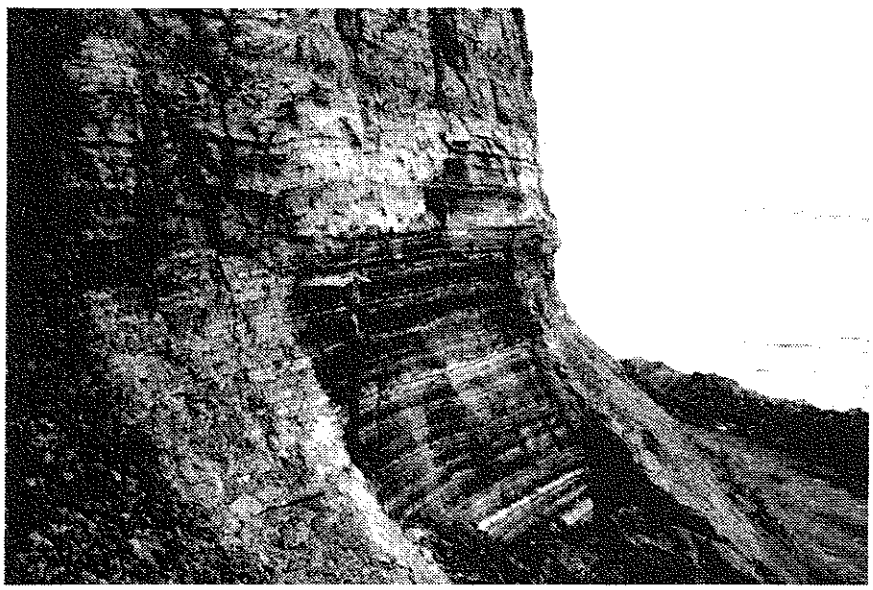

Figure 4d. Ozaukee rhythmites. See figure 3 for photo location.

The gradation between diamicton and rhythmites extends farther south in the lower part of the transition zone than above, where poorly bedded deposits in the lower meter are sharply overlain by well-bedded rhythmites. Because of the lateral fining trend in the rhythmite couplets, an extension of this contact can be traced southward over much of the exposure. The rhythmite thickness below this contact is variable, ranging from one to twelve centimeters. Above the contact the grain size in the sand couplets decreases, and the couplets thin to a consistent thickness of several centimeters, further evidence for an upward transition from surge to suspension rhythmites. The two fining trends, both upward, and laterally away from the transition zone, define a regressive sequence with rapid northward retreat of the glacial source.

The most obvious interpretation of the transition described above is of a glacial terminus in standing water. The transition apparently marks the southern limit of the initial Port Huron advance which deposited the first of the red till units in eastern Wisconsin. Further evidence supporting the terminal position is that there is no similar red diamicton in the bluffs south of this point (Mickelson and others, 1977; Rovey and Borucki, 1995), although an identical deposit is continuously present at the top of bluff exposures north of Milwaukee Harbor.

The transition between massive diamicton and rhythmites slopes generally to the south, implying that the transitional sediments were deposited as a series of sediment flows off the ice front, progressively building away from the ice and into Lake Chicago. However, the lack of discrete boundaries indicates a continuum beginning with subglacial melt-out and no resedimentation, progressing to slight remobilization, to extensive flowage, and ending with complete resedimentation and segregation into coarse and fine-grained rhythmite couplets.

CORRELATION OF RED DIAMICTON

Introduction

The upper red diamicton at the St. Francis site was first noticed by Lasca (verbal communication)in 1977, and he provisionally correlated it with the red till north of Milwaukee. However, subsequent slumping obscured the upper exposure; hence, Lasca (1983) later did not mention it. We propose that this uppermost diamicton indeed is the oldest of the red till units, now known as the Ozaukee Member of the Kewaunee Formation (Table 1).

Red Till Controversy

The red tills of eastern Wisconsin, present along the margins of Lake Michigan and Green Bay, is of historical interest due to their long controversy. T.C. Chamberlin (1887, 1883) noted interbedded laminated sediment and the parallelism to shorelines and described them as entirely lacustrine deposits from a high-elevation precursor to Lake Michigan. He was also influenced by the relative lack of large erratics, and his descriptions show that, in his judgement, glacial sediment must meet certain textural criteria in order to be true till. His misdiagnosis was not corrected until Alden (1918) reported the presence of faceted and striated boulders, proving that most of the material is till.

The second major controversy involves stratigraphic subdivision. Thwaites (1943) established the name "Valders" for the red till at Valders Quarry, and later (Thwaites and Bertrand, 1957) applied the same name to all the red till in eastern Wisconsin, including that overlying the Two Creeks forest bed. Eventually, the term "Valderan" took on a time-stratigraphic meaning as well (Valderan Substage) for deposits stratigraphically above the Two Creeks (Twocreekan) forest bed (Frye and Willman, 1960; Frye and others, 1968). However, other authors (Evenson, 1973; Mickelson and Evenson, 1975) found evidence that the type-Valders is actually below the forest bed and, therefore, pre-Twocreekan (and pre-Valderan). The controversy is now largely resolved with the recognition of multiple red till units both older (Woodfordian) and younger (Greatlakean) than the forest bed (Mickelson and others, 1977; Acomb and others, 1982).

Additional Evidence for Correlation

The diamicton composition is direct evidence that it is the Ozaukee. As shown in Table 1, lithologic properties are identical with undisputed Ozaukee till north of Milwaukee Harbor, and its properties are distinct from every other till unit exposed in the lake bluffs of southeast Wisconsin.

All previous workers, however, mapped the southern Ozaukee terminus at the mouth of the Milwaukee River at Milwaukee Harbor. This interpretation dates back to Alden (1918) who mapped the western margin of the red till (Ozaukee in this study area) roughly parallel to the Milwaukee River in Milwaukee and southern Ozaukee Counties (fig. 1). The implication is obvious; if the river occupies an ice-marginal position, then the Ozaukee could not extend southward beyond the river mouth. However, as shown in figure 1, the river does breach the moraine at several locations, and a series of morainal ridges are traceable from the St. Francis site northward to undisputed Ozaukee margins in northern Milwaukee and southern Ozaukee counties. The ridges south of Milwaukee Harbor are generally more subtle, but they are present at or just below elevations of proglacial Lake Chicago. Hence, they are likely to have been partially eroded and/or covered with lake or estuary sediments. Nevertheless, the ridges line up well with the Ozaukee morainal trend and are cored with a reddish-hued till (Need, 1983). Need also mapped these ridges as a moraine, although he interpreted them as the youngest recessional moraine of the Oak Creek Formation. He cautioned, however, that his assignment to the Oak Creek was based on visual inspection of soil boring samples without corroborating lab analysis. We unsuccessfully attempted to locate the samples in question for laboratory analysis. Without the samples we cannot eliminate the possibility that they are indeed Oak Creek till, but we think it unlikely for the following reason. Till with a slightly reddish hue is present within the Oak Creek Formation, but along the lake bluffs, at least, it always occurs at the base of the formation; it is the oldest or stratigraphically lowest Oak Creek till (Rovey and

Table 1. Clay mineralogy and textural parameters of glacial till exposed in the Lake Michigan bluffs, southeast Wisconsin. Subdivisions within the Oak Creek and New Berlin Formations are informal, based on Rovey and Borucki (1995). X denotes mean value, (S) standard deviation and [N] number of samples. The sand/silt boundary is .05 mm, the silt/clay boundary is 0.002 mm. See Rovey and Borucki (1994) and Borucki (1988) for methods of analysis.

	Sand		Silt		Clay			Expandables		Illite		Kaolinite + Chlorite		
	X	(S)	X	(S)	X	(S)	[N]	X	(S)	X	(S)	X	(S)	[N]
Ozaukee Member, Kewaunee Formation														
North of Milwaukee Harbor	22	(4.9)	38	(3.4)	40	(3.0)	[18]	22	(1.7)	59	(1.5)	19	(1.2)	[11]
St. Francis site	24	(6.2)	34	(3.5)	42	(3.2)	[8]	21	(2.9)	60	(4.1)	19	(2.9)	[5]
Oak Creek Formation														
Oak Creek 5	19	(3.8)	51	(2.1)	29	(3.7)	[11]	14	(.87)	67	(1.4)	19	(2.2)	[9]
Oak Creek 4	22	(5.8)	47	(3.0)	31	(5.3)	[36]	10	(2.2)	69	(2.0)	21	(2.0)	[28]
Oak Creek 3	13	(2.4)	42	(3.6)	45	(3.8)	[22]	13	(1.7)	65	(1.5)	22	(1.6)	[20]
Oak Creek 2	40	(3.8)	34	(3.1)	26	(6.4)	[9]	18	(3.0)	60	(1.8)	22	(2.2)	[10]
Oak Creek 1	14	(2.8)	39	(3.3)	47	(3.4)	[19]	16	(1.7)	62	(2.5)	22	(1.9)	[15]
New Berlin Formation														
New Berlin 2	30	(5.0)	45	(6.0)	25	(7.1)	[12]	18	(3.2)	63	(3.0)	19	(1.3)	[8]
New Berlin 1	57	(5.4)	30	(2.3)	13	(4.3)	[5]			NOT ANALYZED				

Borucki, 1995). But, Need (1983) found two additional Oak Creek till units between the morainal ridges and the underlying New Berlin Formation. Therefore, the reddish till in the ridges cannot be part of the Oak Creek Formation unless two additional Oak Creek till units are present just a few kilometers inland that are not preserved anywhere along the bluffs.

CONCLUSIONS

Based on the evidence so far available, we conclude that the Ozaukee moraine does not intersect the Lake Michigan shoreline at the mouth of the Milwaukee River as previous investigators maintained; rather, it continues south to the St. Francis Power Plant exposure. The Ozaukee till, however, is probably not present continuously behind (east of) the morainal front, because most of the area is slightly below 195 m in elevation, the Glenwood level of Lake Chicago, and would have been susceptible to removal by wave scour. The till is primarily preserved along the morainal ridges which themselves may be partially eroded or draped with later lake/estuary sediment.

Several unique features of the Ozaukee terminal ice front position are preserved at the St. Francis site. First, the Ozaukee till grades directly into rhythmite sediments. This proves that the ice front was advancing south into the standing water of Lake Chicago, and that the resulting transitional sediment is an ice-contact deposits. Such transitions and associated sedimentary features are frequently hypothesized and have been described conceptually (Powell, 1981; Powell and Molnia, 1989), but have seldom been conclusively recognized and described in the field. The most surprising aspect of the transition is its abruptness. The non-stratified till grades through a series of chaotic mass flow deposits into perfectly stratified rhythmites over a distance of approximately 90 m. Ice-rafted debris, likely to be an important sediment source near the glacial margin of most ice-contact lakes, is generally lacking beyond 30 m past the transition.

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