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QUATERNARY STRATIGRAPHY OF THE LOWER MILWAUKEE AND MENOMONEE RIVER VALLEYS, MILWAUKEE, WISCONSIN

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ABSTRACT

Numerous geotechnical borings have been drilled along the Milwaukee and Monomonee Rivers as part of the Milwaukee's Water Pollution Abatement Program, encountering as much as 60 m of Pleistocene and Holocene deposits. These deposits are differentiated into lithostratigraphic and lithogenetic units based on visual examination of split-spoon and Shelby-tube samples and a small amount of engineering test data.

The Pleistocene units consists of three distinct till units; fine-, medium- and coarse-grained, proglacial-lake sediment; and a complex and variable ice margin unit. The three till units correspond to till units 1, 2, and 3 described in bluff exposures along the Lake Michigan shoreline by Mickelson and others (1977) and to members of New Berlin, Oak Creek and Kewaunee Formations of Mickelson and others (1983). Two separate till sheets are present within the New Berlin Formation and three till sheets are present within the Oak Creek Formation. One till sheet from the Kewaunee Formation is present in the study area. This till sheet is the youngest till in the area and corresponds to the Ozaukee Member as defined by Mickelson and others (1983). Correlation of till sheets and lake sediment layers in the subsurface indicates the presence of a major meltwater outlet along the Menomonee River and a terminal ice-margin position for the youngest of the Oak Creek advances.

The Holocene units consist of fine-grained, organic-rich estuarine deposits and alluvial deposits that range in composition from silty sand to sand and gravel. This sediment occupies valleys that were eroded into the glacial deposits when the lake level was at the very low Chippewa stage. Valley filling occurred as the lake level rose to the Nipissing stage. Slight overconsolidation of some estuarine deposits and the interstratification of estuarine and alluvial deposits indicate that the lake level did not rise steadily at this time.

INTRODUCTION

More than 200 geotechnical borings were drilled along the Milwaukee and Menomonee River valleys as part of the Milwaukee Water Pollution Abatement Program (MWPAP). These borings , most of which were drilled during the last two to three years, provide an opportunity to study the subsurface stratigraphy of a large part of Milwaukee in detail. This paper is a progress report on efforts to analyze the large amount of high quality data collected from these borings. The findings are preliminary in nature and are concerned with the Pleistocene and Holocene deposits of the lower Milwaukee and Menomonee River valleys, deposits found to be as much as 60 m thick. The interpretations presented here are considered to be working hypotheses that will guide further studies.

My findings are based on visual examination of samples collected from the MWPAP geotechnical borings. The samples were taken with split-spoon and Shelby tube samplers in borings drilled using wash-rotary or hollow-stem auger techniques. Sampling intervals ranged from continuous to sampling on 5-ft centers. The samples, as well as boring logs and laboratory test data, became available to me through my work in the MWPAP. The visual examination was made to identify depositional environments so that subsurface conditions could be correlated between borings. Three lithostratigraphic units, the till units, and six lithogenetic units, the other sediment types, were identified through this process. These nine units are used to describe the general aspects of the Quaternary stratigraphy of the lower Milwaukee and Menomonee River valleys and serve as a starting point for further lithostratigraphic studies.

The Lower Milwaukee and Menomonee River valleys and the locations of borings drilled for the Milwaukee Water Pollution Abatement Program are shown in figure 1. The study area extends from Milwaukee Harbor west and north along the Milwaukee River to the North Avenue Dam, and west along the Menomonee River to the 27th Street Viaduct. Alden (1918) mapped the low-lying areas along the two rivers as terraces related to the Nipissing stage of Lake Michigan. In a compilation of old maps of Milwaukee, Rose (1978) indicates that these low areas were mostly wetlands with patches of drier ground. The upland area east and north of the Milwaukee River was mapped as red drift end moraine by Alden (1918), and the other upland areas were mapped as ground moraine of an earlier Lake Michigan Lobe advance with segments of discontinuous end moraines in several locations. The presettlement topography is shown in figure 2.

Previous stratigraphic studies of this area are limited to two engineering theses (Williams, 1954; Rose 1978) which were more concerned with foundation conditions and other engineering problems than Quaternary stratigraphy. Williams (1954) examined foundations conditions in the area roughly bounded by 12th Street, Juneau Avenue, Cass Street, and Menomonee River. Rose (1978) studied the engineering geology of an area roughly bounded by 12th Street, Wisconsin Avenue, Lake Michigan, and Greenfield Avenue. The work of Mickelson and others (1977) along the shoreline of Lake Michigan is relevant to the Pleistocene deposits in the area, but no comparable work on the Holocene deposits exists.

LITHOGENETIC UNITS

The Pleistocene and Holocene deposits found in the MWPAP borings are differentiated into three lithostratigraphic units, the till units, and six lithogenetic units, the other sediment types, the Pleistocene units include three distinct till units, fine-, medium-, and coarse-grained, proglacial lake sediment, and a complex and variable ice margin unit. A schematic diagram of the depositional environments that produced these deposits is shown in figure 3. The two Holocene units include fine-grained, organic-rich, estuarine and marshy backwater deposits, and coarse-grained point-bar and channel-lag, alluvial deposits. A schematic diagram of these depositional environments is shown in figure 4. The characteristics of the lithostratigraphic and lithogenetic units are presented below.

Pleistocene Units

The three distinct till units correspond to till units 1, 2, and 3 identified by Mickelson and others (1977) in their work on the bluff exposures along the Lake Michigan shoreline in Milwaukee County and adjacent areas. The till unit formerly called till 1 is now considered to be part of the New Berlin Formation, unit 2 is considered to be part of the Oak Creek Formation, and unit 3 is the Ozaukee Member of the Kewaunee Formation (Mickelson and others, 1983). These names will be used for the rest of this paper.

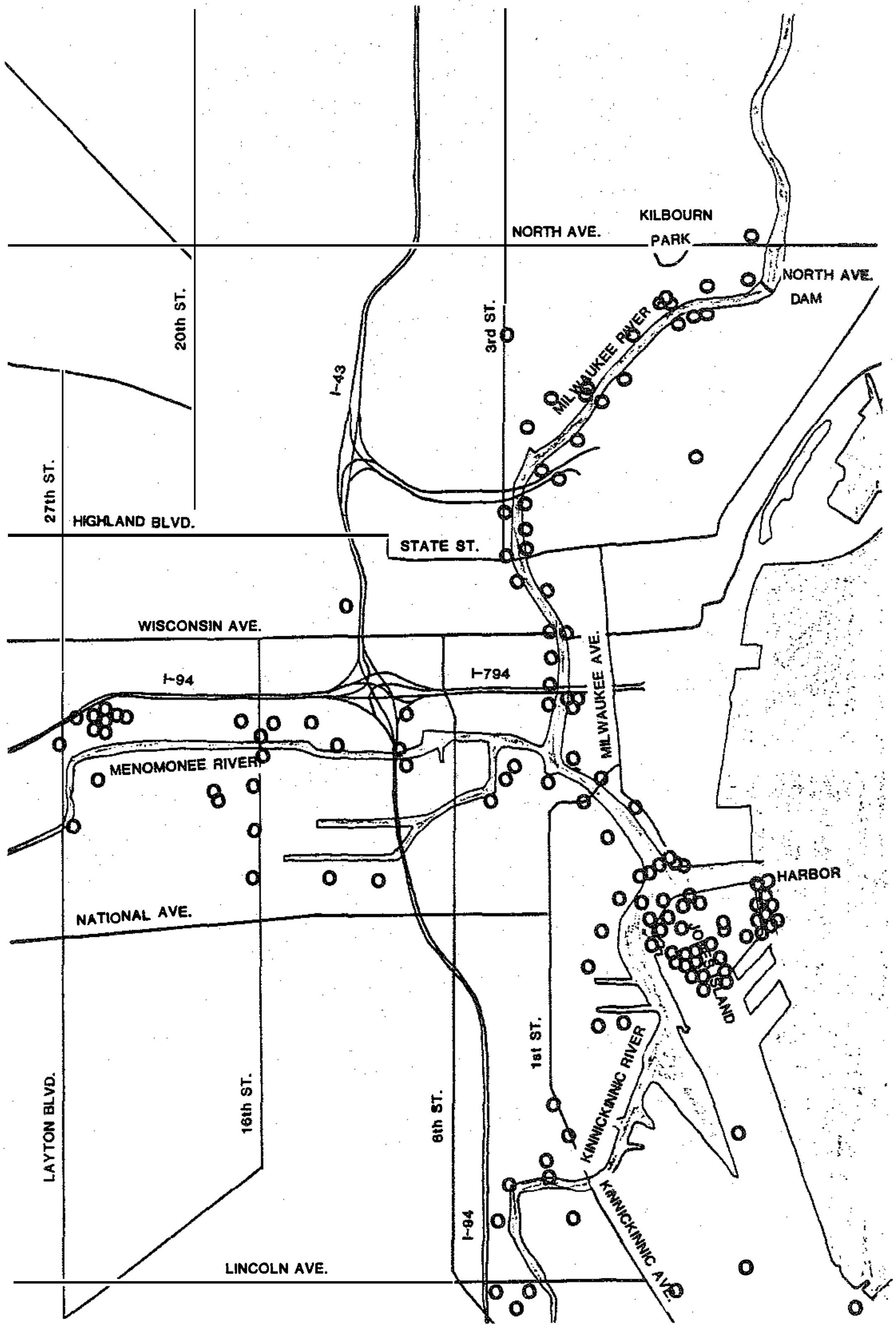

FIGURE 1.--Vicinity map of the lower Milwaukee and Menomonee River valleys. Dots show the locations of MWPAP geotechnical borings. Lines connecting selected borings are the sections shown in figures 8 and 9. Scale: 1 inch is approximately equal to 1 km (3225 ft).

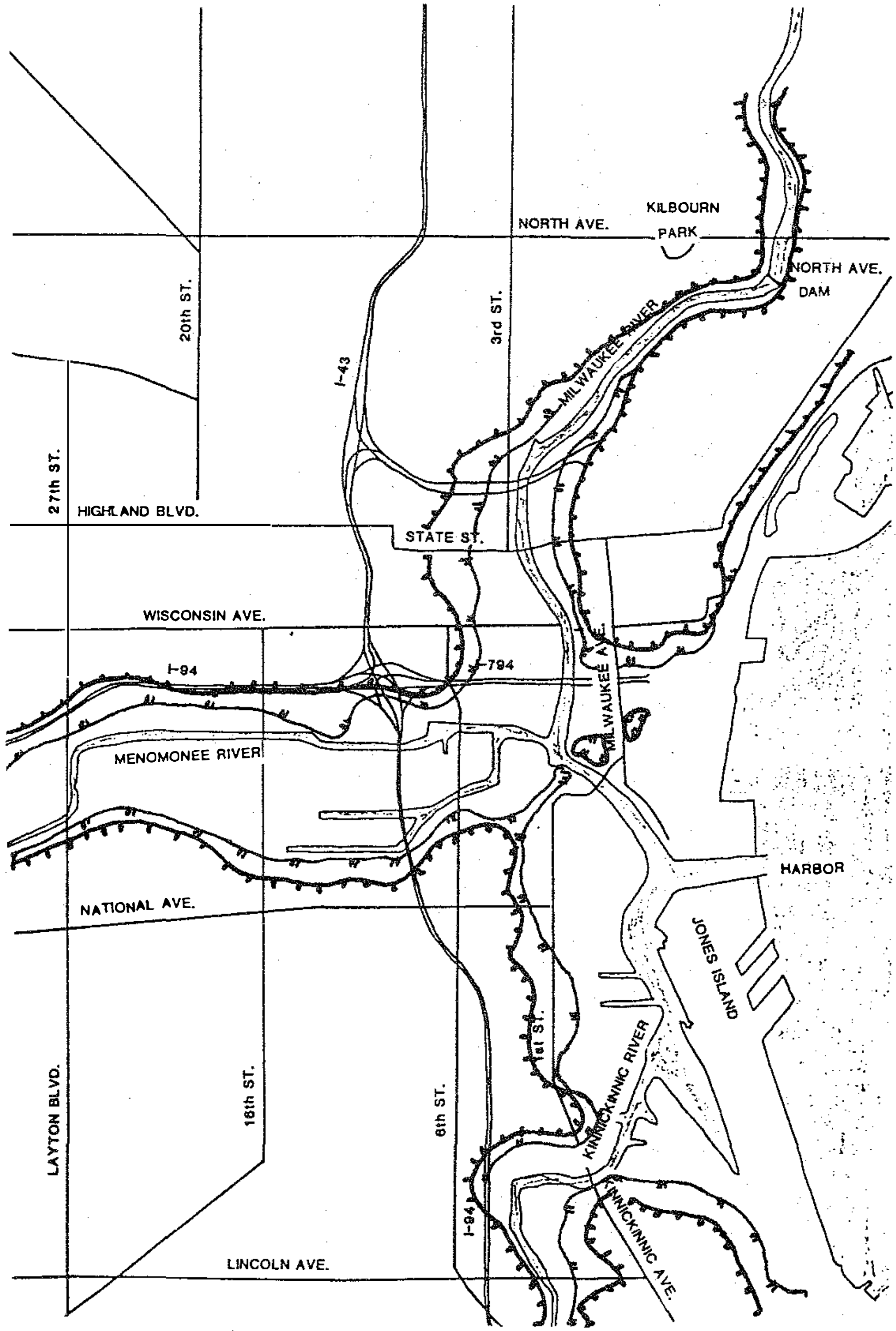

FIGURE 2.--Presettlement topography of the lower Milwaukee and Menomonee River valleys. Heavy lines are former bluffs with ticks on uplands. Light lines show extent of dry lowlands. Other lowlands were wetlands. Scale: 1 inch is approximately equal to 1 km (3225 ft). After Rose, 1978.

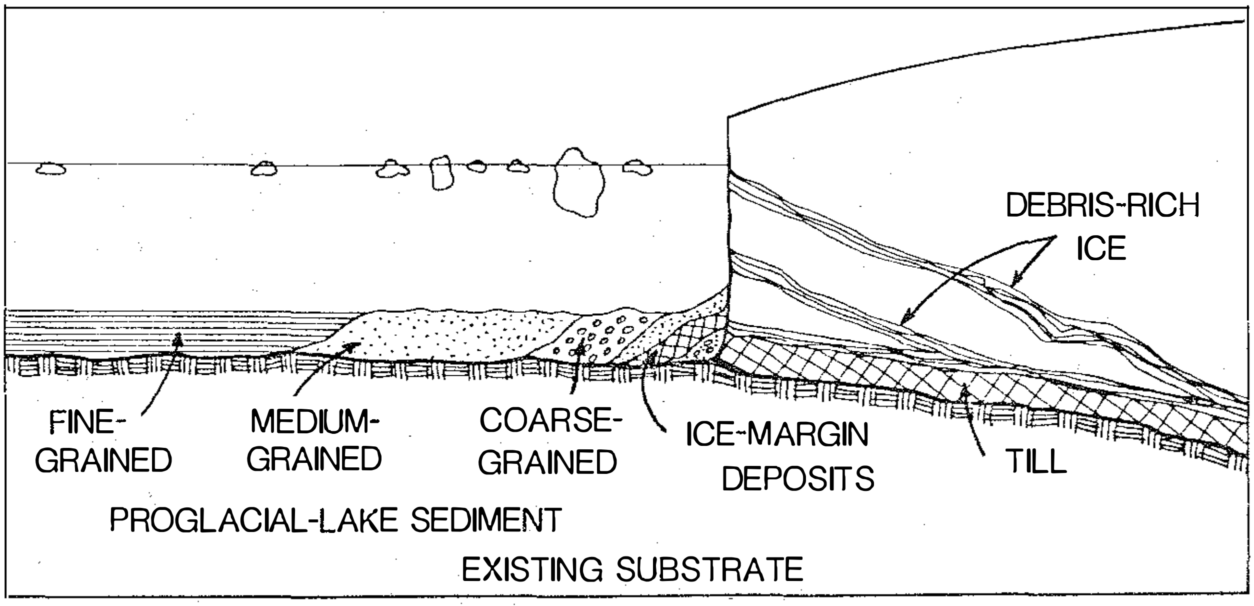

FIGURE 3.--Schematic diagram of glacial depositional environments for a calving ice margin.

The correlation of samples from the MWPAP borings to the units of Mickelson and others (1977) and Mickelson and others (1983) is based only on lithologic criteria distinguishable in visual examination. No sand:silt:clay or mineralogical data are yet available for samples recovered from the MWPAP borings. Thus, all of the grain-size descriptions presented below use engineering terminology with estimated textures shown in parentheses.

The New Berlin till, the oldest till found, is generally dense to very dense, light gray to brown, very poorly sorted, silty sand to silt that has a substantial amount of clay (loam to sandy loam) and commonly contains pebbles, cobbles, and boulders, Due to its gravelly character, borehole recovery of this till is usually poor and sample interpretation is sometimes difficult.

Holocene Units

The alluvial deposits originated in streams as channel and point-bar sediment. They are typically composed of loose to medium dense, sandy silt, and silty sand and gravel (silt loam to loamy sand). The estuarine deposits originated on marshy backwater areas and in shallow estuaries created as the lake level rose from the Chippewa stage to the Nipissing stage. The deposits are typically composed of organic-rich to peaty, silty clay and clayey silt, and they are generally soft to medium stiff and quite compressible.

GENERAL STRATIGRAPHY

The Quaternary stratigraphy of the lower Milwaukee and Menomonee River valleys is shown schematically in figure 5. The oldest Pleistocene deposits are part of the New Berlin Formation in which two till sheets are present. The next three till sheets belong to the Oak Creek Formation and may or may not be separated from each other or from the New Berlin Formation by lacustrine deposits. The till sheets of the Oak Creek Formation are overlain by till of the the Ozaukee Member in part of the study area. A major unconformity is present between the Pleistocene deposited and the overlying Holocene depos-

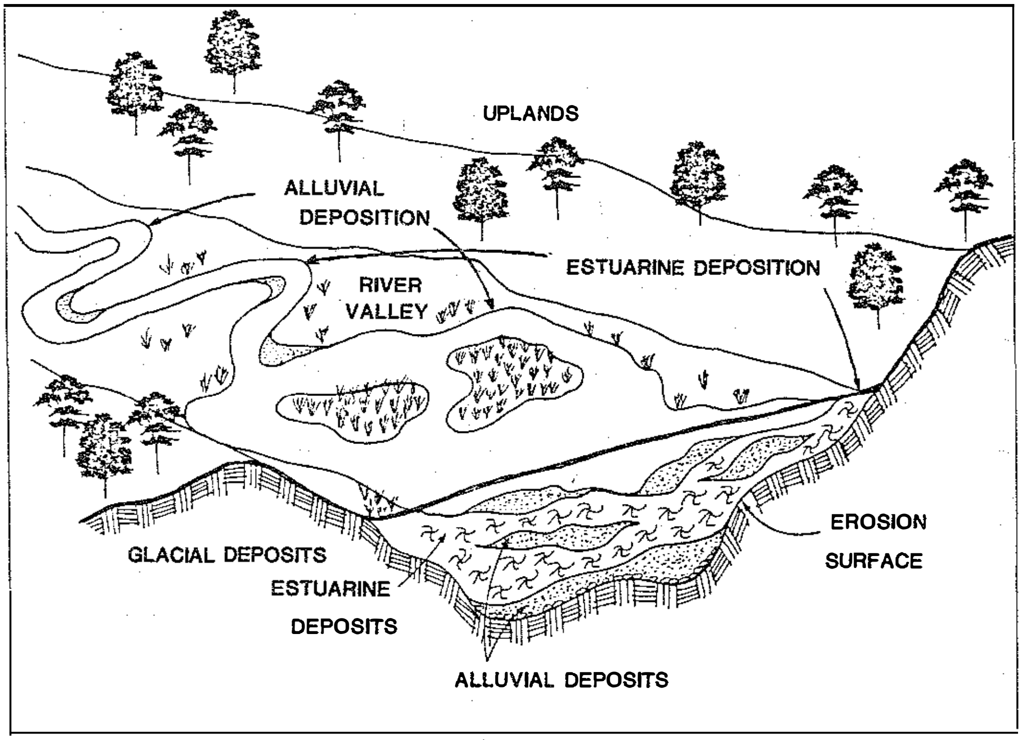

FIGURE 4.--Schematic diagram of postglacial depositional environments in the lower Milwaukee and Menomonee River valleys.

its. The oldest material overlying this unconformity is an alluvial deposit that commonly contains a large amount of gravel in the lower part of the deposit. The youngest sediment in the study area consists of estuarine deposits, which contain discontinuous lenses of alluvial deposits in places.

Samples recovered from the Oak Creek till typically stiff to hard (dense to very dense), gray to purplish or pinkish gray, silty clay to clayey silt, and clayey or silty sand (silty clay loam to silt loam to loam) in which the largest particles are usually fine pebbles. Cobbles and boulders are commonly encountered where this till directly overlies bedrock.

The Ozaukee till is typically stiff to hard, reddish brown, poorly sorted, silty clay to clayey silt (silty clay loam to silt loam) in which the largest particles are usually pebbles. This till corresponds to the red till mapped by Alden (1918) and was identified and characterized by Acomb and others (1982).

The three types of proglacial-lake sediment are distinguished primarily on grain-size distributions. The fine-grained sediment is typically composed of stiff to hard clay to clayey silt (clay to silty clay loam) that is commonly laminated and relatively well sorted. The medium-grained sediment is composed of medium dense to very dense, silty fine sand to silt (sandy loam to silt) with very little clay. The coarse-grained sediment is typically composed of dense to very dense, nonsilty sand and gravel (loamy sand to sand).

The ice-margin unit is interpreted to be present when closely spaced samples indicate interbedded lacustrine and till deposits. Individual beds

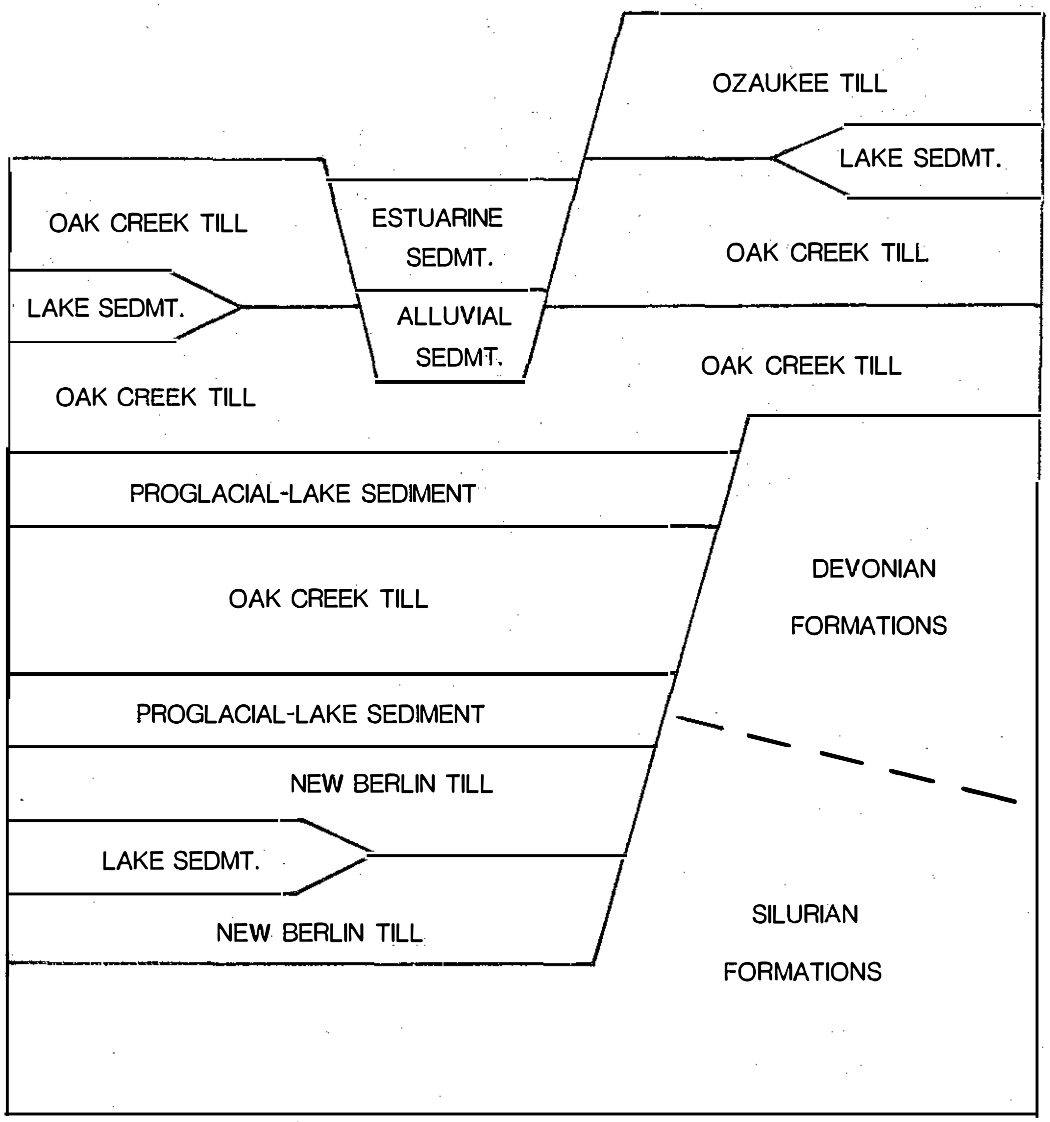

FIGURE 5.--Schematic diagram of stratigraphic relatioships among Quaternary deposits in the lower Milwaukee and Menomonee River valleys.

within the complex range from 0.2 to 2 m in thickness, but the amount of any given type of deposit and the sequence of their interbedding are quite variable. The rapid changes in depositional environment inferred from the interbedding of till and lacustrine deposits are indicative of a sedimentary complex that originated at the ice margin.

In general, the distribution of the till sheets is partly related to sub-Pleistocene topography and partly related to the extent of the glaciers that deposited them. The sub-Pleistocene topography is shown in figure 6. The main feature of this surface is the asymmetrical valley beneath the current Menomonee River valley with a steeply rising slope beneath the Milwaukee River valley. The distribution of the Holocene strata is related to the topography of the sub-Holocene unconformity, shown in figure 7, and the water level in the lake basin. The relationships are illustrated in figures 8 and 9, which are subsurface sections developed from selected borings along the Menomonee and Milwaukee Rivers.

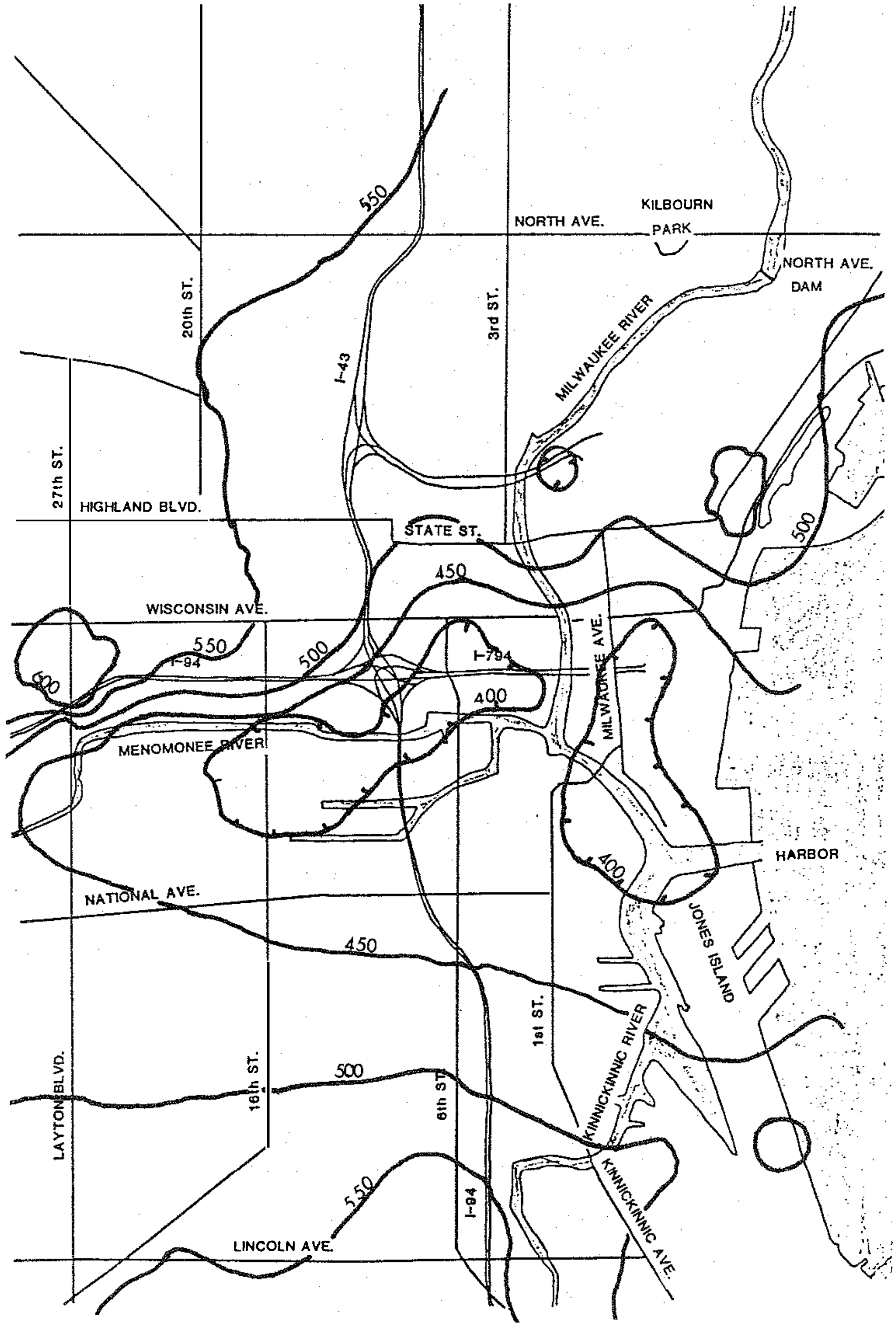

FIGURE 6.--Sub-Pleistocene topography of the lower Milwaukee and Menomonee River valleys. Scale: 1 inch is approximately equal to 1 km (3225 ft). Contour interval: 15 m (50 ft). Datum: Mean Sea Level--elevations shown are in feet.

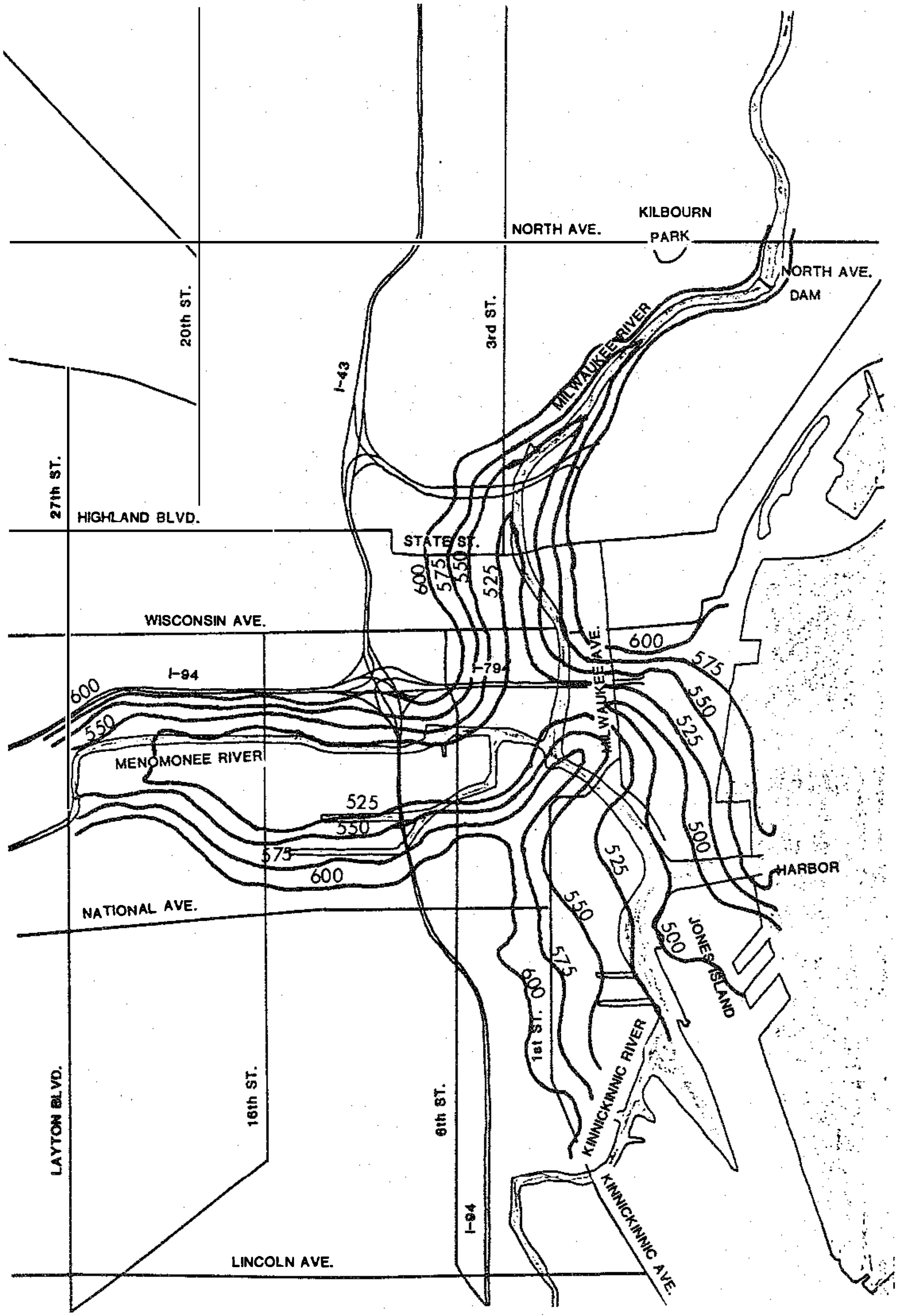

FIGURE 7.--Sub-Holocene topography of the lower Milwaukee and Menomonee River valleys. Scale: 1 inch is approximately equal to 1 km (3225 ft). Contour interval: 7.5 m (25 ft). Datum: Mean Sea Level--elevations shown are in feet.

New Berlin Formation

The New Berlin Formation seems to occur mainly within the deeper parts of the pre-Pleistocene valley along the Menomonee River and appears to he draped on the underlying topography. Presumably subsequent ice advances eroded these deposits from the higher parts of the sub-Pleistocene surface. Two layers of the sandy New Berlin till, separated by reddish-brown, fine-grained, proglacial-lake sediment, are present from the harbor area to the confluence of the rivers; but only a single till sheet appears to be present farther west. It has not been determined if the transition from more than one till sheet to a single till sheet is due to erosion of the intervening lacustrine deposit or if it marks the extent of the upper layer of New Berlin till.

Oak Creek Formation

The New Berlin Formation is generally separated from the Oak Creek Formation by proglacial-lake sediment. As shown in figures 8 and 9, the oldest till sheet in the Oak Creek Formation extends throughout the Menomonee River valley and almost extends to the pre-Pleistocene upland beneath the Milwaukee River. The bedrock high shown in the northern end of figure 9 is higher than much of the adjacent area. Thus, the oldest layer of Oak Creek till may extend, more or less continuously, across most of the area.

The middle layer of Oak Creek till is the oldest till sheet that is clearly not restricted in its areal extent by the sub-Pleistocene topography although its distribution still reflects the shape of the bedrock surface. A pinching out of this till sheet, shown in figure 8, is probably not indicative of a maximum ice-margin position. This interpretation is based on borings, located beyond the western end of the section, in which the middle layer of Oak Creek till is present. In the harbor area, the middle till sheet becomes a complex composed of till and lacustrine deposits. Beneath Jones Island, which has been extensively drilled, conditions in this stratigraphic interval change rapidly in short distances; in some borings, the middle layer of the Oak Creek till is completely absent. The reasons for the complexity are not clear. Along the Milwaukee River, the middle layer of Oak Creek till rises out of the pre-Pleistocene valley. The correlations shown in figure 9 are based on borings, located at the edge of the valley, that were not subject to as much postglacial erosion as those in the section.

The distribution of the youngest layer of Oak Creek till appears to be predominantly controlled by the extent of the glacier that deposited it. In the Menomonee River valley it occurs from the harbor area (not shown in the section) to the confluence of the rivers. At the confluence it has the form of an abrupt ridge, situated at right angles to the valley axis and extending up into the overlying Holocene deposits. Along the Milwaukee River, the youngest layer of Oak Creek till appears to occur only on the east side from the confluence of the rivers to North Avenue. At North Avenue, the till sheet is found on the west side, where a well defined segment of end moraine is present. The interpretation that the distribution of the youngest layer of Oak Creek till is controlled by the extent of the ice that deposited it is discussed below.

Ozaukee Member

The distribution of the Ozaukee till on the upland north and east of the Milwaukee River is presumed only on the basis of Alden's mapping because there are not yet sufficient borings to confirm or refute Alden's interpretation. Ozaukee till was encountered about 1.5 km north of the study area in a boring located at the top of the

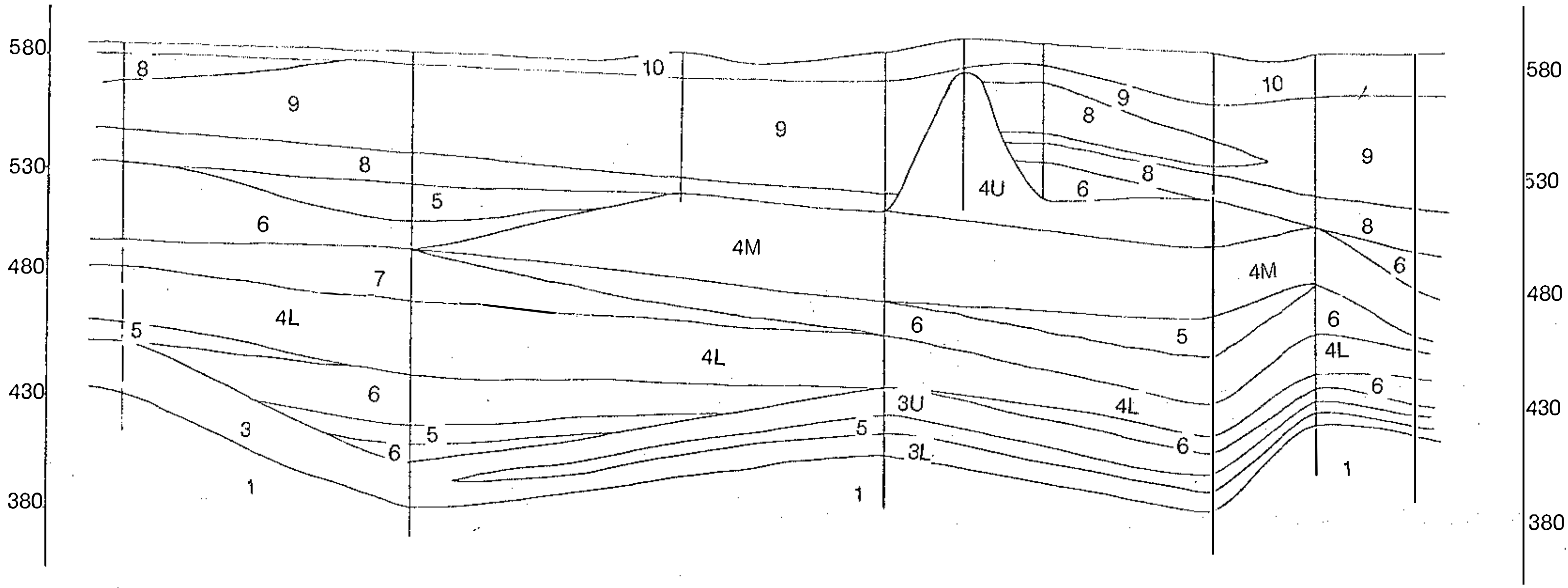

FIGURE 8.--Subsurface section of the Quaternary deposits along the lower Menomonee River valley. View is looking north. Deposits are identified by number below. The section shown crosses the section in figure 9 at the fifth boring from the right, and the dashed vertailc line indicates data projected from borings not in the section. Horizontal scale: 1 inch is approximately equal to 250 m (830 ft). Vertical scale: 1 inch is approximately equal to 25 m (83 ft). Datum: Mean Sea Level--elevations shown are in feet.

(1) Silurian formations. (2) Devonian formations. (3) New Berlin till. (4) Oak Creek till. (5) Fine-grained proglacial-lake sediment. (6) Medium-grained proglacial-lake sediment. (7) Coarse-grained proglacial-lake sediment. (8) Alluvial sediment. (9) Estuarine sediment. (10) Fill. U=upper till layer, M=middle till layer, L=lower till layer.

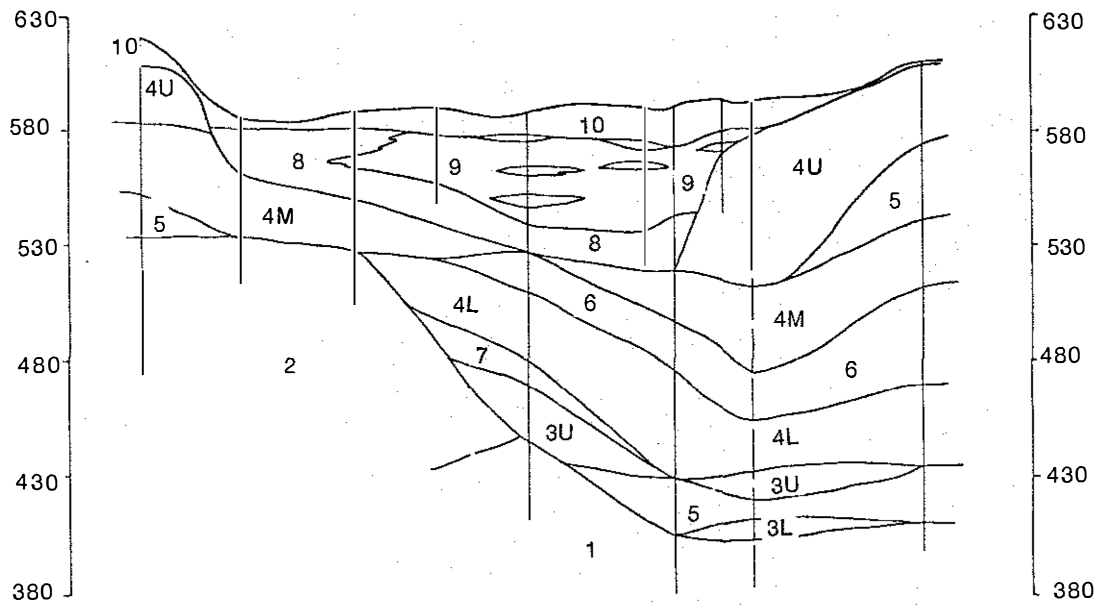

FIGURE 9.--Subsurface section of the Quaternary deposits along the lower Milwaukee River valley. View is looking east. Deposits are identified by number below. The section shown crosses the section in figure 8 at the second boring from the right, and the dashed vertical line indicates data projected from borings not in the section. Horizontal scale: 1 inch is approximately equal to 250 m (830 ft). Vertical scale: 1 inch is approximately equal to 25 m (83 ft). Datum: Mean Sea Level--elevations shown are in feet.
(1) Silurian formations. (2) Devonian formations. (3) New Berlin till. (4) Oak Creek till. (5) Fine-grained proglacial-lake sediment. (6) Medium-grained proglacial-lake sediment. (7) Coarse-grained proglacial-lake sediment. (8) Alluvial sediment. (9) Estuarine sediment. (10) Fill. U=upper till layer, M=middle till layer, L=lower till layer.

bluff overlooking the Milwaukee River. The distribution of this till sheet is such that it does not appear in either figures 8 or 9.

Alluvial Deposits

The distribution of the Holocene units is essentially coincident with the extent of the sub-Holocene valley, which probably formed by fluvial downcutting while the lake level was falling to and at the Chippewa stage. Most of the alluvial deposits occur in a continuous layer in the bottom of the sub-Holocene valley. The layer ranges up to 10 m in thickness. The alluvial deposits grade from sand and gravel at the erosion surface to silty sand at the upper contact with the estuarine deposits. The upper contact generally occurs at consistently higher elevations in the upstream direction. This relationship is somewhat distorted in figures 8 and 9 because the sections deviated from the valley axis. The basal alluvial layer is probably the result of fluvial aggradation caused by the lake level use from the Chippewa stage to the Nipissing stage.

Estuarine Deposits

The inability of the aggrading river to keep up with the rising water level eventually resulted in a transition to an estuarine environment in the sub-Holocene valley. This transition was probably time-transgressive. The estuarine deposits fill the rest of the buried valley, from the upper contact of the basal alluvial layer to a surface that coincides with the present lake level. Within the estuarine deposits are discontinuous lenses of alluvial deposits that may be the result of pauses in the rise of the lake level, or perhaps the temporary existence of local, low-order drainage systems on the valley sides. Toward the upstream ends of the buried sub-Holocene valleys, alluvial deposits seem to lap back over the top of the estuarine deposits. Because ancestral Lake Michigan rose to the Nipissing Stage, which is about 7.5 m higher than the present level, following the erosion event, it is possible that the Holocene deposits soils were once as much as 7.5 m thicker.

DISCUSSION

Basis of Correlations

The correlations presented in figures 8 and 9 are tentative because the laboratory analyses needed to establish a glacial stratigraphy in situations where several till sheets of similar lithology are present are not complete. Likewise there may be some errors in interpretation of poorly sampled sediment such as parts of the New Berlin Formation. The main guide for the correlations presented here was the till stratigraphy identified by Mickelson and others (1977) from their work along the bluffs of the Lake Michigan shoreline. The similarities of the till units in the two areas has already been mentioned; and, no evidence has been found that contradicts the shoreline stratigraphy. With that framework as a guide, correlations were made by working both from the bottom up and from the top down. These correlations were significantly influenced by the identification of what appears to be a terminal moraine for the youngest layer of Oak Creek till.

Terminal Moraine of the Youngest Oak Creek Advance

An end moraine, identified for the first time here, is interpreted to be the maximum ice-margin position of the advance during which the youngest layer of Oak Creek till was deposited. The evidence for a traceable end moraine includes the following:

(1) There is a buried, ridge-shaped body of till oriented perpendicular to the axis of the Menomonee River valley near the confluence of the Milwaukee and Menomonee Rivers. This ridge corresponds to a former point of dry lowland that extended into the wetlands in the valley bottom. This land, known as Walkers Point, is shown in figures 2, 7, 8, and 9.

(2) Two other areas of dry lowland, in line with Walkers Point, located northeast of the Milwaukee River.

(3) Alden (1918) mapped a sharp, well-defined ridge extending northwest from Kilbourn Park as end moraine.

(4) The higher parts of the upland north and east of the Milwaukee River trend northerly. This trend is difficult to completely explain as a result of events associated with the deposition of the Ozaukee till. The upland connects the fragment of end moraine identified by Alden with the Walkers Point end moraine remarkably well.

(5) A second buried ridge of till occurs across the Kinnickinnic River valley along Kinnickinnic Avenue.

(6) Subtle ridges and other high areas that cut across topographic trends of the uplands are present south of the Menomonee River and west of the Kinnickinnic River. These features can be used to connect the Walkers Point moraine to the ridge across the Kinnickinnic River valley.

The locations and spatial relationship of these features is shown in figure 10 which also shows the probable ice-margin position. The evidence that this end moraine marks the maximum extent of the ice that deposited the youngest layer of Oak Creek till consists of the following:

(1) Several borings on or east of this moraine have encountered three distinct layers of Oak Creek till, but no unequivocal occurrences of this kind have been found to the west.

(2) Pinkish gray colors in the uppermost Oak Creek till layer are restricted to the area east of the end moraine, although all of the uppermost Oak Creek till in this area is not pinkish gray.

(3) The moraine can be connected from the Kinnickinnic River to the St. Francis Power Plant site with a series of subtle ridge features. The St. Francis site is the most southern (and only clearly identified) occurrence of the youngest layer of Oak Creek till along the shoreline.

Meltwater Outlet Along Menomonee River Valley

There is generally not much surficial outwash mapped or encountered by MWPAP borings in the study area and adjacent to it. This is true even on areas east of the basin divide and above the elevation of the highest lake level that presumably had freely draining margins. This phenomenon was probably caused by the concentration of meltwater discharge at points along the margin that were abutted by proglacial lakes. The character of the proglacial-lake sediment in the Menomonee River valley. Specifically, the coarser-grained and medium-grained sediment are predominant relative to the fine-grained sediment. Furthermore, the coarse-and medium-grained sediment appears to occur in layers 9 to 15 m thick that are continuous for substantial distances in the western end of the valley. The relatively small amount of the coarse-grained sediment, as compared to the medium-grained sediment, may be due to source effects on the coarse fraction of the till is mostly pea gravel or slightly smaller so there was little coarse material available.

The deposition of material as the result of a meltwater concentration probably occurred during the time when the ice margin retreated from the vicinity of County Stadium to the vicinity of the present shoreline. Tracing a drainage path from the western end of the lower Menomonee River valley south of the main proglacial lake is not easy. If one can assume about 6 m of ground-surface lowering due to isostatic depression or a slightly higher local lake level, a poorly defined pathway can be traced from the vicinity of County Stadium south of the Kinnickinnic River basin, then southeast through Mitchell Field to the Oak Creek basin. This drainageway is shown in figure 11.

Character of Lake Level Rise to the Nipissing Stage

The nature and timing of the rise in lake level from the Chippewa stage to the Nipissing stage are not well documented. The deposits in the study area provide no data on when the rise began or on the rate of rise during much of the recovery, but they do provide information for approximately 30 m of the 105 m change. Radiocarbon dating of organic fibers in the estuarine deposits and pieces of wood recovered

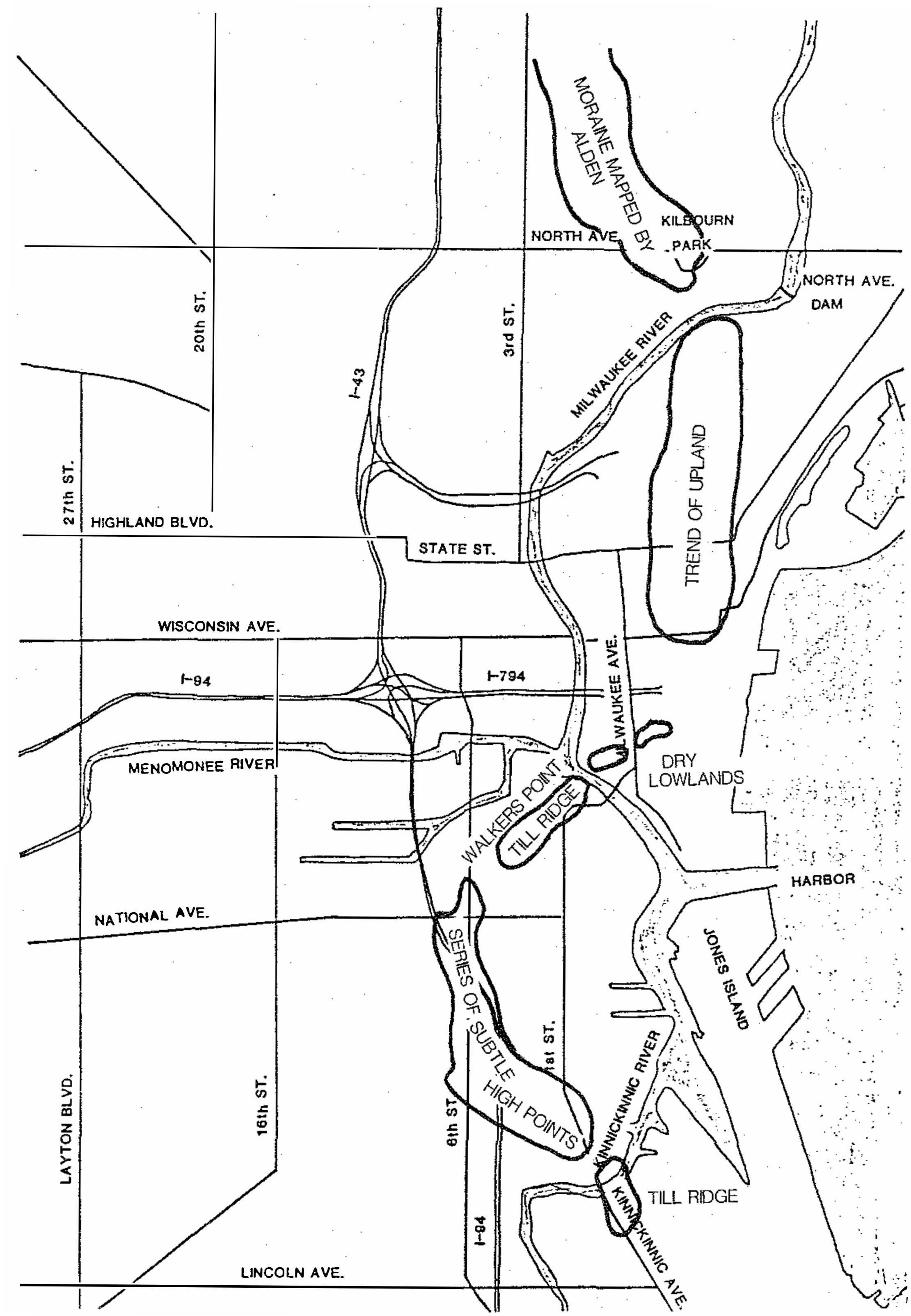

FIGURE 10.--Features used to identify and trace the Walkers Point end moraine. Scale: 1 inch is approximately equal to 1 km (3225 ft).

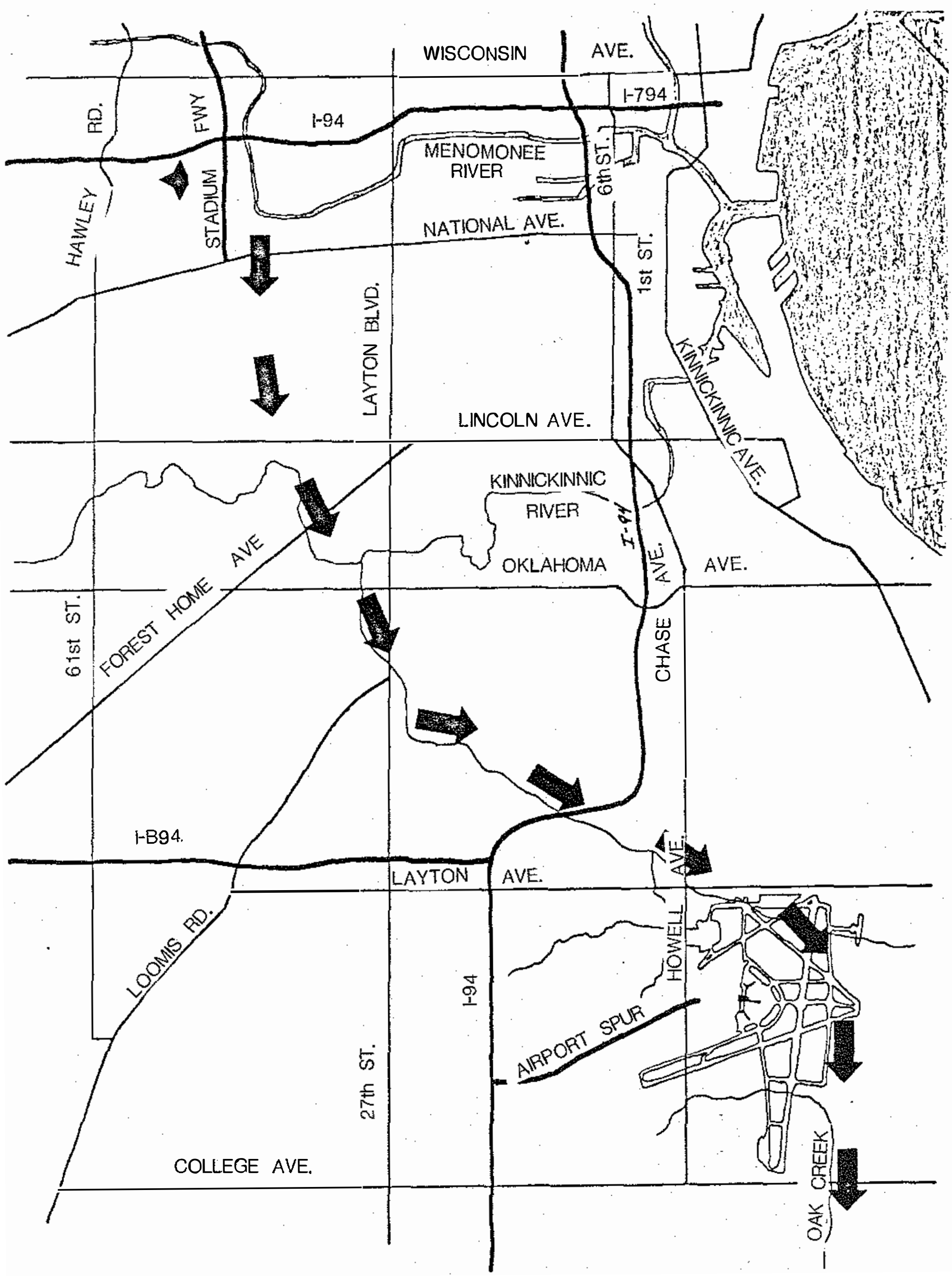

FIGURE 11.--Meltwater drainage path from the vicinity of County Stadium to the Oak Creek basin. The star is County Stadium. Scale: 1 inch is approximately equal to 1.9 km (6050 ft).

in samples of the basal alluvial deposit would provide data on (1) when the lake level had risen high enough to cause aggradation of the river, (2) when the first estuaries formed, and (3) the subsequent rate of lake level rise. The dates and rates would be minimum values because they actually apply to sedimentation events. Significant palynological data should also be obtainable from the estuarine deposits because they were deposited in an aggrading, quiet-water environment.

There is some indirect evidence regarding the character of the lake level rise already available. Several dozen consolidation tests were performed on samples of estuarine meterial. The results indicate that the esturaine deposits are slightly overconsolidated. Some of the overconsolidation could have been caused by sediment deposited while the lake occupied the Nipissing stage. Subsequent erosion of this hypothetical sediment would leave the underlying deposits overconsolidated. However, the observed overconsolidation cannot be fully explained as the result of overburden erosion. If the erosion of former overburden were the only cause of overconsolidation, the samples closest to the surface would be the most highly overconsolidated because the percentage in load reduction is greatest for such samples. The relationship between depth and overconsolidation does not have these characteristics; it is instead somewhat trendless.

A more likely cause for most of the overconsolidation and for the trendless relationship between overconsolidation and depth is dessication. This dessication could have occurred sporadically throughout deposition during pauses in lake level rise or slight lake level drops or both. Evidence for this idea is the occurrence of lenses of alluvial sediment within the thicker estuarine deposits. Although other explanations are possible, the alluvial lenses may reflect short periods of time during which the river prograded across existing estuarine deposits in response to a lower lake level.

Relationship to Earlier Studies

I have relied considerably on the till stratigraphy formulated by Mickelson and others (1977) from their work along the shoreline of Lake Michigan. This stratigraphy framework is consistent with the data from the MWPAP borings. Substantial agreement can also be seen among the data presented by Williams (1954) and Rose (1978) and this study although there are some differences in terminology and interpretation. Given the state of Quaternary geology when it was written, the study by William (1954) is remarkably perceptive in its geologic interpretations. Rose (1978) treated the geology of his study area more generally, and his criteria for distinguishing Pleistocene from Holocene deposits lead him to some erroneous conclusion. However, Rose did recognize the basic Holocene stratigraphy. There are two basic differences between the earlier studies and this study: (1) the interpretations in the earlier studies were made only from boring-log data whereas the interpretations presented here are based on boring logs <u>and</u> visual examinations of the actual samples, and (2) the interpretations presented here reflect the changes in both knowledge and methods that have occurred in Quaternary studies during the past 30 years.

SUMMARY

The Quaternary deposits of the lower Milwaukee and Menomonee River valleys are differentiated into three lithostratigraphic and six lithogenetic units on the basis of visual examinations of samples obtained from numerous geotechnical borings drilled for the Milwaukee Water Pollution Abatement Program. The Pleistocene units include three lithologically distinct till

units, which correspond to till units 1, 2 and 3 of Mickelson and others (1977) and to members of the New Berlin, Oak Creek and Kewaunee Formations of Mickelson and others (1983), fine-, medium- and coarse-grained, proglacial-lake sediment, and a complex and variable ice-margin unit. The Holocene units include alluvial and estuarine deposits laid down as the lake level rose from the Chippewa stage to the Nipissing stage.

The stratigraphic framework of Mickelson and others (1977), which is consistent with the data from the MWPAP borings, was used to correlate between borings so the extent and distribution of the units could be evaluated and described. From correlations and other data at hand, an end moraine that may mark the maximum extent of the ice that deposited the youngest layer of Oak Creek till and a meltwater outlet along the Menomonee River valley are tentatively identified. Pauses in lake level rise or slight lake level drops are recorded in the stratigraphic record during the general lake level rise from the Chippewa stage to the Nipissing stage.

AUTHOR'S NOTE

The terminology used in this paper for the proglacial-lake sediment is different than that used in MWPAP GEOTECHNICAL REPORTS. Deposits referred to as fine-grained proglacial-lake sediment in this paper are called lacustrine silt and clay in the MWPAP reports, medium-grained sediment is called lacustrine sand and silt, and coarse-grained sediment is called (subaqueous) outwash. The terminology was changed for the purposes of this paper because one of the reviewers felt that most Midwestern Quaternary geologists would assume a glaciofluvial setting for the outwash rather than a glaciolacustrine one.

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