University of Wisconsin-Extension

GEOLOGICAL AND NATURAL HISTORY SURVEY
3817 Mineral Point Road
Madison, Wisconsin 53705

M.E. Ostrom, State Geologist and Director

PRAIRIE DU CHIEN GROUP (L.Ord.) IN THE UPPER MISSISSIPPI VALLEY

by

R.A. Davis, Jr.

Open-File Report 71-2
71 p.

1971

WESTERN MICHIGAN UNIVERSITY

KALAMAZOO MICHIGAN 49001

July 17, 1972

Dear Buzz,

Enclosed is a good copy plus figures of the Prairie du Chien tome. Please hold it until the Survey is ready to publish it in its entirety. I think your idea of a publication on Wisc. Geol. with a few lengthy papers is a good one. If you think you can get it under way this fall that's fine.

I don't know if I told you or not but I'm giving a short paper w/ manuscript at an international symposium on "intertidalites" this winter in Florida. It's on intertidal deposits - past + present. I am talking on the stromatolite sequences of the Prairie du Chien. Before I send in the manuscript I'll send it to you for a review.

Our work is going alright over here but the weather sure has been lousy. We are finally having a good blow that should shift the sand bars around. George Knudsen was over last week & talked with us a few minutes. He seems like the "type naturalist" & a pretty good guy.

Enclosed is a short blurb I did while a Texas.

Regards,

Skip

PRAIRIE DU CHIEN GROUP (L. ORD.) IN THE UPPER MISSISSIPPI VALLEY

Richard A. Davis, Jr.
Department of Geology
Western Michigan University
Kalamazoo, Michigan 49001

ABSTRACT

Redefinition of some existing lithostratigraphic units as well as the designation of two new units within the Prairie du Chien Group in the upper Mississippi valley provides a logical solution to past problems and misinterpretations. A comprehensive regional field study of the Prairie du Chien has resulted in the subdivision of this group into the Oneota and Shakopee formations. The Oneota includes the newly designated Stockton Hill and Hager City members. The Stockton Hill is a mixture of dolomitic quartz sandstone and quartzitic dolomite whereas the Hager City is pure dolomite. An unconformity separates the Oneota from the Shakopee throughout the outcrop area. The Shakopee Formation is comprised of the New Richmond and Willow River members both of which contain various mixtures of quartz sandstone and dolomite with the New Richmond having more of the former.

Quartz sandstone is the only abundant terrigenous constituent of the Prairie du Chien. It is medium grained, sorted and rounded at most locations with ripples and cross-beds abundant. A wide variety of recognizable carbonate types comprise the dolomites. Grain sparite, oosparite, intrasparite and algal stromatolites are all abundant with lesser amounts of micrite and pelsparite. Silicification has taken place in some of the algal and oolitic beds. Thin illitic shale seams are present at most exposures.

Cyclic patterns characterize the depositional history of the Prairie du Chien. The lower part of the Stockton Hill Member

represents a beach and inner neritic environment whereas the upper part was deposited in an intertidal to shoaling environment characterized by algal stromatolites, oolites and intraclasts. The Hager City Member represents a deeper open marine shelf in the lower part and an intertidal environment was dominant during accumulation of the upper portion. This represents a cycle which terminated with the post-Oneota erosion. The beach and nearshore sands of the New Richmond in the central area mark the beginning of the second cycle. Much of the remainder of the New Richmond and the lower half of the Willow River represent intertidal and shoaling environments. Most of the upper part of the Willow River was deposited on a shallow open marine shelf. A major unconformity terminated the second cycle.

Prairie du Chien Group (L. Ord.)
in the Upper Mississippi Valley

INTRODUCTION

A few years ago this writer made a study of a stromatolitic dolomite sequence in the Prairie du Chien Group from a single quarry in southwestern Wisconsin (Carozzi and Davis, 1964). Investigation of the literature in completing that study made the writer aware of the general lack of agreement on, and knowledge of, Prairie du Chien stratigraphy. A thorough review of both published and unpublished reports on these strata indicated that a regional stratigraphic study of the Prairie du Chien Group had never been undertaken. At least there was not sufficient data presented in any one study or combination of studies which established the character, distribution, and relationships of Prairie du Chien strata throughout the upper Mississippi valley area.

During the course of a paleoecologic study of the upper carbonate unit (Davis, 1966b) it became evident that the many problems of Prairie du Chien stratigraphy which have been perpetuated in the literature were greatly exaggerated. Systematic field study of the Prairie du Chien in western Wisconsin, northeastern Iowa and southeastern Minnesota has provided data which indicate a logical solution to past problems.

The primary purpose of this paper is to describe and define or redefine the rock-stratigraphic units within the Prairie du Chien

Group in order to provide some standardization for what has been a confused literature. In doing so, some changes in stratigraphic nomenclature are necessary. The definition and character of rock-stratigraphic units presented herein are usable in the field as well as the subsurface.

In addition to the purely descriptive aspect of the Prairie du Chien, an effort was made to determine the depositional history and environments of these strata. Though dolomitization is complete throughout the carbonate portion of the Prairie du Chien, preservation is such that relict textures and composition can generally be determined. The actual diagenetic phenomena of dolomitization and silification were not studied in detail.

The stratigraphic nomenclature presented herein is supported by the Wisconsin Geological and Natural History Survey; however, the author takes all responsibility for the contents of this paper.

DISTRIBUTION OF PRAIRIE DU CHIEN GROUP

Strata comprising the Prairie du Chien Group crop out in numerous roadcuts and quarries throughout the "driftless" area of the upper Mississippi valley (Fig. 1). Natural exposures are not common and are mostly restricted to the high bluffs along the Mississippi River and adjacent coulees. The physical nature of some of these exposures and particularly steep-sided quarries is not conducive to close field examination.

The areal extent of the Prairie du Chien outcrop belt extends beyond the "driftless" area to the east and west (Fig. 1) but low relief in these areas and the cover of glacial drift do not provide good exposures. A few small exposures are present in north-central Illinois associated with the LaSalle Anticline and the Sandwich Fault, and in west-central Indiana near the Kentland Structure. These are not included in the present study.

Prairie du Chien strata thin toward the northwest and north in the direction of the Wisconsin Dome. In the subsurface these strata thicken considerably and are recognized in Iowa, Illinois, Indiana, and Michigan. Thickest occurrences are in central Iowa and Illinois where more than 700 feet of Prairie du Chien strata are recognized. This report is primarily concerned with field data and only general information about the subsurface Prairie du Chien is included.

HISTORY OF PRAIRIE DU CHIEN NOMENCLATURE

Strata belonging to the Prairie du Chien Group were first described and named "Lower Magnesian Limestones" by D. D. Owen (1840, p. 17). All rocks between the "upper sandstone" (St. Peter sandstone) and the "lower sandstone" (Jordan Sandstone) were included under this designation. From Owen's time to the present there has been considerable confusion about the nomenclature applied to these rocks. A detailed account of the nomenclatoral history can be found in an earlier paper by this writer (Davis, 1966a). The following summary is condensed from that report.

The first attempt at applying names to any of the natural subdivisions in the Lower Magnesian was by Winchell (1874). He named the carbonate strata cropping out near the town of Shakopee, Minnesota after that town (Winchell, 1874, p. 138). Winchell believed that this carbonate sequence represented the upper carbonate unit of the Lower Magnesian. This notion was based on the character and thickness of the Lower Magnesian in the Mississippi River valley, over 100 miles to the east. In reality Winchell's Shakopee Limestone included the entire lower Magnesian (Fig. 2) and he had confused the underlying Jordan Sandstone with the middle sandstone unit of the Lower Magnesian to the east.

Shortly thereafter Wooster (1882) named two units in the upper portion of the Lower Magnesian in the St. Croix River area of northwestern Wisconsin. The uppermost unit was named the "Willow River Beds" and the dominantly quartz sandstone below was designated the "New Richmond Beds" (Wooster, 1882, p. 106). These units were named from exposures near Burkhardt, Wisconsin on the Willow River and from the town of New Richmond, Wisconsin on the same river. The remainder of the Lower Magnesian was termed the "Lower Magnesian proper" (Wooster, 1882, p. 106) (Fig. 2). These three units are those which have been the traditional subdivisions of the Prairie du Chien Group.

The thick lower carbonate unit (Lower Magnesian proper) was named the "Oneota Limestone" by McGee (1891, p. 331-333). The name was taken from exposures along the valley of the Oneota River (now Upper Iowa River) in Allamakee County, Iowa where the unit is well exposed. McGee correlated the units he observed correctly with those described by Winchell (1874) and Wooster (1882), but placed them in the St. Peter Sandstone (Fig. 2). This is understandable because the New Richmond is a thick, sorted, quartz sandstone in the area of McGee's work and it resembles the St. Peter.

The renaming of the Lower Magnesian to the Prairie du Chien Group was by Bain (1906, p. 19). This includes most of the nomenclature that has been applied to Prairie du Chien (Lower Magnesian) strata until this time. An exception is the substitution of the term "Root Valley Sandstone" for the New Richmond by Stauffer and Thiel (1941). They renamed the New Richmond because of its great thickness and homogenous quartz sandstone character in the Root River Valley of southeastern Minnesota. The term "Root Valley Sandstone" has not been widely accepted or used in the literature.

Even though the names of rock units within the Prairie du Chien have been in use for many years there has been considerable shifting of stratigraphic rank. Some authors have designated the Prairie du Chien as a formation with three members: Oneota, New Richmond (Root Valley) and Shakopee (Willow River) (Powers, 1935; Stauffer and Thiel, 1941; and Heller, 1956). Others have preferred to consider the Prairie du Chien as a group with three formations (Kay, 1935; Raasch, 1952; Ostrom, 1964) while this writer prefers to consider the Prairie du Chien as a group composed of two formations (Sardeson, 1934; Davis, 1966a).

It is apparent from the above discussion and the nomenclature chart for the Prairie du Chien (Fig. 2) that there has been a variety of opinions on the rock-stratigraphic terminology of these strata. Investigations prior to this report have included only local areas or a superficial treatment of the entire upper Mississippi valley. A workable and logical solution to these nomenclatural problems is presented in the following sections of this report.

STRATIGRAPHY

Strata comprising the Prairie du Chien Group in the upper Mississippi valley area lie between the underlying Jordan Sandstone and the overlying St. Peter Sandstone. In the outcrop belt the thickness ranges from about 100 to 250 feet. Thin beds of chert, oolite, and shale occur locally as well as scattered chert nodules, dolomite clasts, and quartz grains.

The name is taken from the town of Prairie du Chien (Crawford County) in southwestern Wisconsin. The type exposures are about one mile east of town along State Highway 27 and the natural bluffs at the edge of the Mississippi River valley (Secs. 29 & 30, T. 8 N., R. 6 W.).

The Prairie du Chien group is considered to be Early Ordovician in age and the group comprises the entire Lower Ordovician, Canadian Series. Fossils are scarce and poorly preserved so that age determinations are speculative. The best available age data is based on conodont studies by Furnish (1938) which show the Prairie du Chien to be Upper Tremadocian in age (D. L. Clark, personal communication). The following report is concerned primarily with lithostratigraphy and will not discuss time-stratigraphic boundaries.

The Prairie du Chien Group is correlated with the Beekmantown Group of the Appalachian area, the upper Knox Group in Tennessee, the upper Arbuckle Group in Oklahoma and the Ellenburger Group of central Texas (Twenhofel, et. al., 1954). Attempts at more detailed interregional correlation have been made by Heller (1956) between the Prairie du Chien and Lower Ordovician strata in the Ozark region. He correlated the Gasconode Formation, Roubidoux Formation and Jefferson City Group of that area with the Prairie du Chien.

Basal Contact

One of the major difficulties in studying the Prairie du Chien is the lack of agreement on placement of its basal contact with the underlying Jordan Sandstone. The Jordan has been considered in past reports as containing three members. In ascending order they are Norwalk, VanOser, and Sunset Point members (Ostrom, 1965; 1967). At least one author (Raasch, 1951; 1952) has considered the Sunset Point as a formation.

Inclusion of this dolomitic quartz sandstone and quartzite dolomite in the Jordan or giving it formation rank violates the basic principles of lithostratigraphy. The gross lithology changes at the top of the VanOser Member of the Jordan as does the weathering profile (Fig. 3). Dolomitic strata form resistant ledges above the friable quartz sandstone of the VanOser. As a result of the above characteristics the contact between the friable quartz sandstone (VanOser Member of the Jordan Formation) and the overlying dolomitic strata is chosen as the basal contact of the Prairie du Chien Group.

The presence of Cambrian fossils in the lower dolomitic strata has caused these beds to be grouped with the Jordan Formation and given a separate name (Sunset Point). As a result lithostratigraphic units were defined on the basis of fossils. Sound rock stratigraphic units should be completely divorced from any paleontological bases. It is of no major consequence where the Cambro-Ordovician boundary occurs with respect to the Prairie du Chien Group.

The above designated contact is conformable at all exposures visited. There have been suggestions of an unconformity at the base of the Prairie du Chien Group (Fig. 2) but there is no physical evidence for such a stratigraphic relationship.

Oneota Formation

The Oneota Formation (McGee, 1891) is the best exposed formation in the Prairie du Chien Group. It is thickest in the type area of the Upper Iowa River valley in Allamakee County, Iowa (loc. 7) where more than 200 feet are exposed (Fig. 4). The Oneota is a medium crystalline, medium to thick bedded dolomite with local zones of algal stromatolites, oolites, shale, and chert.

In naming the Oneota for the "Main body of limestone" of Owen (1840), McGee included all of the "magnesian and arenaceous limestone" above the Potsdam (Jordan Sandstone) and below the New Richmond which he included in the St. Peter Sandstone (McGee, 1891, p. 332). His intentions clearly seem to include the entire sequence of dolomitic strata above the pure quartz sandstone of the Jordan. Such an intention is evident by the distinct lithologic and weathering profile difference in the Upper Iowa River (Oneota River) valley where McGee made his observations.

This designation by McGee (189) was evidently overlooked in establishing the Sunset Point (Madison) as a lithic unit. At all exposures and in the subsurface, these quartzitic dolomites and dolomitic quartz sandstones are obviously better considered as part of the Prairie du Chien Group for mapping and subsurface recognition. It is recommended therefore that the term Sunset Point (Raasch, 1951; 1952) be limited to informal usage in the upper Mississippi valley.

Stockton Hill Member

The name Stockton Hill is here introduced for all the dolomitic quartz sandstone, quartzitic dolomite, and associated strata in the lower portion of the Oneota Formation. It represents a transition sequence from the pure quartz sandstone of the Jordan Formation to the overlying pure dolomite strata of the Oneota. The Stockton Hill Member contains algal stromatolite beds, intraclastic zones, oolites, chert, and some glauconite in addition to the dominant lithologies. This makes for considerable lithic heterogeneity within the Stockton Hill but it is also quite distinct and easily recongizable from units above and below.

The Stockton Hill Member ranges in thickness from only a few feet over the Wisconsin Arch (Fig. 4) to more than 50 feet along the Mississippi River in the north-central portion of the outcrop area (Fig. 1). The unit is thin and somewhat irregularly bedded, buff to tan in color and forms a resistant profile that generally conforms to that of the overlying pure dolomites.

The name Stockton Hill is taken from the bluff bearing that name that overlooks the town of Winona, Minnesota (Goodhue County). The reference exposure (Fig. 5) is a roadcut on the north side of U. S. Highway 14 as it ascends the bluff 3 miles west of Winona (T. 107 N., R. 7 W., Sec. 30) (loc. 11). The roadcut is quite accessible and exhibits the entire unit with a thickness of 42 feet.

The basal boundary of the Stockton Hill Member coincides with that of the Prairie du Chien Group and is as discussed above. The upper limit of the Stockton Hill is much more subtle but it is easily recognizable and consistent throughout the outcrop belt. The upper boundary is here defined as the top of the quartzitic bed above which there is dolomite without quartz. At most exposures this change in lithic character is abrupt; however, there is no surface expression in the weathering profile (Fig. 5), not even a bedding plane break. Consequently, the contact cannot be recognized at a distance but it is readily apparent at hand lens range.

The Stockton Hill Member is therefore a distinct lithic entity composed of irregular mixtures of quartz and dolomite. It is nicely bounded by pure quartz sandstone below and pure dolomite above (Fig. 5).

History of Nomenclature - During the past several decades strata of the Stockton Hill Member have been subjected to a variety of nomenclature. The result has been considerable confusion and lack of general agreement among stratigraphers.

The Madison Sandstone was originally designated by Irving (1875) for dolomitic sandstones in the Madison, Wisconsin, area. This was subsequently modified by Wannemacher, Twenhofel, and Raasch (1934) to include only the "beds of transition" between the quartz sandstone of the Jordan and the Oneota carbonates. Such a designation at first seems reasonable; however, the upper limit of the Sunset Point was poorly defined and has not been agreed upon by subsequent workers (Raasch, 1952; Ostrom, 1965; Melby, 1967). The boundary has been picked at grain size changes, oolite, chert and algal content, and other minor differences. In all cases this boundary was below that chosen by this author for the upper limit of the Stockton Hill. The distinct lithic change at this horizon was either not recognized or not deemed significant.

In addition, the Sunset Point was almost universally excluded from the Prairie du Chien (Raasch, 1935, 1952; Ostrom, 1965; Melby, 1967). Raasch's original definition (1935, p. 314) states that:

> The upper boundary of the formation lies at the line of separation between the fine grained, well-sorted and in many cases very firmly indurated dolomitic sandstones below and the prominent cobble-conglomerates or ill-sorted, calcareous sandstones and green glauconitic siltstones above. These latter rocks mark the base of the Ordovician Oneota formation . . .

McGee's original designation of the Oneota (1891) indicates that the dolomitic strata discussed above should be included in the Oneota. Apparently the presence of Cambrian trilobites in these strata and what was believed to be an unconformity at the top, caused Raasch to separate them from the Prairie du Chien. There is no physical evidence for an unconformity and the presence of the Cambrian fossils is irrelevant to lithostratigraphic procedures.

All of the above discussion supports the concept of a newly designated unit in this transition zone and a unit that is easily defined and recognizable in the outcrop and subsurface. The Stockton Hill Member as here defined fulfills these criteria.

Hager City Dolomite Member

The term Hager City is here designated to be applied in member rank to the dolomite strata between the Stockton Hill Member below and the Shakopee Formation above. This unit is mineralogically homogenous with only thin beds of chert and shale in an otherwise pure dolomite. The Hager City reaches a maximum thickness of 180 feet in northeastern Iowa and thins to less than 100 feet in the Wisconsin Arch area and the northern portion of the outcrop belt (Fig. 4). In the subsurface of Iowa and Illinois it thickens to several hundred feet.

The name Hager City is taken from exposures above the town of that name in Pierce County, Wisconsin. The reference section is designated as that exposed on the west side of the roadcut through the dolomite bluffs along U. S. Highway 65, 1.5 miles northeast of Hager City and 2 miles north from the intersection of U. S. 65 and Wisconsin 35 (T. 25 N, R. 18 W, Sec. 35) (loc. 14). Although the Hager City is only 92 feet thick at this locality it is well exposed, fairly accessible, and both boundaries are recognizable.

The Hager City is the most lithologically homogenous of the Prairie du Chien units. It is pure dolomite with only a few thin discontinuous beds of quartzitic dolomite. Several such quartz bearing beds are in the area of the Baraboo Syncline and one is present at the type locality near Hager City, Wisconsin.

The bulk of the Hager City is homogenous medium crystalline dolomite (Fig. 5). At many exposures it has a saccroidal texture. The dolomite is dense at most places but may be vuggy locally. Commonly these vugs are lined with drusy quartz. Small vugs a few millimeters in diameter are also common locally. Close examination suggests that these are apparently fossil fragment molds.

Algal stromatolites are the only common and readily identifiable organic remains in the Hager City and in the entire Prairie du Chien Group. Preservation is generally fair to poor but in some exposures algal stromatolites show nicely preserved laminated structures. Poor preservation is apparently the result of recrystallization of the carbonates and occurs in medium to coarsely crystalline dolomites. These stromatolites are vuggy and show a characteristic weathered surface. Although it is difficult to determine for certain, these appear to be mostly laterally linked hemispheroids--closely spaced (LLH-C type) (Logan, Rezak, and Ginsburg, 1964).

The well preserved algal stromatolites are smaller (less than one foot in diameter) than those described above but of the same LLH-C type. They are finely crystalline dolomite and laminations are well preserved. Some are silicified. Stratigraphically the well preserved stromatolites are most abundant near the base of the unit although they have been found at several horizons.

Digitate stromatolites (Howe, 1966) of the SH (spaced hemispheroid) type are common in much of western Wisconsin, and northeastern Iowa in the upper half or so of the Hager City Dolomite. These stromatolites are generally poorly preserved and show a unique vertical weathering pattern (Fig. 6). Each digit is two to four inches in diameter and is relatively resistant to weathering whereas elongate vugs are present between them. These vugs are commonly lined with quartz crystals and the stromatolites are at least partially silicified.

Intraclastic dolomite is present but uncommon in the Hager City. It is associated with the small well preserved algal stromatolites. The clasts are very finely crystalline dolomite and range widely in size.

Oolites are also present in the Hager City both as dolomite and in silicified form. Distinct beds of oolites may occur throughout the unit with highest concentrations in the lower portion associated with stromatolitic beds.

Greenish gray shale in thin discontinuous beds is also present in the Hager City particularly in southwestern Wisconsin. Some are parallel to bedding and some undulate with a few feet of relief. There are pockets of this shale locally along some beds which seem to be solution pockets where the shale is concentrated. Some of these are filled with reddish-brown clays which are mixed-layer types common in soils formed on a dolomitic terrain (Ostrom, 1965).

Chert nodules and thin beds of chert are present at most exposures of the Hager City. They are pink or gray and may be massive or with a concentric structure. Large calcite cleavage fragments are common where the Hager City is overlain by a pure quartz sandstone New Richmond Member of the Shakopee Formation. The calcite crystal may be as large as a persons fist and are probably due to ground water percolation through the permeable quartz sandstone above.

Key Beds and Lithic Subdivisions - At least two attempts have been made to designate beds or lithic units within the Oneota. Starke (1949) correlated a series of key beds in the lower part of the Oneota from Prairie du Chien to Madison, Wisconsin. Raasch (1952) made a detailed study of the Oneota in a small area (15 min. quadrangle) where he subdivided the unit into four members (Fig. 2). In each of these cases the Oneota was not well defined.

Starke (1949) made detailed correlations within the Oneota using a chert bed, a "chiton" bed, algal stromatolites, oolites, and a "green speckled" bed. The key beds occur in the lower 40 feet of the Oneota and Starke believed he could demonstrate onlap of the beds onto the Wisconsin Arch. Chert, algal stromatolites, and oolites are fairly common in the Stockton Hill Member (Fig. 7). Glauconite ("green speckled" bed) is also abundant in several beds at this general stratigraphic horizon and chiton beds have been recognized at a different horizon than that reported by Starke (1949). The Stockton Hill Member contains a variety of stratigraphic arrangements of these "key beds" throughout the upper Mississippi valley. It is, therefore, the opinion of this writer that such lithologic correlations must be viewed with caution.

An intensive study of lithic associations led Raasch (1952) to conclude that the Oneota can be subdivided into four members. His report was restricted to the Stoddard Quadrangle along the Mississippi River in southern LaCrosse and northern Vernon counties, Wisconsin, however he had many years of experience with these strata in other areas. A dozen closely spaced exposures of the lower part of the Oneota were described in detail. The result was the designation of the Hickory Ridge, Mound Ridge, Genoa, and Stoddard Members (Fig. 2) in ascending order. Such lithic characteristics as chert, oolite, "chiton" beds, "green speckled" beds, quartz sandstone, and algal stromatolites were used in defining the members. M. E. Ostrom (personal communication) of the Wisconsin Geological and Natural History Survey has been able to recognize Raasch's members in areas of western Wisconsin beyond the Stoddard Quadrangle.

The present writer does not concur with stratigraphic conclusions in either of the above mentioned studies. All of Starke's (1949) key beds are restricted to the lower portion of the Oneota. The correlation of environmentally controlled local depositional features like glauconite, oolites, and algal stromatolites over an area the size of the upper Mississippi valley is not likely with any degree of accuracy.

Raasch's upper members, Genoa and Stoddard, are based on subtle criteria such as color, bedding characteristics, and weathering appearance (Raasch, 1952). While it may be possible to recognize these differences in a small area and correlate them on closely spaced exposures, the members do not persist throughout the upper Mississippi Valley area. The only lithologic trends within the Oneota are the concentration of stromatolites in the upper part and the generally dense, uniform dolomite in the lower part (Fig. 7). It is not suggested that these contrasting lithic types be used as formal units because there is some mixing and they are not recognizable throughout the entire outcrop area.

Oneota - New Richmond Contact

The sharpest and most easily recognized rock-stratigraphic boundary within the Prairie du Chien Group is that between the Oneota Formation and the overlying New Richmond Member . For several decades there has been some debate over the nature of this contact with some authors describing it as resulting from continuous deposition (Powers, 1935; Heller, 1956; Shea, 1960) and some interpreting it as an unconformity (Ulrich, 1924; Andrews, 1955). The present writer falls into the latter category (Davis, 1968).

Those who consider the Prairie du Chien as a formation are generally the same people who believed the Oneota-New Richmond contact to be conformable. This type of thinking follows the old tradition that formations may be bounded by unconformities but don't contain them. Some authors who advocated a break between the Oneota and New Richmond did so on the basis of paleontologic criteria. Sardeson (1896), Stauffer (1937a; 1937b) and Furnish (1938) in particular, found distinct changes in fauna across the contact. Physical evidence for an unconformity at this horizon was cited by Ulrich (1924), Needham (1932), Andrews (1955), and Crain (1957) as well as the present writer (Davis, 1968).

Ulrich (1924) was the first to describe both physical and biological evidence for an unconformity within the Prairie du Chien. This surface in the upper Mississippi valley area was correlated with the boundary between Ulrich's Ozarkian and Canadian systems. These terms have not gained acceptance and were designated as systems by Ulrich because of the great thickness and faunal zones of equivalent strata in the Appalachian area.

Physical evidence cited by Ulrich (1924) includes 1) thin Oneota, 2) uneven contact at the top of the Oneota, 3) basal conglomerate of chert and dolomite pebbles mixed with quartz sand, and 4) local absence of a fossiliferous zone in the upper Oneota. Field data by the present writer (Davis, 1968) support these data (Figs. 8 and 9) with the exception of the fossiliferous zone which was not studied. There are three excellent exposures which exhibit distinct truncation of the Oneota. One is an abandoned quarry near Eastman (Vernon County), Wisconsin where uppermost Oneota beds are arched locally (Fig. 8b) (Andrews, 1955). Several feet of Oneota are truncated in the Upper Iowa River valley north of Waukon (Allamakee County), Iowa, (Fig. 8a) and at the Chicago, Burlington and Quincy Railroad quarry near Wyalusing (Grant County), Wisconsin. Small scale relief (Fig. 9a and 9b) and basal conglomerates are present at several exposures with coarse quartz sand, and pebbles of dolomite and chert. The dolomite pebbles are typical Oneota lithology (Fig. 9c and 9d). Thin sections of the contact show small scale irregularities on this surface and truncation of grains (Fig. 9e and 9f). The latter suggests that dolomitization may have taken place before erosion of the surface.

Although the upper surface of the Oneota is clearly one of erosion (Figs. 8 and 9), it is apparently not of major significance as suggested by Ulrich (1924). Exposures in the western part of the outcrop area (Olmsted and Goodhue Counties, Minnesota) do not display this unconformable surface and in fact the contact between the Oneota and the overlying New Richmond is not distinct. At some exposures, for example, near Vasa (Goodhue County), Minnesota, it is not practical to subdivide the Prairie du Chien at all (Crain, 1957). One core was examined from central Iowa and it showed no evidence of an unconformity within the Prairie du Chien.

The overall picture of this contact between the Oneota and New Richmond is one of a typical minor unconformity in a marine sequence. Most of the outcrop area in the upper Mississippi valley shows a distinct erosion surface but it becomes absent to the south and southwest which is the thicker part of the Prairie du Chien. Although ~~he~~ had superficially examined only a few exposures of this contact in the field, Ostrom (1964) he theorized that it should be unconformable in order to fit the cyclic pattern of the Cambro-Ordovician strata in this area.

Shakopee Formation

A recent paper by this writer (Davis, 1966a) revised the nomenclature of the Prairie du Chien Group based on regional field studies. The most significant contribution in that report was in considering the upper two units of the Prairie du Chien as members (New Richmond and Willow River) of a formation (Shakopee). This differed from most previous reports which considered each of the three recognizable rock-stratigraphic units to have the same rank regardless of whether the Prairie du Chien was considered a formation or a group (Fig. 2).

Lithologically and sedimentologically the New Richmond and Willow River are similar and are distinct from the underlying Oneota which is similarly associated with the Jordan Formation (Davis, 1966a, 1966b). The New Richmond and Willow River were considered as sedimentological cycle by Ostrom (1964). These two units are composed primarily of dolomite, quartzitic dolomite, and quartz sandstone with some shale and chert. In most sections of the Upper Mississippi valley the New Richmond and Willow River can easily be distinguished from each other although there are places where they cannot. Several exposures exhibit a pure New Richmond quartz sandstone which is in contrast to the overlying Willow River interbedded facies (Fig. 7). It is logical to consider these two units as members because of the locally similar lithologies, sedimentological association, and the New Richmond is not thick enough in some areas to be mapped on the scale necessary for a formation.

Various applications of the term Shakopee have been made since its introduction by Winchell (1874). Most commonly it has been considered as the upper dolomite unit of the Prairie du Chien. Because of Winchell's confusion about the stratigraphy on the Minnesota River valley and the strata present at the town of Shakopee, Minnesota, the term has also been used to include the quartz sandstone unit and the upper dolomite (Davis, 1966a).

Two reference sections are here designated for the Shakopee: U. S. Highway 63, about 2 miles northeast of Hager City, Wisconsin (loc. 14) and the other on Iowa State Highway 364, about 2 miles south of Waukon Junction, Iowa (Secs. 9 & 16, T. 96 N., R. 3 W.) (loc. 5). The latter exposure shows the entire formation (Fig. 10) but its basal contact with the Oneota is poorly exposed.

The thickness of the Shakopee Formation ranges from being absent due to pre-St. Peter Sandstone erosion to 80 feet. Only one exposure was found which included the entire formation overlain by the St. Peter Sandstone and it is located near Mr. Vernon, Wisconsin, where the formation thins over the Wisconsin Arch. The Shakopee is not a prominent ledge former nor is it quarried extensively as is the Oneota. As a result exposures are restricted to roadcuts and become at least partially grown over. This probably has contributed to the confusion and lack of study of this unit.

New Richmond Member

The New Richmond Member (Wooster, 1882) has the greatest variety of lithologic characteristics of all Prairie du Chien units. Commonly designated as the "New Richmond Sandstone" it is not a sandstone at most exposures but generally is a sequence of interbedded quartz sandstone, quartzitic dolomite, and shale, with chert, oolites, and algal stromatolites locally common. The only area in the upper Mississippi valley where the New Richmond is a homogenous quartz sandstone is in southeastern Minnesota and northeastern Iowa (Fig. 7). This is the area where the New Richmond attains maximum thickness of 46 feet.

In most sections of the outcrop area the New Richmond is easily recognized and distinguished from the overlying Willow River Member. The basal contact with the Oneota is distinct and obvious as discussed above. There is no problem in picking the upper boundary where the New Richmond is a quartz sandstone because an obvious lithologic change occurs at that horizon.

In areas where the New Richmond and Willow River members are more similar the boundary is not so obvious. It can, however, be recognized, and as one becomes familiar with these two members there is really no problem in picking this contact. There is commonly a change in weathering and resistance at this horizon in that the New Richmond is high in quartz sandstone and shale which are relatively non-resistant as compared to the dolomite ledges of the overlying Willow River (Fig. 10). Shale and quartz sandstone beds are present in the Willow River but not abundant. The contact is picked at the top of the uppermost greenish-gray shale or quartzitic shale below dolomite which at most exposures is algal stromatolites. Because of the general similarities of the New Richmond and Willow River lithologies at many localities it is difficult to explain how they can be distinguished; however, when viewed on a quarry face or roadcut the distinction between them is obvious (Figs. 8b and 10).

The wide range of lithic types that may be found within the New Richmond can be considered as two distinct facies which are essentially mutually exclusive geographically. One facies is a quartz sandstone facies which occurs in the central portion of the outcrop area (southeastern Minnesota and part of northeastern Iowa). The other is the quite heterogenous interbedded terrigenous and carbonate facies described above. Throughout northwestern Wisconsin, part of southeastern Minnesota and southwestern Wisconsin this facies is present (Fig. 7). There is a subtle but consistent difference between the northern and southern areas. It is in terms of abundance of greenish gray shale which is not common in the north but is quite abundant in most southwestern Wisconsin exposures.

It has long been realized that the type area chosen by Wooster (1882) when he named the New Richmond is about the poorest place to see the unit exposed. This was the primary reason for Stauffer and Thiel (1941) changing of the name to Root Valley. Reference sections where this unit is well exposed and thick are those in Allamakee County, Iowa (locs. 5 and 7), and at Lanesboro (Fillmore County), Minnesota (loc. 10) (Fig. 4).

<u>Willow River Member</u>

The Willow River Member of the Shakopee Formation was also named by Wooster (1882) and also presents problems regarding the type area he designated. Along the Willow River near Burkhardt (St. Croix County), Wisconsin where Wooster first described the unit there are a series of three dams which have ponded water submerging some exposures. There is a deep, steep sided gorge where type strata are exposed but it is presently not accessible for detailed examination. It is, therefore, necessary to designate reference sections for the Willow River Member. At most localities the Willow River is thin because of erosion prior to deposition of the overlying St. Peter Sandstone, however, there are three thick, geographically spaced, and easily accessible exposures of the Willow River that can serve this purpose. They are 1) near Hager City (Pierce County), Wisconsin on U. S. Highway 63 (loc. 14), 2) on Minnesota State Highway 74 at the village of Troy (Fillmore County), and 3) the exposure near Waukon Junction (Allamakee County), Iowa (loc. 5).

The Willow River is primarily dolomite and quartzitic dolomite with thin beds of quartz sandstone, oolite, chert and shale. Algal stromatolites are abundant and well preserved particularly in the lower part of the unit. Intraclasts are also abundant and at most exposures are concentrated above the stromatolites.

The distinction between Hager City type lithology and that of the Willow River can be made with ease. The most striking contrasts are the ubiquitous presence of at least a few quartz grains in Willow River samples, generally finely crystalline dolomite, and the thin bedded character. The Willow River is a much more heterogenous unit than the Hager City. Primarily because of the quartz content there are few quarries in this unit but many in the pure dolomite Hager City.

As is the case with other Prairie du Chien units there are no key beds within the Willow River Member that can be correlated over a significant part of the outcrop area. Several algal stromatolite beds can be traced between a few exposures. There is, however, a general pattern to the distribution of lithic types in the Willow River. In general it closely parallels that in the New Richmond. Terrigenous constituents (shale and quartz sandstone) are most abundant in southwestern Wisconsin. A broad belt of algal stromatolite concentration (Fig. 7) extends from the southwestern corner of Wisconsin near the town of Prairie du Chien to the north-northwest. Southeastern Minnesota and northwestern Wisconsin contain noticeably little of the above mentioned constituents.

Prairie du Chien - St. Peter Sandstone Contact

Although some question has been raised about the character of the upper surface of the Prairie du Chien Group (Flint, 1956) it is interpreted by most geologists as a major unconformity. It serves as the boundary between Lower and Middle Ordovician strata and can be traced for considerable distances beyond the upper Mississippi Valley. Sloss (1963) uses this surface as the boundary between the Sauk and Tippecanoe sequences.

There is as much as 300 feet of relief on the pre-St. Peter surface and in some places the St. Peter Sandstone rests directly on known Cambrian strata with the entire Prairie du Chien removed. There are some localities where the St. Peter is in direct contact with the Oneota. Although this surface is well known and has been mapped it is not well exposed. Most of the available data are from subsurface records.

In the study area there are a few exposures where the Willow River can be seen in direct contact with the St. Peter. At each there is a striking contrast in lithology between the dominantly carbonate Willow River and the sorted and rounded, generally friable quartz sandstone of the St. Peter (Fig. 11). A bed of varigated shale is present at the base of the St. Peter which may represent residium from eroded carbonate material.

The situation that led Flint (1956) to question the unconformable nature of the pre-St. Peter surface is the apparently parallel relationship of some Willow River and St. Peter strata and the locally steep dipping upper beds of the Willow River. In southwestern Wisconsin there are several localities where these strata dip as much as 40° and in a variety of directions. Flint did not observe any exposures that showed truncation of Willow River strata by the overlying St. Peter. He assumed that the steeply dipping beds were depositional features caused by sediments being draped over algal reefs and that the St. Peter was subsequently and conformably deposited over them.

These conclusions are not substantiated by field data. First of all there are no reefs in the Willow River that would cause the draping of overlying strata as suggested by Flint (1956). There are localities where St. Peter Sandstone clearly truncates Willow River strata (Fig. 11). The steep and randomly oriented dips may better be explained by a karst surface prior to deposition of St. Peter with the steep dips being the result of collapse as theorized by Buschbach (1961) for the Illinois area or subaerial erosion as postulated by Palmquist (1969).

PETROLOGY

General

Rock types in the Prairie du Chien Group are mineralogically simple but diverse from the standpoint of origin and texture. Carbonates which are essentially all dolomitized and quartz sandstone are the only common lithic categories with the former being distinctly dominant. Local thin beds of microcrystalline chert and greenish gray illitic shales are also present.

Dolomitization has prohibited determining the specific origin of many grains, however, depositional textures are still evident in the vast majority of Prairie du Chien carbonates. In all descriptions and discussions of carbonates, the terminology used is that of Folk (1959, 1962) and will consider the predolomitization character of the rocks as they are uniformly dolomitized. One modification of Folk's terminology is necessary as the result of nearly complete obliteration of the character of biogenic debris. Many medium to coarsely crystalline dolomites are undoubtedly biogenic and are here called "grain sparites" (Davis, 1966b). Textural terminology also follows that suggested by Folk (1962).

Carbonate types in Prairie du Chien strata include grain sparite, intrasparite, oosparite, micrite and algal biolithite. Of these micrite is the only one which is not present at most outcrops. There is also a conspicuous scarcity of pellet rocks which are common in many Lower Paleozoic carbonates. It is possible that these may have been completely destroyed during dolomitization or that their occurrence has been overemphasized by previous workers. Quartz sandstone and illitic shale are the only significantly abundant terrigenous rock types in the Prairie du Chien.

Grain Sparite

By far the most prevalent lithic type is grain sparite which occurs in a variety of textural arrangements. Without exception, it seems to be a grain supported texture with the grains at least approaching equidimensional character. These shapes yield a rock which exceeds about 50 percent "grain bulk" (Dunham, 1962) in all cases, however, the nature of the preservation in the grains or ghosts prevents an estimate of the "grain-solid." Most grains are apparently fragments of skeletal material rather than complete organisms so that "grain bulk" and "grain-solid" would be at least subequal. Preservation of grains ranges widely, from nicely defined individuals (Fig. 12a & 12b) to being completely invisible and only inferred (Fig. 12e). The inference is based on the generally medium to coarsely crystalline dolomite and the absence in these rocks of any other allochems such as intraclasts and oolites which are apparently more resistant to complete destruction. Most samples of what are here called grain sparites have at least some grain ghosts present.

Grain sparites in the Prairie du Chien are sorted and rounded; however, a few thin sections show some interstitial micrite indicating absence of significant currents. Grain size ranges through medium and fine calcarenite with some extending into the calcirudite category. Oolites, intraclasts and quartz grains comprise minor percentages of the total grain composition at some horizons.

Sparry cement is typically in the form of a dolomite mosaic but locally distinct zoned dolomite rhombs are present (Fig. 12e).

Recrystallization* has caused the grain size to be generally uniform in the authigenic and transported constituents.

Intrasparite

There seems to be little or no destructive effect of dolomitization and recrystallization on intraclasts. Intraclasts are readily visible in thin sections and also in hand specimens of most samples. Aphanocrystalline to very finely crystalline clasts of dolomite are present in a wide variety of sizes from medium sand up to diameters of a few centimeters. Large clasts tend to be elongate as expected from their inferred origin but all sizes show some evidence of rounding. Sorting is generally not as good as in grain sparites. Pure intrasparite is rare with grains, quartz sand and oolites, generally appearing in moderate to small quantities (Fig. 12c). Most clasts are pure carbonate mud but a few have quartz or carbonate grains incorporated in them.

Intrasparites in the Prairie du Chien are most commonly associated with algal stromatolite horizons although they do occur in thick sequences of grain sparites as well. Some clasts which are juxtaposed with stromatolites are actually "algalclasts" (Davis, 1966b) in that they are laminated and built by the algae but were torn up while semi-lithified. They represent the mode of origin proposed by Folk (1959) in his original definition of intraclasts.

*Recrystallization is used in the sense of that prescribed by Folk (1965).

Locally intraclasts are virtually <u>in situ</u> and can be related to subjacent layers of micrite providing convincing evidence for their origin. Some layers of micrite show disruption and what seem to be cross sections of desiccation features, but there has been no transportation of the "clasts."

<u>Oosparite</u>

Oolites occur as dolomites and in silicified or partially silicified form in the Prairie du Chien. The environment of modern oolite formation and accumulation suggests that these were all probably oosparite although this cannot be directly determined for the silicified samples. There is no evidence of any micro-crystalline carbonate in any of the oolitic rocks examined. By their inherent properties and their mode of formation, oolites are spherical and generally at least moderately well sorted. In many samples from the Prairie du Chien, however, there are numerous elongate oolites, superficial oolities, compound oolites, reworked oolites, and quiet water oolites (Fig. 13f) (Freeman, 1962; Davis, 1966c). Locally oosparites lack their typical sorted character. These characteristics indicate that some of the Prairie du Chien oolites formed under less than the normal moderate to high energy conditions commonly associated with oolite generation. Nuclei of the oolites can be recognized in most samples and are composed of quartz grains, small spherical intraclasts, and what are apparently biogenic grains.

Micrite

Microcrystalline carbonate (Fig. 12d) is not abundant in the Prairie du Chien and where present it is in thin beds which may not persist across some of the exposures. Most of these beds are structureless and may be overlain by, or laterally grade into, intraclastic rocks thereby indicating the origin of the intraclasts. There has evidently been some grain growth and recrystallization because locally the grain size is greater (6-10μ) than the common limit of micrite so that the term microspar (Folk, 1959) would seem appropriate. The grains probably grew as the result of coalesive neomorphism (Folk, 1965) as evidenced by the homogenity of the texture.

Dololutites that are thinly laminated, some with quartz silt incorporated, are present at some exposures. These may have been lime mud that was reworked and deposited by gently currents or detrital biogenic debris that has undergone degradational recrystallization and all evidence of grain boundaries eliminated in the process. The former hypothesis seems most plausible.

Algal Biolithite

The only abundant organic remains which are readily recognizable in the Prairie du Chien are algal stromatolites. There is a wide range in preservation and consequently only those composed of well preserved laminae are visible in thin section. The well perserved structures (Fig. 13a & b) are composed of very fine to finely crystalline dolomite with local patches or gains of quartz sand, oolites, and "grains." Laminae range from less than one to several millimeters in thickness. Some laminae have thin opaque black lines which have been interpreted as organic films from the blue-green algae which constructed these structures. Some of the thick laminae show the original character of detrital particles such as pellets and biogenic debris.

Quartz Sandstone

Primary terrigenous contribution to the Prairie du Chien Group is in the form of generally well sorted and rounded, fine to medium quartz sandstone. It occurs as thin beds in carbonate sequences and in thick accumulation in the Shakopee Formation but is essentially absent from the Hager City Member of the Oneota. Mean grain size data from thin section measurements of about 50 samples falls just about at the fine-medium sand boundary (2.0ϕ). Some samples show a distinct bimodal character.

There are three general categories into which Prairie du Chien quartz sandstones fall: 1) those that are friable with practically no cement, 2) those cemented by secondary growth of the quartz grains (Fig. 13c), and 3) those cemented by carbonate material (Fig. 13d). In the case of the latter, the cement may be poikilotopic with the crystals of cement reaching several centimenters in diameter (Fig. 13e). Most quartz sandstones studied are almost pure quartz but locally there are minor amounts or reworked silicified oolites, rock fragments, intraclasts, "grains," and feldspar. Nearly every thin section has a grain or two of feldspar. Both plagioclase and potassium feldspar are present and there is noticeably wide range or weathering in the potassium feldspar. Many also show overgrowths.

Oneota Formation

Stockton Hill Member

The Stockton Hill Member of the Oneota contains every lithic type found in Prairie du Chien strata. It is quite heterogenous from base to the top at each exposure but this characteristic tends to aid in recognition of the Stockton Hill. Even though it contains a wide range of lithic types the Stockton Hill Member is quite similar at all outcrops and in this respect it is the most predictable of all Prairie du Chien units (Fig. 7).

There is a general stratigraphic pattern to the lithology of the Stockton Hill at each exposure. The lower portion contains mostly quartz sandstone with the upper portion being comprised of various carbonate types in addition to quartz. Quartz sandstone in the Stockton Hill is less sorted, generally finer grained and is carbonate cemented in contrast to the underlying Van Oser Member of the Jordan Formation.

Glauconite is common at multiple horizons at several localities. This might serve to distinguish the Stockton Hill from the New

Richmond in which glauconite is quite rare. In all other respects these two units are remarkably similar except where the New Richmond is a pure quartz sandstone.

Quartz in the Stockton Hill is in the fine to medium range and is mostly sub- to well-rounded. Detrital chert and feldspar grains are present in most quartz sandstone. Quartz grains lack overgrowths and are nearly all of the straight extinction variety.

Allochems tend to be fairly well preserved in most dolomites in the Stockton Hill although some are medium crystalline rhombic dolomite that lacks any evidence of allochems. Intraclasts and oolites are the most abundant varieties. The latter occur in both dolomitized and silicified form. Grain sparites are rare in the Stockton Hill which is not unexpected because of the other carbonate types present.

The typical associations of oolites, algal stromatolites, and intraclasts is prevalent in this unit. Quartz grains occur in varying percentages throughout these rock types but they are rarely incorporated into the stromatolite structures.

Pure dolomite is uncommon in the Stockton Hill except for thin discontinuous micritic stringers. These are not present at many exposures. Most dolomite can be categorized as one of two types: a finely crystalline anhedral mosaic, and a medium crystalline rhombic type. The former is usually associated with quartz rich beds and recognizable allochems while the latter contains few, if any, recognizable detrital grains.

Chert nodules are present but uncommon in the Stockton Hill as are silicified oolites. Silicified algal stromatolites are rare in this unit.

Hager City Dolomite Member

Rocks comprising the Hager City Dolomite are by far the most lithologically homogenous of the Prairie du Chien Group. Grain sparite and algal biolithite constitute almost the entire member. Although both carbonate types may be present at any single exposure, there is a distinct concentration of algal biolithite in the western portion of the study area (Fig. 7).

In thin section, it is frequently possible to identify Hager City type grain sparite and distinguish it from that of the overlying Shakopee Formation. Grain size of the dolomite is coarser in the Hager City ranging between 1.50Ø and 2.00Ø in 75 percent of the samples examined with the remaining samples much finer (3.00Ø to 3.50Ø). The dominant coarsely crystalline dolomite is subequally divided into an anhedral mosaic type and another type comprised largely of well formed, zoned dolomite rhombs.

Grains which provided the original allochemical framework for this rock type appear in a fairly narrow range of sizes, at least in those samples where preservation is such that measurement is possible. Mean size is near the middle of the medium sand range (1.40Ø) with good sorting present in virtually all samples. Grains are also well rounded and unidentifiable in almost all samples. One medium crystalline sample from Mr. Vernon, Wisconsin, near the Wisconsin Arch, shows a small bivalve which may be an immature pelecypod or an ostracode. The overall composition of grains probably represents fragments of mollusks, trilobites, ostracodes, brachiopods, echinoderms, and other invertebrates.

Preservation of laminations in the algal biolithite is not good in most places particularly in the area of concentration of stromatolites. These structures are much better seen in place than in hand specimen and are absent in most thin sections. There are, however, some well preserved LLH-C type stromatolites (Logan, _et_. _al_., 1964) occur in isolated places throughout the predominantly grain sparite facies (Fig. 7). In thin section, these structures show distinct laminations of fine to medium crystalline dolomite with small cut and fill channels continuing "grains." Disruptions of the laminae and associated algalclasts are common. Some of the disruptions are suggestive of desiccation.

Oosparites occur in thin distinct beds in the Hager City but these cannot be correlated with any degree of certainty even between adjacent exposures. There is some variety of types present including the typical apparently spherical and well sorted types. Quartz grains are not present as nuclei of Hager City oolites complying with the almost total exclusion of quartz from this formation. Mean grain size is about 1.00ϕ and is consistent throughout the formation. Sorting is good in all but a few of the samples studied.

Distinct beds of dolomite cemented quartz sandstone were found at only two exposures of the Oneota that are not proximal to the apparent source area for Cambro-Ordovician terrigenous detritus. At each exposure [Hager City, Wisconsin (loc. 14) and Lanesboro, Minnesota (loc. 10)] the bed is a thin (0.3 ft.) discontinuous and poorly laminated medium, quartz sandstone. There are many detrital chert grains at both locations and each shows some bimodality in size and rounding with fine subangular quartz and medium well rounded quartz. Both are carbonate cemented. The exposure near Denzer, Wisconsin (loc. 2) contains many grain sparite beds with up to 35 percent angular fine quartz sand incorporated. This exposure is in the area of the Baraboo Syncline and is interpreted to be close to the source of terrigenous materials.

Shakopee Formation

<u>New Richmond Member</u>

All rock types present in the Prairie du Chien can be found in the New Richmond. The two facies that represent the New Richmond show a distinct geographic distribution with the quartz sandstone facies in the central portion of the outcrop belt and the interbedded facies to the northwest and southeast of that area (Fig. 7).

There is an overall homogenity within the quartz sandstone in this unit, in both the pure quartz sandstone facies, and as it occurs in the area of interbedded lithologies. The New Richmond is a sorted and rounded medium quartz sandstone. Mean grain size is actually near 2.0ϕ for most samples placing it on the fine-medium sand boundary. This overall homogeneity does not mean to imply that there is no variety within the quartz sandstone of the New Richmond; there is, but volumetrically it is small.

The interbedded facies contains a wide range of quartz sandstones from those composed entirely of quartz to a subequal mixture of quartz and various types of carbonate allochems. In the latter, quartz may be associated with a single allochem type such as oolites or grains, or with a variety of allochems in the same thin section. Sorting is moderate to good in these areas but in general not as well sorted as in the quartz sandstone facies.

Some local bimodality is present with a coarse (about 1.00Ø) well rounded mode and a finer (about 2.50Ø) less rounded mode. This bimodality occurs both as a homogenously mixed quartz sandstone and a laminated quartz sandstone with the individual laminations being very well sorted. Angular quartz is rare in the New Richmond except when it is due to euhedral faces of secondarily enlarged grains.

Quartz sandstone in the central area is pure with almost all samples 98 percent or more quartz. Every sample examined, however, does have at least a few grains of some other non-carbonate grains. Most common among these are detrital chert, orthoclase, microcline, and rarely plagioclase. Feldspar appears in various weathering stages and many grains have overgrowths.

Silicified oolites are also common in many of the otherwise pure quartz sandstones. The oolites appear in about the same grain size as the quartz, some show truncation of concentric rings and other evidence of abrasion. Occurrence of these silicified oolites is unusual because there is apparently no proximal source for them. Beds of these are not present in this facies of New Richmond. They had to come from the Stockton Hill or Hager City members of the Oneota

Formation, or from the distant interbedded facies of the same New Richmond Member.

Cementation of the quartz sandstone occurs in three forms or cement may be essentially lacking. Silica cement in the form of secondary enlargement of quartz grains is present at many places. In thin section these overgrowths are fairly easy to recognize around the original well rounded grain. The overgrowths may appear in anhedral or subhedral forms which can be seen with the hand lens. This form of cement tends to mask the roundness character of individual grains and reduces porosity considerably. Dolomitic cement is also common (Fig. 13d) and generally in fine to medium crystalline texture. At some locations where the quartz sandstone facies of the New Richmond is massive there is a poikilotopic cement where the cementing material is crystallographically continuous for up to a few centimeters. In hand specimen these samples can be recognized by the glistening cleavage surfaces and in thin section (Fig. 13e) by the optically continuous cement.

Oolites in the New Richmond appear in several forms and textures and because of their possible environmental implications, it is germain to describe these forms in some detail. Virtually all of the types are recognizable in the field. The only outstanding contrast between New Richmond and Hager City oolites is the abundance of quartz grain nuclei in the former and their total absence in the Hager City.

There is some regular geographic and stratigraphic distribution of oolite types in the New Richmond. In the quartz sandstone facies, oolites are uncommon and where present they are represented by mostly quiet water (Freeman, 1962; Davis, 1966) and superficial forms. The quiet water oolites (Fig. 13f) are characterized by accentric nuclei and less than the usual good sorting associated with oolites. Superficial oolites have only a few concentric rings about the nuclei, occur with abundant free quartz grains and also show less than normal sorting.

Throughout most of the interbedded facies oolites are more common and are for the most part more "normal," in that the nuclei are centered with thick concentric coatings and they are well sorted. There are some superficial oolites and a few with accentric nuclei but they are uncommon.

Intrasparite is much more abundant in the Shakopee Formation than the Oneota. In the New Richmond Member this lithic type occurs throughout most of the interbedded facies, but is rare in the quartz sandstone facies. Apparently the texture of intraclasts has not been significantly affected by dolomitization because they are still distinct and easily recognized.

Willow River Member

The petrology and petrography of Willow River rocks has been discussed at length in an earlier report (Davis, 1966b). Lithologic types are much the same as those in the New Richmond but with somewhat different distributions. The most prominent differences are in the abundance of algal biolithite and grain sparite in the Willow River. Oolites are common and for the most part are the normal variety. Intrasparite is generally present in association with algal biolithite but also occurs where stromatolites are absent.

Of all Prairie du Chien units the Willow River contains the greatest concentration of algal stromatolites. Both mounds and mats are present at most exposures although there is a distinct zone of concentration in southwestern Wisconsin and northeastern Iowa (Fig. 7). Overall preservation of stromatolites in the Willow River is good particularly in comparison with those in the Hager City Dolomite Member of the Oneota.

Algal stromatolites in the Willow River display a variety of textures and composition although most contain silt size dolomite of indeterminable origin. Some contain obvious biogenic debris, pellets, oolites, intraclasts, and quartz grains. The latter three constituents are particularly common in small cut and fill structures within the stromatolites.

Most intrasparite in the Willow River is poorly sorted and is located above, and in pockets between algal stromatolites. Some intraclastic rocks are associated with or grade into, thin micrite beds or occur in isolated beds.

Willow River grain sparites are somewhat finer grained than those in the Hager City Dolomite and commonly contain a more recognizable suite of detrital constituents than any of the other Prairie du Chien units. Identifiable biogenic constituents include echinoderm, gastropod, pelecypod, ostracode, and conodont fragments. Most grain sparites are well sorted although a few are poorly washed.

Oosparite in this unit occurs as distinct thin beds or as local pockets in between algal heads. These oolites are more "typical" than those in the New Richmond in that quiet water types are rare except near Vasa, Minnesota. Mean size ranges from 0.25 to 1.00 mm; however, most are near 0.75 mm. Nuclei are composed of both carbonate and quartz. Oosparites are partially or totally silicified at some locations. Those in which silicification is incomplete show individual ooids undergoing the replacement process but little or no change is present in the sparry dolomite cement.

Micrite is not common in the Willow River and where present it is in thin discontinuous beds or in disrupted beds. Most occurrences are pure finely crystalline dolomite although quartz and oolites have been found in these micrites.

Non-carbonate constituents of the Willow River include quartz and shale with minor amounts of feldspar. Few discrete beds of quartz sandstone are present although quartz is scattered at most places. Where it occurs in distinct beds the quartz sandstone is sorted, rounded, medium sand and is quite like that of the New Richmond. Most samples of quartz sandstone have small quantities of potassium and/or plagioclase feldspar with the maximum concentration reaching 21 percent.

DEPOSITIONAL ENVIRONMENTS

Like most of the Lower Paleozoic of the mid-continent area the Prairie du Chien was deposited in a warm shallow sea. This, of course, says essentially nothing but it does serve as a general framework upon which it is possible to be quite specific regarding Prairie du Chien depositional environments. Although dolomitization had obliterated most fossil remains there are numerous features that can be used to reconstruct the probable conditions that prevailed during Prairie du Chien time.

Regional Setting

The north-central portion of the United States did not contain any spectacular structural or topographic features during Late Cambrian and Early Ordovician time. Positive features include the Wisconsin and North Huron domes along the southern Canadian Shield (Fig. 14) and the Ozark Dome. The latter probably had little, if any, influence on the upper Mississippi valley area. The Illinois and Michigan basins were subsiding and receiving Prairie du Chien sediments. The overall tectonic setting was one of stability in the study area.

General Environment

All criteria available in the Prairie du Chien strata indicate that deposition of the entire sequence took place in a shallow marine environment ranging from the intertidal zone to a maximum depth of less than 100 feet. Probably most of the deposition took place in less than 25 feet of water. These general interpretations are based on the bedding characteristics, sedimentary structures, textural and compositional nature of the strata, and biogenic content where preserved.

Ostrom (1964) has postulated a series of cycles for the pre-Cincinnatian strata of the upper Mississippian valley. In all, five cycles are present with four major environments represented in each. Each cycle contains strata representing the littoral, nondepositional shelf, depositional shelf, and biogenic zones (Ostrom, 1964), and is separated from the next by an unconformity.

The Prairie du Chien Group includes nearly all of two cycles with the exception of the basal littoral quartz sandstone which is the Jordan Formation. According to this scheme the Stockton Hill represents both the nondepositional and depositional shelf environments; the Hager City is a biogenic zone with the top of the unit marking the end of the transgressive cycle. The Shakopee Formation represents a complete cycle with the New Richmond containing the first three environments and the Willow River the biogenic shelf. The pre-St. Peter unconformity (Fig. 2) marks the end of this cycle.

With some modification and change in terminology these cycles seem to be valid for the Prairie du Chien. Note that Ostrom did not study these strata in detail. His conclusions were really more like predictions as to where the cycles ought to fall within the Prairie du Chien. The Oneota-Shakopee unconformity was also predicted by Ostrom (1964) without field evidence.

Unquestionably the Oneota and the Shakopee formations represent quite similar environments and there is a similar pattern to changes within the two units. The following discussion will consider each unit individually in order to be specific about temporal and geographic changes in depositional environments.

Oneota Formation

Stockton Hill Member

According to most workers the Jordan Formation represents a beach and inner nearshore type environment. The clean sorted and rounded quartz sandstones are cross-bedded and burrowed throughout the outcrop extent. The basal portion of the Stockton Hill represents the same environment (Fig. 15a) but with some carbonate influx.

Scattered intraclasts and mixed quartz sandstone with various allochemical carbonate constituents suggest a slowing down of terrigenous influx. This transition from a dominantly quartz sand shallow shelf to a carbonate platform apparently extended throughout the upper Mississippi valley.

The upper part of the Stockton Hill is quite varied in composition but all constituents fit nicely into a shallow carbonate platform type environment (Fig. 15b). Oolites, intraclasts and algal stromatolites represent a complex environment that ranges from intertidal to a depth of perhaps 20 feet or so. Oolites form in areas where currents are present and water is shallow. Modern oolite bars in the Bahamas may be awash at low tide. Algal stromatolites are exclusively intertidal to supratidal in modern environments. Intraclasts were probably wave formed so they must have originated at depths less than wave base. Some quartz sand and biogenic debris was accumulating at this time.

There is evidence of reworking in the upper part of the Stockton Hill which is in agreement with Ostrom's (1964) nondepositional shelf environment. Fragments of grapestone (Illing, 1954) like material are present in a few places (Fig. 12f). These clasts are a few millimeters in maximum diameter and contain oolites or both oolites and detrital quartz grains. Lithification must have been rapid as evidenced by truncated oolites in some clasts. The only source of these clasts is the Stockton Hill itself. Rapid cementation must have occurred locally with subsequent wave activity, perhaps storms, in the shallow platform. This would yield similar clasts.

Hager City Member

All sources of quartz sand were essentially shut off during this time except near the Baraboo Syncline in south-central Wisconsin. Two major depositional environments are represented by the Hager City Dolomite; an intertidal environment and shallow neritic shelf. The intertidal environment is characterized by a dominance of algal stromatolites but oolites, intraclasts, and some biogenic debris are associated with them. The shallow shelf area is characterized by the well bedded, fine-medium crystalline dolomite that lacks oolites, algae and other intertidal and near intertidal zone deposits. These beds contain abundant small molds of biogenic debris and are the "buffy beds" of Raasch (1952).

The basal few feet of the Hager City contains algal stromatolites at nearly every exposure. This marks the end of the intertidal environment which characterized the Stockton Hill Member. Except for the south-central Wisconsin area the lower one-third to one-half of the Hager City represents a normal marine platform accumulation (Fig. 15c) of biogenic debris. The basal 15 to 20 feet or so of this lithotype show evidence of bioturbation. Oolites and intraclasts are rare and there is much evidence to suggest a rather diverse fauna occupied this environment and contributed greatly to the resulting grain sparites. Micrite is rare suggesting that currents were probably sufficient to remove fines. Cross-bedding is preserved at several locations to further substantiate this hypothesis. Water depth was probably from about 10 to 100 feet but could have been more.

The upper portion of the Hager City at most locations and the entire unit in south-central Wisconsin is dominantly algal stromatolites (Fig. 15d) with the usual associated lithic types. This represents extensive intertidal areas throughout a moderately long time. There are two major stromatolite forms present and a general pattern to their distribution is present. The two forms are the digitate type (Howe, 1966) and the dome shaped heads described as hemispheroids by Logan, et al (1964). The digitate variety display a characteristic vertical weathering pattern (Fig. 6) but usually have poor preservation of the internal structure. They are present at most exposures but are quite abundant in the northwestern Wisconsin area. The hemispheroid or dome shaped types predominate throughout the remainder of the outcrop area where this intertidal facies is present.

It is generally accepted that differences in form of algal stromatolites can be attributed to environmental differences (Logan, 1961; Logan et al, 1964). Howe (1966) has postulated a headland complex in a transgressive phase of sedimentation for the digitate type. The present writer concurs with the general environment but in the case of the Hager City it represents a regressive phase. The widespread intertidal area of the digitate development was probably in the outer portion of the tidal zone with moderate physical energy characterized by tidal currents. In contrast the more domal shaped stromatolites probably represent a similar general environment but with less physical energy. The logical conclusion one might draw is that the digitate variety represent an area of greater tidal range. The restricted distribution and comparison with modern forms supports this premise. Although a difference in tidal range is suggested modern analogues indicate maximum range is low; probably less than 4 feet.

Shakopee Formation

New Richmond Member

After regression of the Hager City seas there was subsequent erosion prior to the influx of terrigenous quartz sand that comprises much of the New Richmond. This was a minor regression and probably did not include much of the area that is now in the subsurface. Examination of a core from central Iowa yielded no physical evidence for erosion at this horizon.

The New Richmond is the one unit within the Prairie du Chien Group that displays marked facies changes throughout the outcrop area. This reflects the lateral variation in environments during this time (Fig. 15e). In the central part of the outcrop area (northeastern Iowa and southeastern Minnesota) the environment represents the littoral shelf zone of Ostrom (1964, 1970) and is grossly similar to the Jordan Formation in lithology. The two extremities of the outcrop area have a mixed lithology and are comparable to the Stockton Hill (Fig. 7).

The pure quartz sandstone facies of the New Richmond represents accumulation of shallow nearshore sands. Abundant ripples and well preserved small scale cross beds testify to the presence of currents and wave activity. Carbonate is virtually absent as are the thin clay seams which are common in the mixed facies. Rate of accumulation in the area occupied by the quartz sand was high relative to the other areas.

In northwestern and southwestern Wisconsin the New Richmond was accumulating slowly on a very shallow platform (Fig. 15d). Both terrigenous and carbonate material were available but the carbonate constituents are the typical intertidal to shallow neritic types: oolites, stromatolites and intraclasts. Biogenic debris was present but not a dominant factor in sedimentation. Reworking of sediments was also taking place as evidenced by the incorporation of silicified oolites within the mixed facies.

Willow River Member

Sedimentation from the New Richmond through the Willow River was continuous. The overall environment of deposition for much of the Willow River was similar to that of the mixed facies of the New Richmond. The lateral and temporal changes in the Willow River are subtle. The only major environmental change is from the intertidal or very shallow neritic to the normal marine shallow shelf environment.

The lower portion of the Willow River throughout its outcrop extent and most of the unit in southwestern Wisconsin represent the intertidal platform type environment (Fig. 15f) of the Stockton Hill and part of the New Richmond. Detailed study of the unit has indicated a protected intertidal bay type environment for much of southwestern Wisconsin, with an algal headland separating this area from the open marine shelf (Davis, 1966b).

Much of the Willow River Member is missing due to the pre-St. Peter erosion so that it is difficult to determine the conditions that prevailed during the later stages of Willow River deposition. Where thick sections of Willow River are present the uppermost portions indicate an intertidal to very shallow environment. It is easy to see that there is a marked similarity to the sequence of environment in the Oneota and the Shakopee formations. The general conditions of deposition and the cyclic nature of these strata are in agreement with the hypotheses stated by Ostrom (1964).

Summary of Depositional History

Prairie du Chien sediments accumulated on a shallow platform that ranged from intertidal to shallow neritic. A definite cyclic pattern for the changes within this framework can be recognized. The Stockton Hill Member represents a fairly uniform environment of intertidal and near intertidal deposition with many local shoaling areas. The only major change during this time was a trend from the beach and nearshore quartz sands to platform carbonate bodies that received only limited terrigenous influx.

This continued without interruption and with increasing water depth to a biogenic carbonate shelf environment that throughout the area of accumulation except for the Wisconsin Arch in south central Wisconsin which remained as an intertidal and shoaling environment again dominated by carbonates but without any quartz influx. Erosion of the Oneota then terminated the first cycle.

The subsequent sedimentation was not uniform but represented two of the cyclic environments simultaneously. Beach and nearshore sands were being deposited in the central area while a shoaling to intertidal platform was accumulating both carbonate and terrigenous sediments. The intertidal and shoaling environment continued in southwestern Wisconsin while the remainder of the area became a neritic carbonate shelf much like that in the previous cycle. Again erosion terminated the cycle. This time it was extensive and removed hundreds of feet of strata in some places.

General Paleogeography

Directional structures are not widespread in Prairie du Chien strata and those present do not show any patterns. Nevertheless, it is quite reasonable to assume that the Wisconsin Dome and adjacent positive elements provided the source of terrigenous materials. Petrographic evidence indicates that nearly all of the quartz and other detrital noncarbonates were derived from previously existing sedimentary rocks; in this case the Upper Cambrian sandstones. The rounded character of nearly all grains and the predominance of straight or slightly undulatory quartz both testify to this hypothesis. The short distance of transport from igneous and metamorphic areas of the upper midwest would not provide the well rounded and generally spherical quartz grains that occur. Feldspar is present in small quantities. It occurs in a variety of stages of alteration but most grains are fresh and show overgrowths.

Relief was probably not great and the climate was apparently arid to semi-arid through most of the Prairie du Chien. Lack of terrigenous weathering products and evidence of evaporitic conditions support this premise.

The shoreline was probably somewhere to the northeast of the outcrop belt but no evidence for its location is available. Its migration is reflected in the changing environments of deposition.

The basin of accumulation was shallow throughout with some lateral variations. The only structural feature that was apparently present throughout Prairie du Chien time is the Wisconsin Arch extending about north-south just west of Madison. Throughout deposition of these strata this area remained at or near the intertidal environment (Fig. 15). Similar evidence has been recognized for this area in Cambrian sandstones (Ahlen, 1952).

SUMMARY

Field and laboratory studies of Prairie du Chien strata in the upper Mississippi valley have made the following observations and conclusions possible:

1) Prairie du Chien strata can be readily identified in the field and in the subsurface using gross lithic characteristics. The Group consists of two formations: the Oneota and the Shakopee. The Oneota contains the newly designated Stockton Hill and Hager City members and the Shakopee contains the New Richmond and Willow River members. Each of these units is recognizable on the basis of its gross lithic composition.
2) An erosional unconformity separates the Oneota and Shakopee formations throughout the outcrop area. This surface is not deemed to be of major time-stratigraphic significance.
3) Although the carbonate sequences are dolomitized it is possible to recognize their original texture in nearly all samples and their original composition in most.
4) All Prairie du Chien strata represent shallow neritic to intertidal environments of deposition with some alternation of terrigenous influx. Nearly all of the terrigenous material is quartz.
5) Detail study of the Prairie du Chien has confirmed the cyclic nature of these strata as proposed by Ostrom (1964) with some modificatinn of his environments.

ACKNOWLEDGMENTS

I am grateful to A. V. Carozzi of the University of Illinois for introducing me to the algal stromatolite sequences of the Prairie du Chien Group (Carozzi and Davis, 1964). This brief acquaintance with these strata eventually mushroomed into the entire study as reported herein.

L. M. Cline of the University of Wisconsin supervised post-doctoral research on the Willow River Dolomite (Davis, 1966b). A fellowship from the Wisconsin Alumni Research Foundation provided support for this portion of the work. Additional financial support has been provided by a Sigma Xi-RESA Grant-in-Aid, Western Michigan University Faculty Research Grants, and by the Wisconsin Geological and Natural History. Dr. M. E. Ostrom of the latter agency has been particularly helpful in all phases of the study and has critically read the manuscript.

REFERENCES CITED

Andrews, G. W., 1955, Unconformity at the Base of the New Richmond Sandstone: A.A.P.G. Bull., v. 39, n. 3, p. 329-332.

Bain, H. F., 1906, Zinc and Lead Deposits of the Upper Mississippi Valley: U. S. Geological Survey Bull. 294, p. 17-19.

Buschbach, T. C., 1961, The Morphology of the Sub-St. Peter Surface of Northeastern Illinois: Ill. State Academy of Science, v. 54, n. 1-2, p. 83-89.

Carozzi, A. V. and Davis, R. A., 1964, Petrographie et Paleoecologie d'une Serie de Dolomies a Stromatolithes de l'Ordovicien Inferieur du Wisconsin, U.S.A.: Archives des Sciences, Geneve, v. 17, n. 1, p. 47-63.

Crain, W. E., 1957, The Areal Geology of the Red Wing Quadrangle: Univ. of Minn., M.S. thesis, 105 p.

Davis, R. A., 1966a, Revision of Lower Ordovician Nomenclature in the Upper Mississippi Valley: Jour. Geol., v.74, n. 3, p. 361-365.

__________, 1966b, Willow River Dolomite: Ordovician Analogue of Modern Algal Stromatolite Environments: Jour. Geol., v. 74, n. 6, p. 908-923.

__________, 1966c, Quiet Water Oolites from the Ordovician of Minnesota: Jour. Sed. Petrology, v. 36, p. 813-818.

__________, 1968, "Canadian-Ozardian" Unconformity in the Upper Mississippi Valley: (abs.) Amer. Assoc. Petroleum Geologists Bull., v. 52, p. 524.

Dunham, R. J., 1962, Classification of Carbonate Rocks According to Depositional Texture: Amer. Assoc. Petroleum Geologists, Mem. 1, p. 108-121.

Flint, A. E., 1956, Stratigraphic Relations of the Shakopee Dolomite and the St. Peter Sandstone in Southwestern Wisconsin: Jour. Geol., v. 66, p. 396-421.

Folk, R. L., 1959, Practical Petrographic Classification of Limestone: Amer. Assoc. Petroleum Geologists Bull., v. 43, n. 1, p. 1-38.

__________, 1962, Spectral Subdivision of Limestone Types; Classification of Carbonate Rocks: Memoir No. 1, Amer. Assoc. Petroleum Geologists, Tulsa, p. 62-84.

__________, 1965, Some Aspects of Recrystallization of Ancient Limestones in Dolomitization and Limestone Diogenesis: Soc. Econ. Paleo. and Min. Spec. Publ., No. 13, p. 14-48.

Freeman, T., 1962, Quiet Water Oolites from Laguna Madre, Texas: Jour. Sed. Petrology, v. 32, n. 3, p. 475-483.

Furnish, W. M., 1938, Conodonts from the Prairie du Chien (Lower Ordovician) Beds of the Upper Mississippi Valley: Jour. Paleo., v. 12, n. 4, p. 318-340.

Illing, L. V., 1954, Bahaman Calcareous Sands: Bull. Amer. Assoc. Petroleum Geologists, v. 38, p. 1-95.

Irving, R. D., 1875, Note on Some New Points in the Elementary Stratification of the Primordial and Canadian Rocks of South Central Wisconsin: Am. Jour. Sci., 3rd Ser., v. 9, p. 440-443.

Heller, R. L., 1956, Status of the Prairie du Chien Problem: Geol. Soc. America Guidebook for Field Trips, p. 29-40.

Howe, W. B., 1966, Digitate Algal Stromatolite Structures from the Cambrian and Ordovician of Missouri: Jour. of Paleo., v. 40, n. 1, p. 64-77.

Kay, Marshall, 1935, Ordovician System in the Upper Mississippi Valley: Kansas Geol. Soc. Ninth Ann. Field Conf. Guidebook, p. 281-295.

Logan, B. W., 1961, Cryptozoan and Associate Stromatolites from the Recent, Shark Bay, Australia: Jour. Geology, v. 69, p. 517-533.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and Environmental Significance of Algal Stromatolites: Jour. Geology, v. 72, n. 1, p. 68-83.

McGee, W. J., 1891, The Pleistocene History of Northeast Iowa: U.S. Geol. Survey Eleventh Ann. Rept., p. 187-577.

Melby, J. H., 1967, The Stratigraphy of the Sunset Point Sandstone in Western Wisconsin: Unpubl. M.A. thesis, Univ. Wisc., Madison, 95 p.

Needham, C. E., 1932, Northwestern Contributions to the Subsurface Geology of Northern Illinois, between the Outcrops of the St. Peter and Dresbach Formations, with Special Reference to the (Ordovician) New Richmond Formation: Northwestern Univ., Ph.D. thesis.

Ostrom, M. E., 1964, Pre-Cincinnatian Paleozoic Cyclic Sediments in the Upper Mississippi Valley in Symposium on Cyclic Sedimentation: Kansas Geol. Survey Bull. 69, v. 2, p. 381-398.

____________, 1965, Cambro-Ordovician Stratigraphy of Southwest Wisconsin; Guidebook to 29th Tri-State Field Conference: Wisc. Geol. and Nat. Hist. Survey Info. Circ., No. 6, 57 p.

____________, 1967, Paleozoic Stratigraphic Nomenclature for Wisconsin: Univ. Wisc. Geol. and Nat. Hist. Survey, Information Circ. No. 8.

Owen, D. D., 1840, Report of a Geological Exploration in Part of Iowa, Wisconsin and Illinois: House Ex. Doc. No. 239, 26th Congress, 1st Session.

Palmquist, R. C., 1969, The Configuration of the Prairie du Chien-St. Peter Contact in Southwestern Wisconsin: An Example of an Integrated Geological-Geophysical Study: Jour. Geology, v. 77, p. 694-702.

Powers, E. H., 1935, The Prairie du Chien Problem: Iowa Univ. Studies in Nat. Hist., v. 16, p. 421-448.

Raasch, G. O., 1935, Stratigraphy of the Cambrian Systems of the Upper Mississippi Valley: Kansas Geol. Soc. Guidebook, Ninth Ann. Field Conf., p. 302-315.

____________, 1951, Revision of Croixan Dikelocephalidae: Ill. State Acad. Sci. Trans., v. 44, p. 137-151.

____________, 1952, Oneota Formation, Stoddard Quadrangle, Wisconsin: Ill. State Acad. Sci. Trans., v. 45, p. 85-95.

Sardeson, F. W., 1934, Shakopee Formation: Pan. Am. Geologist, v. 62, p. 29-34.

____________, 1896, The Fauna of the Magnesian Series: Bull. Minn. Acad. Sci., v. 4, p. 92-106.

Shea, J. H., 1960, Stratigraphy of the Lower Ordovician New Richmond Sandstone in the Upper Mississippi Valley: Univ. of Wisc., M.S. thesis, 90 p. and XLVII.

Starke, G. W., 1949, Persistent Lithologic Horizons of the Prairie du Chien Formation from the Type Section Eastward to the Crest of the Wisconsin Arch: Univ. of Wisc., M.S. thesis, 29 p.

Sloss, L. L., 1963, Sequences in the Cratonic Interior of North America: Geol. Soc. America Bull., v. 74, p. 93-114.

Stauffer, C. R., and Thiel, G. A., 1941, The Paleozoic and Related Rocks of Southeastern Minnesota: Minn. Geol. Survey Bull. 29, p. 1-261.

Stauffer, C. R., 1937, A Diminutive Fauna from the Shakopee Dolomite (Ordovician) at Cannon Falls, Minnesota: Jour. Paleo., v. 11, p. 55-60.

______________, 1937, Mollusca from the Shakopee Dolomite (Ordovician) at Stillwater, Minnesota: Jour. Paleo., v. 11, p. 61-68.

Twenhofel, W. H., _et al_, 1954, Correlation of the Ordovician Formations of North America: Geol. Soc. America Bull., v. 65, p. 247-298.

Ulrich, E. O., 1924, Notes on New Names in Table of Formations and on Physical Evidence of Breaks between Paleozoic Systems in Wisconsin: Wisc. Acad. Sci. Trans., v. 21, p. 71-107.

Wanenmacher, J. M., Twenhofel, W. H., and Raasch, G. O., 1934, The Paleozoic Strata of the Baraboo Area, Wisconsin: Amer. Jour. Sci., v. 28, n. 163, p. 1-30.

Winchell, N. H., 1874, Geology of the Minnesota Valley: Minn. Geol. and Nat. Hist. Survey, Second Annual Report, p. 138-147.

Woaster, L. C., 1882, Geology of the Lower St. Croix District: Geology of Wisc., v. 4, p. 99-159.

ILLUSTRATIONS

Figure 11 - St. Peter Sandstone channel cutting into the Willow River Member at Mt. Vernon, Wisconsin (loc. 1). This is near the crest of the Wisconsin Arch.

Figure 12 - Photomicrographs showing various lithic types in the Prairie du Chien. Grain sparite (a and b) is the most abundant rock type, and they may be mixed with quartz and intraclasts (c). Micrite is not abundant and may be burrowed (d) with sparry dolomite lining porespaces. In much of the Hager City Member the dolomite is coarse grained (e) and may contain zoned rhombs. Bahamites or grapestones also are preserved (f) but are not common.

Figure 13 - Well-preserved algal stromatolites (a and b) are common, particularly in the Stockton Hill and Willow River Members. Some show small cut and fill structures (a) containing quartz grains. Quartz sandstone in the New Richmond occurs in many forms; (c) cemented by quartz overgrowths, by (d) dolomite and by (e) poikilotopic dolomite. Quiet water oolites (f) are present at numerous localities in the Shakopee Formation.

Figure 14 - Tectonic setting of central North America showing major structural features present during deposition of the Prairie du Chien Group (after Ostrom, 1964).

Figure 15 - Generalized paleoenvironments for the various units of the Prairie du Chien Group.

APPENDIX

Measured and Described Sections

Exposures 1-16 are shown on Figure 4. An additional 26 exposures were also studied and incorporated into the findings as reported in the text. Exact locations of other exposures may be obtained from the author or the Wisconsin Geological and Natural History Survey.

1. Mt. Vernon, Wisconsin (Dane Co.), SW 1/4, SW 1/4, Sec. 34, T6N, R7E, exposure begins in highway department quarry west of County Trunk G and continues in roadcut on that highway just south of the village.
2. Denzer, Wisconsin (Sauk Co.), W 1/2, SW 1/4, Sec. 14, TION, R5E, state highway department quarry on hilltop 1.5 miles east of village of Denzer.
3. Lancaster, Wisconsin (Grant Co.), NW 1/4, SW 1/4, Sec. 28, T5N, R3W, state highway department quarry on gravel road, 0.4 miles south of intersection with County Trunk K, 3 miles northwest of Lancaster, just west of bridge over Grant River.
4. Boscobel, Wisconsin (Crawford Co.), SW 1/4, NE 1/4, Sec. 21, T8N, R3W, abandoned quarry and roadcut along County Trunk E, 0.7 miles north of intersection with State Highway 60, 2 miles north of Boscobel.

5. Waukon Junction, Iowa (Allamakee Co.), SW 1/4, Sec. 16, T96N, R3W, roadcut along Iowa State Highway 364, 2 miles south of Waukon Junction railroad station.

6. Lansing, Iowa (Allamakee Co.), SE 1/4, Sec. 33, T99N, R3W, abandoned quarry and roadcut along gravel road that ascends from river valley 2.1 miles south of Lansing on Great River Road.

7. Upper Iowa River, Iowa (Allamakee Co.), Secs. 11-14, 23, T99N, R6W, continuous roadcut along State Highway 76 as it ascends south from the Upper Iowa River.

8. Coon Valley, Wisconsin (Vernon Co.), SW 1/4, NE 1/4, Sec. 11, T14N, R6W, roadcut along U.S. Highway 16, 2.5 miles west of the village of Coon Valley.

9. La Crescent, Minnesota (Houston Co.), NW cor. Sec. 3, T104N, R4W, abandoned quarry along county road that ascends the valley wall, 1.4 miles north of La Crescent.

10. Lanesboro, Minnesota (Fillmore Co.), NE 1/4, Sec. 26, T103N, R10W, roadcut along U. S. Highway 16, as it ascends valley, 0.7 miles southwest of Lanesboro.

11. Winona, Minnesota (Winona Co.), SW 1/4, Sec. 30, T107N, R7W, roadcut along U. S. Highway 14 as it ascends Stockton Hill, 3 miles west of Winona.

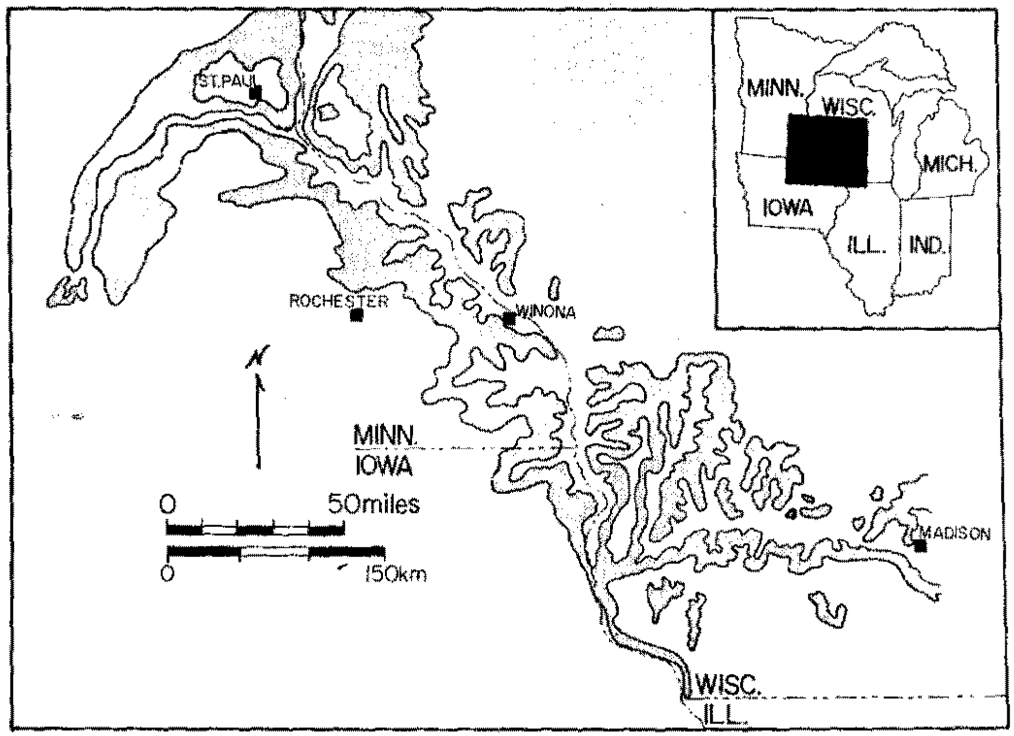
12. Whitewater State Park, Minnesota (Winona Co.), NW 1/4, Sec. 29, T107N, R10W, roadcut along Minnesota State Highway 74 at southern entrance to Whitewater State Park, 7 miles north of St. Charles, Minn.

13. Lake City, Minnesota (Wabasha Co.), Sec. 23, T111N, R13W, roadcut on U. S. Highway 63, 6 miles southwest of Lake City.

14. Hager City, Wisconsin (Pierce Co.), Sec. 35, T25N, R18W, roadcut on U. S. Highway 65, 2 miles north of intersection with Wisconsin Highway 35 and 1.5 miles northeast of the village of Hager City.

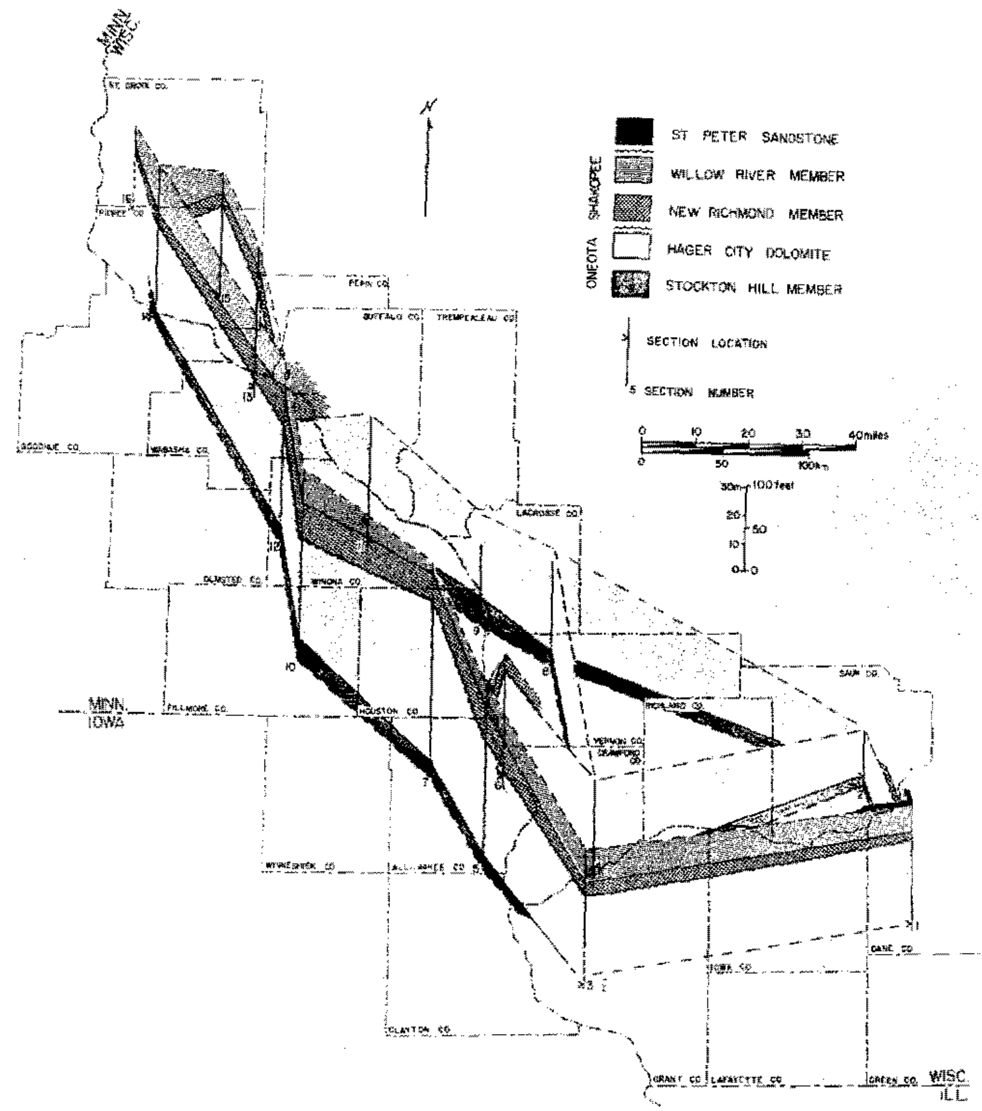
15. Rush River Valley, (Pierce Co.), NW 1/4, Sec. 15, T25N, R16W, roadcut along U. S. Highway 10, 8 miles west of Plum City, Wisc.

16. River Falls, Wisconsin (Pierce Co.), NE 1/4, SW 1/4, Sec. 1, T27N, R19W, on north bank of river just below power dam, southwest side of town of River Falls.

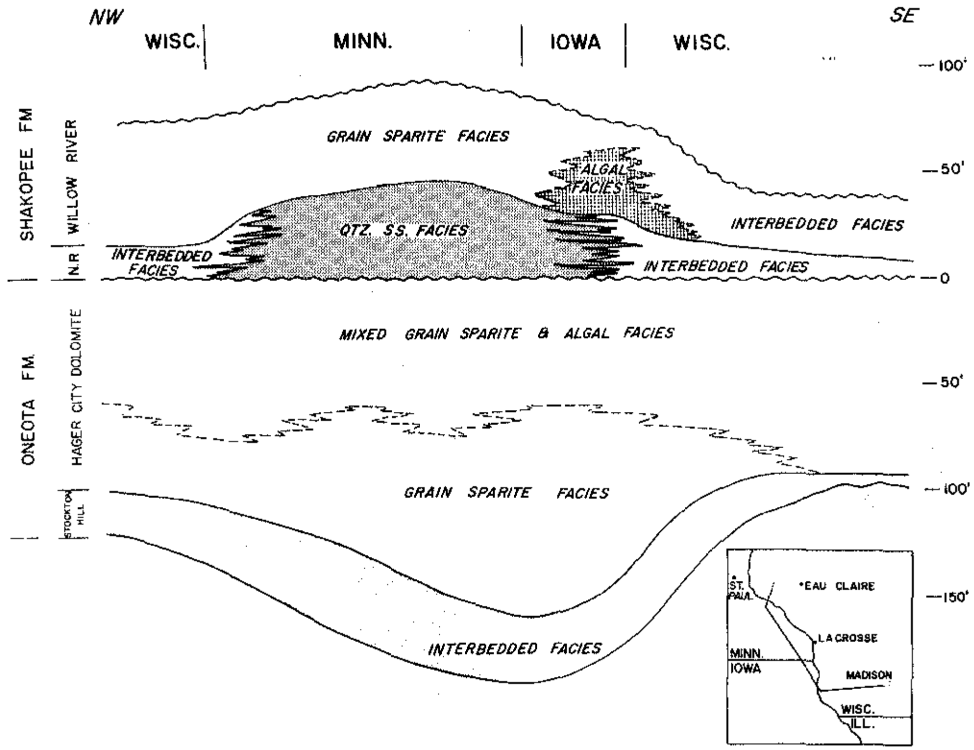


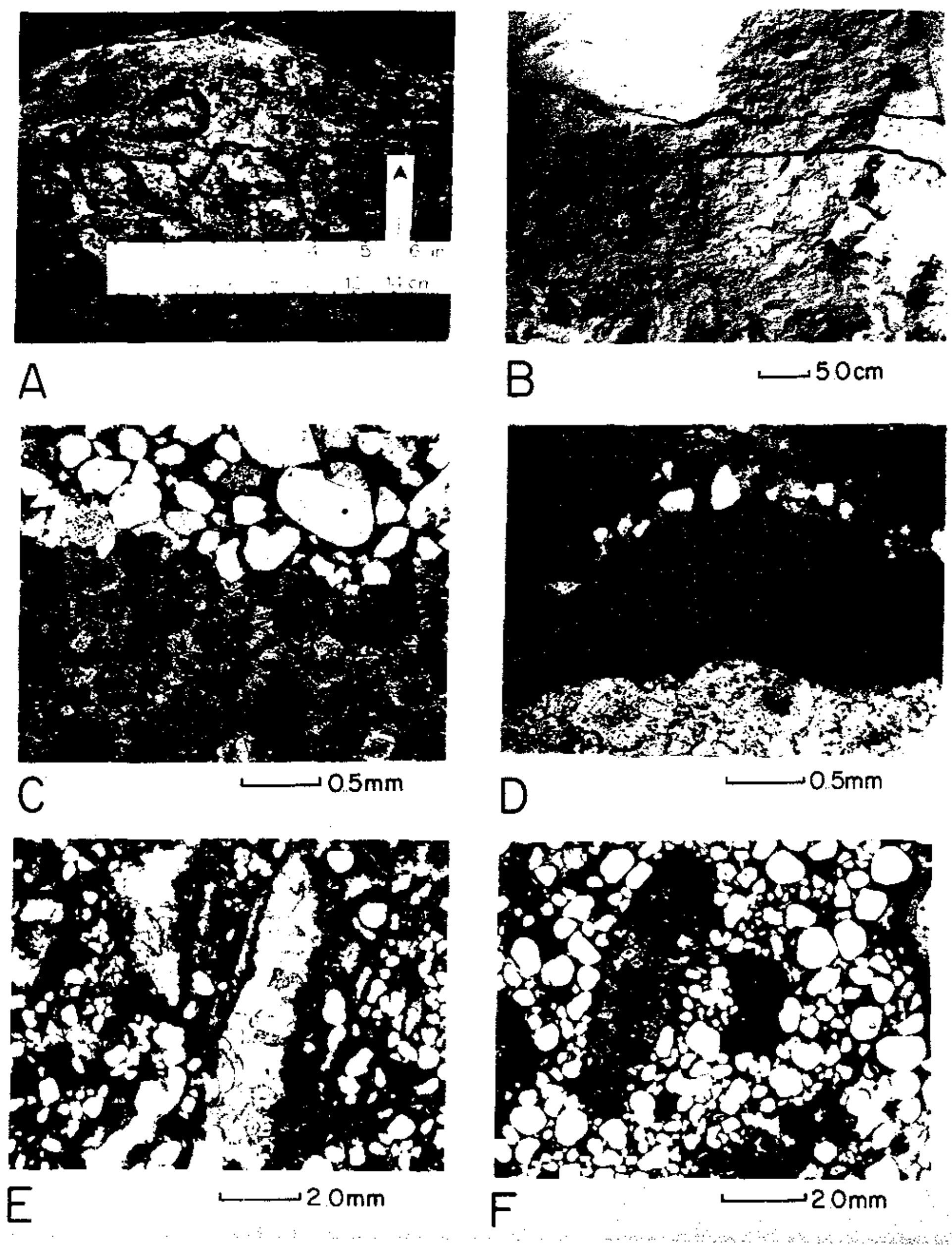
MINN.
WISC.
MICH.
IOWA
ILL.
IND.
ST.PAUL
ROCHESTER
WINONA
MINN.
IOWA
0
50miles
0
150km
MADISON
WISC.
ILL.

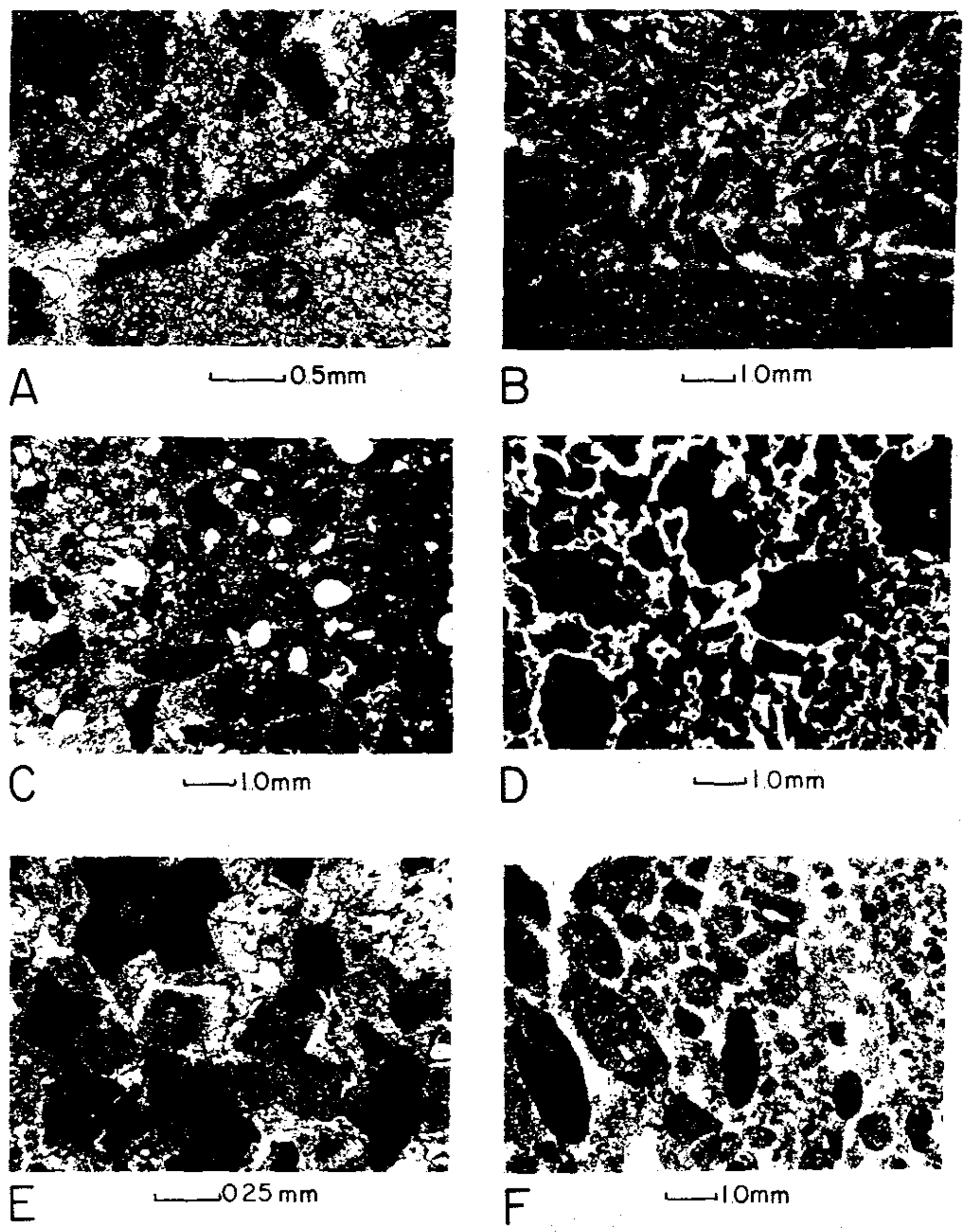
OWEN 1848	WINCHELL 1874	IRVING 1875	WOOSTER 1882	McGEE 1891	BAIN 1906	RAASCH 1951	RAASCH 1952	DAVIS 1966	THIS PAPER
SOUTHERN MINNESOTA	MINNESOTA RIVER VALLEY	SOUTHWESTERN WISCONSIN	ST. CROIX RIVER VALLEY	NORTHEASTERN IOWA	SOUTHWESTERN WISCONSIN	SOUTHERN WISCONSIN	STODDARD QUADRANGLE WISCONSIN	UPPER MISSISSIPPI VALLEY	UPPER MISS VALLEY
UPPER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE (ORDOVICIAN SYSTEM, CANADIAN SERIES)	ST. PETER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE	ST. PETER SANDSTONE
LOWER MAGNESIAN LIMESTONE	SHAKOPEE LIMESTONE	MAIN BODY OF LIMESTONE	WILLOW RIVER BEDS		PRAIRIE DU CHIEN GROUP: SHAKOPEE DOLOMITE	PRAIRIE DU CHIEN GROUP: SHAKOPEE FORMATION	PRAIRIE DU CHIEN GROUP: SHAKOPEE FORMATION	PRAIRIE DU CHIEN GROUP: SHAKOPEE FORMATION: WILLOW RIVER	PRAIRIE DU CHIEN GROUP: SHAKOPEE FORMATION: WILLOW RIVER MEMBER
			NEW RICHMOND BEDS		NEW RICHMOND SANDSTONE	NEW RICHMOND FORMATION	NEW RICHMOND FORMATION	NEW RICHMOND MEMBER	NEW RICHMOND MEMBER
			LOWER MAGNESIAN LIMESTONE PROPER	ONEOTA LIMESTONE	ONEOTA DOLOMITE	ONEOTA FORMATION	ONEOTA FORMATION: STODDARD MEMBER; GENOA MEMBER; MOUND RIDGE MEMBER; HICKORY RIDGE MEMBER	ONEOTA FORMATION	ONEOTA FORMATION: HAGER CITY MEMBER; STOCKTON HILL MEMBER
LOWER SANDSTONE	JORDAN SANDSTONE	MADISON SANDSTONE	POTSDAM SANDSTONE	(CAMBRIAN, POTSDAM) ST. CROIX SANDSTONE	JORDAN SANDSTONE	SUNSET POINT FORMATION	SUNSET POINT FORMATION	JORDAN SANDSTONE	JORDAN SANDSTONE

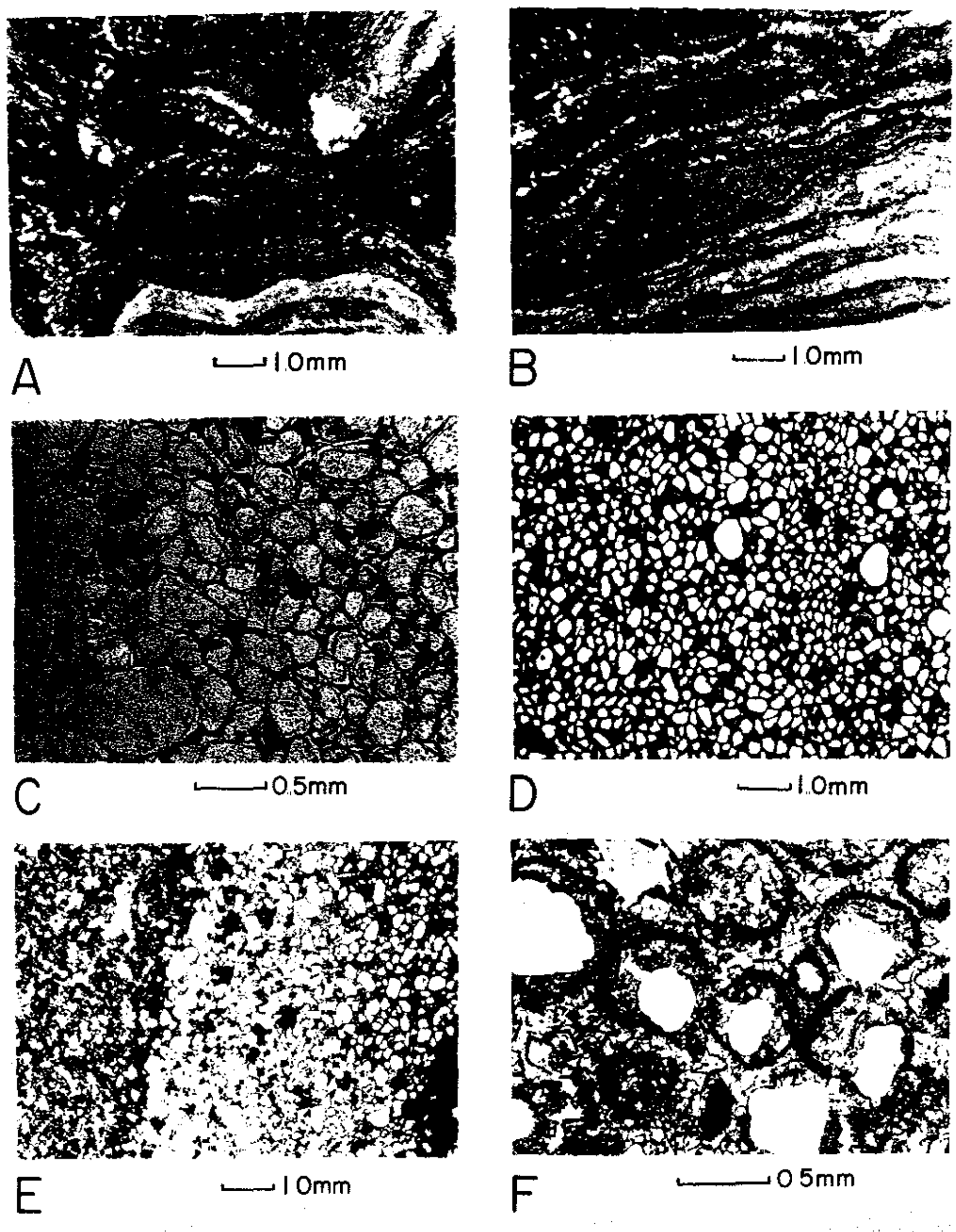


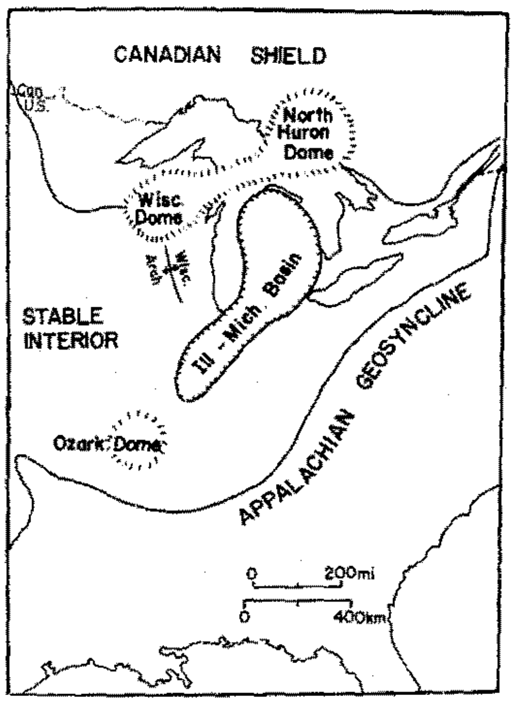
MINN.
WISC.
N
ST PETER SANDSTONE
SHAKOPEE
WILLOW RIVER MEMBER
NEW RICHMOND MEMBER
ONEOTA
HAGER CITY DOLOMITE
STOCKTON HILL MEMBER
SECTION LOCATION
5 SECTION NUMBER
0 10 20 30 40 miles
0 50 100 km
30m 100 feet
20 50
10
0 0
ST. CROIX CO.
PIERCE CO.
PEPIN CO.
BUFFALO CO.
TREMPEALEAU CO.
GOODHUE CO.
WABASHA CO.
LACROSSE CO.
OLMSTED CO.
WINONA CO.
SAUK CO.
MINN.
IOWA
FILLMORE CO.
HOUSTON CO.
RICHLAND CO.
VERNON CO.
CRAWFORD
WINNESHIEK CO.
ALLAMAKEE CO.
IOWA CO.
DANE CO.
CLAYTON CO.
GRANT CO.
LAFAYETTE CO.
GREEN CO.
WISC.
ILL.


NW
SE
WISC.
MINN.
IOWA
WISC.
SHAKOPEE FM
WILLOW RIVER
N.R
ONEOTA FM.
HAGER CITY DOLOMITE
STOCKTON HILL
GRAIN SPARITE FACIES
ALGAL FACIES
QTZ. SS. FACIES
INTERBEDDED FACIES
INTERBEDDED FACIES
INTERBEDDED FACIES
MIXED GRAIN SPARITE & ALGAL FACIES
GRAIN SPARITE FACIES
INTERBEDDED FACIES
100'
50'
0
50'
100'
150'
ST. PAUL
EAU CLAIRE
LACROSSE
MINN.
IOWA
MADISON
WISC.
ILL.

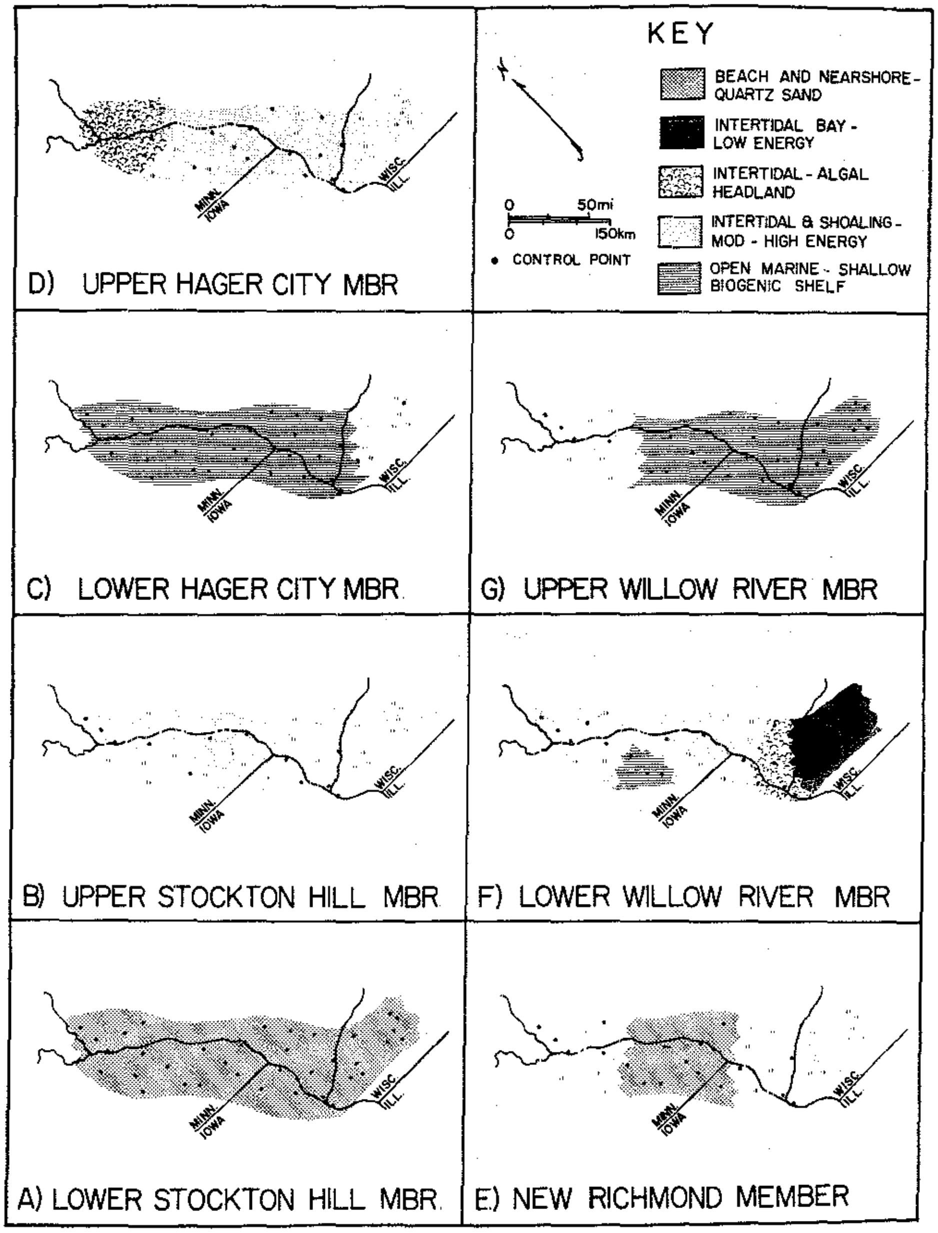

A
B
5.0cm
C
0.5mm
D
0.5mm
E
2.0mm
F
2.0mm


A
0.5mm
B
1.0mm
C
1.0mm
D
1.0mm
E
0.25 mm
F
1.0mm


A
1.0mm
B
1.0mm
C
0.5mm
D
1.0mm
E
1.0mm
F
0.5mm



CANADIAN SHIELD
Can.
U.S.
North
Huron
Dome
Wisc.
Dome
Wisc.
Arch
STABLE
INTERIOR
Ill.-Mich. Basin
APPALACHIAN GEOSYNCLINE
Ozark Dome
0
200mi
0
400km


KEY
BEACH AND NEARSHORE - QUARTZ SAND
INTERTIDAL BAY - LOW ENERGY
INTERTIDAL - ALGAL HEADLAND
INTERTIDAL & SHOALING - MOD - HIGH ENERGY
OPEN MARINE - SHALLOW BIOGENIC SHELF
0 50mi
0 150km
• CONTROL POINT
MINN.
IOWA
WISC.
ILL.
D) UPPER HAGER CITY MBR
C) LOWER HAGER CITY MBR.
G) UPPER WILLOW RIVER MBR
B) UPPER STOCKTON HILL MBR
F) LOWER WILLOW RIVER MBR
A) LOWER STOCKTON HILL MBR.
E) NEW RICHMOND MEMBER