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Contents of Volume XVI

The Prairie Du Chien Problem

by

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Contents

INTRODUCTION

THE PROBLEM

The Prairie du Chien [1] sediments of the Upper Mississippi Valley have been ranked in classification from a formation consisting of three members to two formations of separate systems. The problem involves the relations of the lithologic units, the classification into stratigraphic units, and the application of stratigraphic names. Trowbridge and Atwater [2] have stated the problems and reviewed the complex history of classification and nomenclature of these sediments. Although the main concern of the writer is the solution of the problems brought out by Trowbridge and Atwater, it is necessary to repeat some of their work and of course to carry it farther.

THE INVESTIGATION

Numerous representative exposures of the Prairie du Chien (see Plate 48) were studied and described in detail. Approximately 1,000 samples of the sediments were collected from chosen beds for investigation in the sedimentation laboratories. Available well data in Iowa, Wisconsin, and Illinois were utilized in determining the subsurface distribution and thickness of the lithologic units, and of the entire Prairie du Chien. Paleontological evidences, in so far as they are known to the writer, were considered, and were compared with physical evidences; however, no additional work was done by the writer on the paleontology of the Prairie du Chien in this approach to the problem.

ACKNOWLEDGMENTS

The writer expresses his indebtedness to Dr. A. C. Trowbridge, who directed the field work and who had general supervision in the preparation of the report. He appreciates the direction of Dr. A. C. Tester in the laboratory investigations, and his aid in incorporating the results in the report. Credit is given to the Iowa State Planning Board, Project 1044-C, for supplying subsurface data on the Prairie du Chien of Iowa.

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1 Bain, H. F. Zinc and lead deposits of the Upper Mississippi Valley. U. S. Geol. Surv. Bull. 294: 17-19. 1906.

2 Trowbridge, A. C. and G. I. Atwater. Stratigraphic problems in the Upper Mississippi Valley. Bull. Geol. Soc. Am. 45: 75-77. 1934.

HISTORY OF NOMENCLATURE

Only the literature dealing with the original nomenclature of the Prairie du Chien sediments, and with the present usage of stratigraphers in the Upper Mississippi Valley is reviewed here.

A first attempt at classification was made by Owen,[3] in 1840, when he applied the term Lower Magnesian limestone to a portion of the old division, "Primitive limestone." In a report of 1873 on the geology of the Minnesota River valley, Winchell [4] adopted the "Lower Magnesian formation" expressly for the Saint Lawrence dolomite, the Jordan sandstone, and his proposed Shakopee dolomite (member). Beds of dolomite and sandstone exposed in a quarry and in natural exposures at Shakopee, Scott County, Minnesota, and which lie stratigraphically above the Jordan sandstone and below the Saint Peter sandstone, were chosen as the type section of the Shakopee member. It is clear that the Saint Lawrence dolomite and Jordan sandstone were correctly identified in the Minnesota River valley, and that all the beds between the Jordan and Saint Peter sandstones at Kasota, Ottawa, and Mankato were ascribed to the Shakopee.

At and near New Richmond and Jewetts, on Willow River, Wisconsin, there are isolated exposures of sandstone beds, 5 to 15 feet in thickness. They are associated with beds of dolomite below and above, though rarely more than 10 feet are exposed in any section. Wooster [5] proposed the term New Richmond for the sandstone which he described as a distinct though lenticular unit separating the lower and upper dolomite units of the "Lower Magnesian series." To the dolomite above, he applied the term "Willow River Beds." This term was used for the beds of dolomite lying above the New Richmond sandstone and below the Saint Peter sandstone, and all dolomite beds in that stratigraphic position on Willow River were assigned as the type sections. From the dam, one mile above Burkhardt, to Willow River Falls at Burkhardt, there is an almost complete exposure of the "Lower Magnesian series," beginning at the top and extending to within 10 to 20 feet of the base. Wooster considered "the exposures at Willow River Falls and vicinity — [as] — the type of all," [6] however, he did not distinguish the

3 Owen, D. D. House Doc., Exec. Doc. no. 239, 26th Cong., first session: 17. 1840.

4 Winchell, N. H. Geology of the Minnesota valley. Minn. Geol. and Nat. Hist. Surv. 2nd Ann. Rept.: 138-147. 1874.

5 Wooster, L. C. Geology of the lower Saint Croix district. Geology of Wisconsin 4: 106, 123-129. 1882.

6 *Op. cit.*, p. 125.

"Lower Magnesian proper," the "New Richmond sandstone," and the "Willow River Beds" in that section.

McGee [7] completed a report in 1888 on northeastern Iowa, in which he expressed the belief that the New Richmond and Shakopee (Winchell, 1886) have a gradual transition into the Saint Peter sandstone without unconformity and included them in the base of the Saint Peter for this area only. He intended the proposed geographic term Oneota for the massive beds of dolomite exposed along the bluffs of Oneota River (now Upper Iowa River), and as the equivalent of Irving's Main Body of limestone, Wooster's Lower Magnesian proper, and Upham's Shakopee B limestone. The thickness of 200-300 feet ascribed to the beds between the "Potsdam sandstone" and the New Richmond sandstone in northeastern Iowa is inaccurate and misleading, because the average thickness in that area is 150-175 feet.

The geographic term "Prairie du Chien formation" was proposed by Bain,[8] in 1906, for "(*a*) a dolomite at the base, 200 to 225 feet thick; (*b*) a sandstone in the middle, 15 to 130 feet thick, increasing to the southwest under cover; (*c*) a second dolomite at the top, approximately 40 feet in thickness. These are known, respectively, as the Oneota, New Richmond, and Shakopee or Willow River."

A different trend in the stratigraphy of the lower Paleozoics was started in 1911 by Ulrich,[9] who promoted Broadhead's [10] "Ozark series" to the rank of a system for the deposits in the Ozark region younger than the Elvins formation and older than the Yellville dolomite of northern Arkansas. This proposed system was thought to be represented in the Upper Mississippi Valley by the "(1) Mendota, (2) Jordan (Madison sandstone of Wisconsin), (3) Oneota dolomite, and (4) Shakopee dolomite, with the New Richmond sandstone perhaps an introductory phase of the Shakopee." [11] Dana's [12] term "Canadian system" was revived for a system of deposits "younger than — [the Powell dolomite] — of Missouri and the Shakopee and older than the first sandstone and limestone (Ev-

7 McGee, W. J. Pleistocene history of northeastern Iowa. U. S. Geol. Surv., 11th Ann. Rept. pt. 1: 331-333. 1891.

8 *Op. cit.*

9 Ulrich, E. O. Revision of the Paleozoic systems. Bull. Geol. Soc. Am. 22: 640-641. 1911.

10 Broadhead, G. C. The Ozark series. Am. Geol. 8: 33-35. 1891.

11 *Op. cit.*

12 Dana, J. D. Reasons for some of the changes in the subdivisions of geological time in the new edition of Dana's Manual of Geology. Am. Jour. Sci. 8: 214. 1874.

erton) of the Saint Peter series in northern Arkansas."[13] Under this definition the Canadian system was not represented in the Upper Mississippi Valley. In 1914, Ulrich, through Walcott,[14] shifted the Shakopee to the Upper Canadian and placed the Oneota in the Upper Ozarkian.

Both Ulrich[15] and Sardeson[16] believed the New Richmond sandstone on Minnesota River and at Burkhardt, Wisconsin, not to be a distinct stratigraphic unit but to represent sandstone lenses within the upper part of the Oneota or the lower part of the Shakopee and not to be found between them in other sections. At the same time Ulrich gave physical and paleontological evidences for his classification of the Oneota as the Upper Ozarkian and the Shakopee as Upper Canadian, with the Lower and Middle Canadian series missing between them. He purposely avoided use of a formation or series name to include the Oneota and Shakopee, because that was not in harmony with his proposal to place the two in different systems.

Thwaites[17] seemed hesitant, in 1927, to recognize the New Richmond as a formation of equal rank with the Oneota and Shakopee formations of his Prairie du Chien group because he was not able to recognize it in all well sections of northern Illinois.

The most recent publication of the Iowa Geological Survey[18] retains the original classification of the Prairie du Chien of Bain (1906). Needham,[19] in 1932, adopted the "Prairie du Chien series" consisting of the Oneota, New Richmond, and Shakopee formations. A generalized geological column agreed upon for the Wisconsin Survey[20] contains the Oneota and Shakopee formations, which, combined, are equivalent to the "Lower Magnesian" dolomite. In the same year, Minnesota geologists agreed upon a generalized classification in which occurs the "Prairie du Chien (Lower Magnesian) group" consisting of the Oneota and Shakopee formations.

13 Ulrich, E. O. *Op. cit.* 647.

14 Walcott, C. D. Cambrian geology and paleontology. Smith. Misc. Coll. 57: 353. 1914.

15 Ulrich, E. O. Notes on new names in table of Paleozoic formations in Wisconsin. Trans. Wisconsin Acad. Sci. Arts and Letters 21: 83, 100-104. 1924.

16 Sardeson, F. W. Type outcrops of Minnesota River valley. Pan-Am. Geologist. 41: 115. 1924.

17 Thwaites, F. T. Stratigraphy and geologic structure of northern Illinois. Ill. Geol. Surv. Rept. of Investigations, no. 13: 21-24. 1927.

18 Norton, W. H. Deep wells of Iowa. Iowa Geol. Surv. 33: 24. 1928.

19 Needham, C. E. Contributions to the subsurface geology of northern Illinois, between the outcrops of the Saint Peter and Dresbach formations, with special reference to the New Richmond formation. Unpublished doctor's thesis, Northwestern University library. 1932.

20 Martin, Lawrence. The physical geography of Wisconsin. (Geologic column by W. H. Twenhofel, F. T. Thwaites, G. O. Raasch and R. R. Schrock). Wis. Geol. and Nat. Hist. Surv. Bull. 36, 2nd ed.: 4. 1932.

Trowbridge and Atwater,[21] following a review of literature dealing with these sediments, concluded tentatively that the Prairie du Chien should be recognized as a formation consisting of three members. For the lower dolomite and middle sandstone members, the terms Oneota and New Richmond, respectively, were applied. It was thought that any evidence contrary to the belief that the beds at Shakopee are of Oneota age is paleontological. These authors were not in favor of retaining the term Shakopee for the upper dolomite unit of the Prairie du Chien if the beds at Shakopee are not to be included in it, but hesitated to return to the usage of Wooster's Willow River beds until the age of the beds at Shakopee could be conclusively determined. In support of the belief that the Shakopee type section is of Oneota age, Couser[22] presented a generalized well log obtained from H. H. Strunk at Shakopee and applied stratigraphic divisions according to the then accepted classification as follows:

LOG OF WELL AT CITY WATER WORKS IN SHAKOPEE. ELEVATION OF WELL SITE, 725 FEET

Rock	Thickness	Depth
Shakopee [?] and Oneota	58	58
Jordan	146	204
St. Lawrence and Franconia sandy limestone	133	337
Dresbach		
Galesville (?) white sandstone	95	432
Eau Claire, sandstone and sandy limestone	173	605
Mt. Simon, white and red sandstone	98	703
Very red at bottom—Red Clastics (?)		

He was not able to find in the field and laboratory any physical distinction between the beds exposed at Shakopee and the Oneota of other sections.

Within the year, Stauffer[23] returned to Winchell's interpretation of 1886 concerning the section at Shakopee in that he believed the beds exposed belong to the upper member of the old "Lower Magnesian formation." He presented a generalized description of beds down to Minnesota River level and supplemented his interpretation

21 *Op. cit.*: 71-73.

22 Couser, C. W. Unpublished Thesis, Univ. of Iowa library. — Since Couser's paper was first written, he has modified this section according to: "Paleozoic stratigraphy and structure in the Minnesota River valley." Univ. Iowa Studies Nat. Hist. 16: 451-472. 1935.

23 Stauffer, C. R. Type Paleozoic sections in the Minnesota valley. Jour. Geol. 42: 347. 1934.

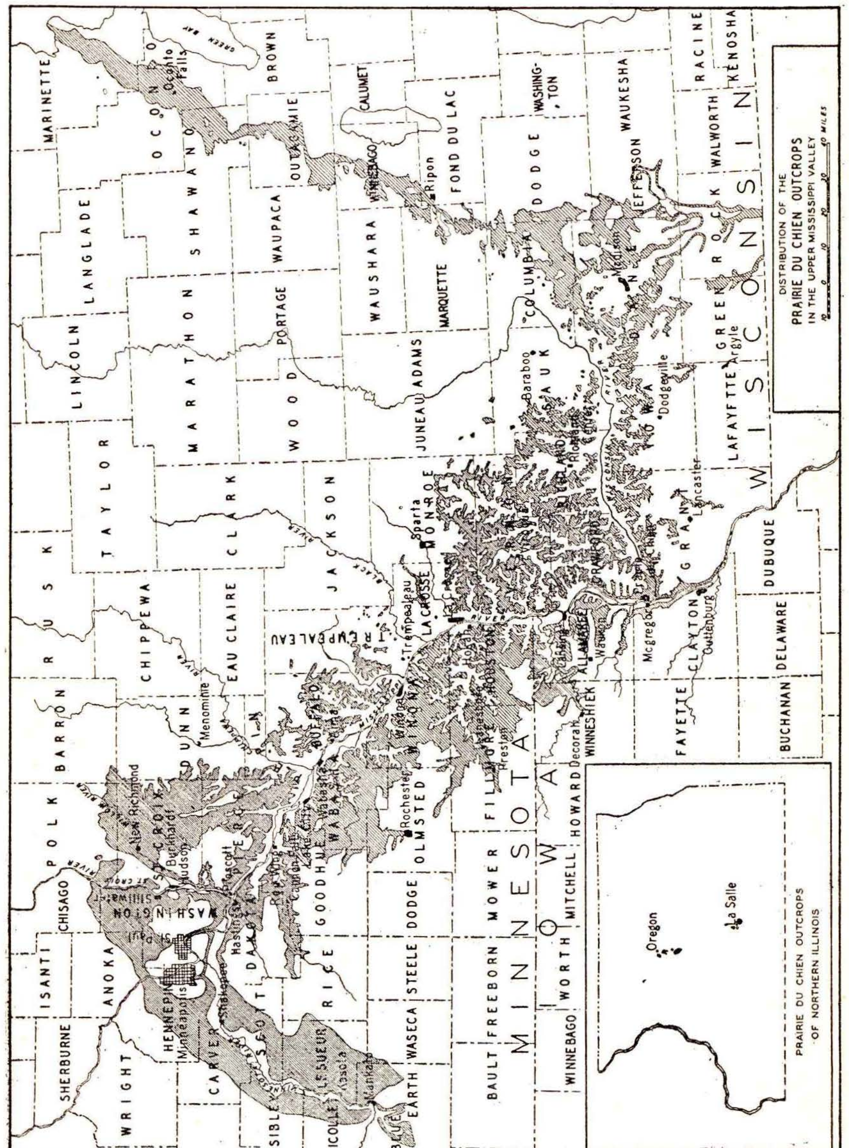

Plate 48

of the local water works well log for beds below river level. Below 38 feet of "Shakopee dolomite" and 2 feet of "New Richmond (?) sandstone" described from exposures above river level he believed the following rocks to be shown by the well log:

Oneota dolomite
- No. 7. Dolomite, gray to drab .... 31 feet
- No. 6. Sand and sandy gray dolomite, water-bearing and reported as sandstone .... 35 feet

Jordan sandstone
- No. 5. Sandstone, buff to white .... 100 feet

St. Lawrence formation
- No. 4. Dolomites, arenaceous, with shales and sandstone .... 144 feet

Franconia sandstone
- No. 3. Sandstone, white .... 95 feet

Dresbach formation
- No. 2. Sandstones, gray, and gray shales .... 173 feet

Hinckley sandstone
- No. 1. Sandstone, white to red. To the bottom of hole, 22 feet A. T. .. 98 feet

In addition to species of fossils already described by Sardeson from the Shakopee section, he reported a diminutive Molluscan fauna from the oolitic chert and several trilobites all of which are yet unidentified.

DISTRIBUTION

Shaded areas on Plate 48 indicate the location and distribution of outcrops of the Prairie du Chien formation. Formation boundaries were traced from geologic maps of Iowa, Minnesota, Wisconsin, and Illinois. The irregular outcrops of northeastern Iowa, southeastern Minnesota and southwestern Wisconsin generally coincide with the Driftless Area. Possibilities of exposure are reduced by glacial drift in the region northwest of the Driftless Area and in eastern Wisconsin. In Illinois, small inliers occur at Oregon and La Salle.

THICKNESS

In addition to thicknesses of the Prairie du Chien measured by the writer in exposures, a large number have been obtained from reports of the Iowa, Minnesota, Wisconsin, and Illinois geological surveys, and other geological reports. A few were furnished by F. T. Thwaites for western and southwestern Wisconsin, and several for Iowa were furnished by the Iowa State Planning Board.

An isopach map of the Prairie du Chien (Pl. 49), constructed from measured thicknesses of exposures and in well records, demonstrates an increase in thickness away from the outcrop as the formation passes beneath younger Paleozoic sediments. A local isopach high, whose axis trends slightly east of north through the Twin Cities, and one east of New Richmond, Wisconsin, coincide in a general way with two minor synclines shown by Trowbridge [24] in 1934. Both the isopach highs and the synclines converge southward to a major isopach high and syncline, respectively, whose axes generally coincide. The line of maximum thickness continues southward into Iowa, east of Des Moines, and thence southeast between Centerville and Bloomfield, whereas the structural basin [25] extends southwest from Des Moines toward Clarinda. The general coincidence of isopach highs with synclines suggests that the latter were basins for Prairie du Chien deposition. The fact that regional structure in Iowa, Minnesota, and Wisconsin is reflected in both the lower and upper beds of the Prairie du Chien, and in the underlying and overlying formations as well, indicates that the basin subsided with deposition during Prairie du Chien time. The syncline in southwestern Iowa seems to be unrelated to changes in thickness of the Prairie du Chien. In the region of the La Salle anticline, Illinois, there is an increase in thickness of the Prairie du Chien. The direct relation of subsidence of the basin to deposition, suggested for the rest of the Upper Mississippi Valley, probably existed in this area also, but the La Salle anticline originated after deposition of the Prairie du Chien. There is no evidence at hand to show any relation of such minor structures as at Ellsworth, Wisconsin, to deposition.

Irregularities in the thickness of the Prairie du Chien in southern and southeastern Wisconsin, extreme eastern Iowa, and in northern Illinois are due principally to post Prairie du Chien and pre-Saint Peter erosion; in fact, the entire formation was removed in much of southeastern Wisconsin and in a portion of north central Illinois. Configuration of isopach lines in this area might be considered in reconstructing pre-Saint Peter topography in that the location of a possible major system of drainage to the northeast toward Lake Michigan is suggested. In the vicinity of La Salle, Illinois, the

24 Trowbridge, A. C. Upper Mississippi Valley structure. Bull. Geol. Soc. Am. 45: 522-523, fig. 1. 1934.

25 Norton, W. H. Deep wells of Iowa. Iowa Geol. Surv. 33, Pl. I, 1928; Structural contour maps of Iowa: furnished by Iowa State Planning Board, 1934.

maximum thickness of the Prairie du Chien is near the axis of the La Salle anticline.

The upper dolomite member of the formation, by virtue of its superposition, was subjected to more pre-Saint Peter erosion than the middle and lower members, except where the entire upper member was removed. An isopach map of the upper member would thus show much greater irregularity than similar maps of the other two members. In exposures and well records, where the three members of the Prairie du Chien have been distinguished, there is an indication that the variation in original thickness of both the lower and middle members is directly proportional to variation in the original thickness of the entire formation. The difficulty in applying that statement to the upper member is obvious, since it is not known that the complete original thickness has ever been measured; however, there is no reason to believe that its thickness varies inversely with the lower part of the formation in any place. The foregoing statements are confirmed by an isopach map of the middle sandstone member (Pl. 50), although the points of control for that map are fewer and less reliable than those for the entire formation, because the individual members are less easily distinguished in well records than is the entire formation from underlying and overlying formations.

LITHOLOGY

During the progress of field work done by the writer in the summers of 1932 and 1933, many exposures throughout the areas of outcrop were studied. Beds were measured and described in detail, and samples were collected from chosen beds. Where laboratory studies of the samples warranted alteration of the field descriptions, those changes were made, and all of the described sections were incorporated in an appendix [26] on file in the geology library at the University of Iowa. From the representative descriptions in the appendix, a general summary of the lithology of the Prairie du Chien sediments is made here.

ONEOTA DOLOMITE

A generalized description of the Oneota dolomite for any small area would have to be altered when applied to adjacent areas, because of gradual lithologic variations along the rather broad band

26 Powers, E. H. The Prairie du Chien Problems. Unpublished appendix, geology library, University of Iowa, Iowa City, Iowa, 1935.

of outcrops in northeastern Iowa, southeastern Minnesota, and western Wisconsin. Within the Minnesota River valley, the Oneota consists of massive beds (3 feet to 5 feet thick) of gray, pink and buff dolomite, which are quarried at Mankato and Kasota for building stone. Certain beds are of sufficient importance to have been given commercial names, which, however, do not extend beyond the quarries where they are applied. Quartz sand, silt, and shale are disseminated throughout the Oneota, at Mankato, though they rarely exceed 10 per cent of the rock by weight. At the base of the Oneota along Minnesota River, between Saint Peter and Mankato, fracturing and solution of the basal beds have allowed large blocks of dolomite to settle into beds of white shaly siltstone, which has been forced upward between them.[27]

The beds which occur at 10-20 feet above Minnesota River level at Shakopee contain a few nodular masses of gray, oolitic chert, and quartz sand locally predominates in thin beds and thin discontinuous lenses. The uppermost beds of Oneota on Minnesota River are exposed only at Mankato, where there is a sharp distinction from the overlying white New Richmond sandstone.

At Stillwater, Minnesota, massive beds of brownish Oneota dolomite rest on a slightly irregular surface of the Jordan sandstone. Of the 124 feet of dolomite exposed, there is no sandstone at or near the top that might be ascribed to the New Richmond. The writer agrees with Trowbridge and Atwater,[28] and with Clement,[29] that there is no evidence of an unconformity within the exposed beds, as Ulrich [30] had expressed, which might represent the contact of Oneota and "Shakopee."

Along the Saint Croix river in Washington County, Minnesota, and in Saint Croix and Pierce counties, Wisconsin, the Oneota consists of uniformly massive beds which are well exposed at Burkhardt (Pl. 51-a) and on Kinnikinick Creek. Quartz sand and small tabular dolomite pebbles are concentrated in certain beds within the section, but do not characterize any particular lithologic zone. Cryptozoon reefs, on the other hand, are abundant in some beds, as, for example, at 80 feet below the top of the Oneota at Willow

27 Graham, W. A. P. Petrology of the Cambrian-Ordovician contact in Minnesota. Jour. Geol. 41: 471-473. 1933; Stauffer, C. R., and G. A. Thiel. Jordan-Oneota contact along Minnesota River. Geol. Soc. Am. Preliminary list of titles and abstracts. 1933.

28 *Op. cit.*: 72.

29 Clement, G. M. Paleozoic stratigraphy and structure in the St. Croix River valley. Univ. Iowa Studies Nat. Hist. 16: 473-496. 1935.

30 Ulrich, E. O. Notes on new names in table of Paleozoic formations in Wisconsin. Trans. Wisconsin Acad. Sci. Arts and Letters 21: 100-103. 1924.

River Falls, Wisconsin. Local wavy structures occur in the upper beds of the Oneota on Willow River, Wisconsin, and are fairly common in Saint Croix and Pierce Counties, Wisconsin, and Dakota County, Minnesota. Some of the structures are reflected in the New Richmond sandstone and the upper dolomite member.

Within the broad band of outcrops along the Mississippi River from Hastings, Minnesota, to as far southeast as La Crosse, Wisconsin, the Oneota is characterized by uniform lithology and massive beds. For a distance of 50-75 miles certain beds of firm grayish brown dolomite with abundant cavities, 2 inches or less in diameter, occur within the lower 50 feet of the Oneota, in contrast to non-porous adjacent beds. Chert is a common but minor constituent of the dolomite in the outcrop northwest of La Crosse, Wisconsin, and Dresbach, Minnesota, whereas to the southeast it is abundant in certain beds. It occurs in nodular masses, either isolated or continuous along bedding planes of dolomite.

Several beds of distinctive lithology persist in Fillmore and Houston counties, Minnesota, in northeastern Iowa, and from La Crosse to as far southeast as Madison in southwestern Wisconsin. Alternating beds of sandstone and dolomite in the upper part of the Jordan sandstone cause difficulty in locating the plane of separation from the overlying Oneota. In the southern parts of La Crosse and Monroe counties, and throughout Vernon, Crawford, and Richland Counties, Wisconsin, there is in most sections a bed of conglomerate, 1-3 feet thick, at the base of the Oneota. It consists of a sandstone matrix with pebbles and boulders of sandstone, dolomite and chert, probably all derived within a very short distance from where they were deposited. The conglomerate is directly overlain, in most sections by 1-2 feet of very oolitic dolomite, which persists for 75 miles in Dane, Iowa, Richland, and Vernon Counties, Wisconsin. Within the outcrops of the Driftless Area in southwestern Wisconsin the persistent conglomerate and oolite beds are commonly overlain by glauconitic dolomite, 6 inches to 1 foot in thickness, which locally contains Cryptozoon reefs. Insoluble residues show a relatively high average per cent of quartz sand in the lower 5-10 feet of the Oneota. Sand predominates as lenses or thin beds in the lower 5 feet of some sections but may rarely be identified in more than one section. Glauconite produces a deep greenish color in the dolomite, and is of sufficient importance to be referred to in field descriptions as the "glauconite bed," immediately overlying the lowest "oolite bed." In exposures where there is a second bed of glauconitic dolomite, at 12-15 feet above the base, the two are distinguished as the "lower glauconite bed" and "upper glauconite bed." Within the lower 15-20 feet, Cryptozoon reefs characterize some beds locally but are not persistent. Where one of these beds contains Cryptozoon reefs replaced by chert, it is referred to as the "lower cherty Cryptozoon bed" and distinguished from the principal "cherty Cryptozoon bed." The more persistent bed occurs at 22 to 27 feet above the base of the Oneota and is recognizable at that horizon in practically every section within the Driftless Area in Wisconsin. Chert occurs in a thin discontinuous layer along the base of this bed and as vertically elongate and irregular masses replacing Cryptozoon reefs or dolomite between the reefs; and the chert content renders the bed conspicuous in exposures (Pl. 51-f).

Cryptozoon reef structures, ranging from 1 foot to 20 feet in horizontal dimension (Pl. 51-c and d), produce minor folds in associated beds of dolomite. They are particularly common in the upper Oneota and also the New Richmond and upper dolomite members at Nelson Dewey State Park, Wisconsin, where subdivision of the three members is difficult.

Beginning at about 45 feet above the base of the Oneota there is a 20 foot zone of brownish buff dolomite that is conspicuous in exposure by its relatively light shade of color, fine crystalline texture and regular bedding (6 inches to 1 foot in thickness). The insoluble residue consists principally of clay which is disseminated through the dolomite and concentrated as green shale laminae along bedding planes. This zone is recognizable in Houston County, Minnesota, in northeastern Iowa, and in La Cross, Monroe, Vernon, Crawford, Richland, and Sauk counties, Wisconsin.

No persistent lithologic character is restricted to any bed or zone within the upper 60-80 feet of the Oneota. Chert is a common constituent in the lower portion of this zone, as nodules and thin layers (Pl. 51-e). Large, irregular masses of chert are abundant in the "upper cherty beds" within the upper 40 feet of the Oneota in the Driftless Area, but do not occur in great abundance northwest of Trempealeau.

Exposures of the Prairie du Chien are rare in eastern Wisconsin to the northeast of Madison. A few exposures were studied and described for comparison with the lithology west of the northwest-southeast axis of the central Wisconsin arch. T. C. Chamberlin,[31]

[31] Chamberlin, T. C. Geology of eastern Wisconsin. Geol. of Wis. 2: 268-285. 1877.

in 1877, described the Prairie du Chien beds of eastern Wisconsin. He was not able to recognize a three-fold division of the formation comparable to that west of Madison, possibly because the middle sandstone and upper dolomite units were removed by pre-Saint Peter erosion.

NEW RICHMOND SANDSTONE

The middle member of the Prairie du Chien in Minnesota River valley is a thin, but persistent bed of white friable sandstone. In the vicinity of New Richmond and Jewetts on Willow River, Wisconsin, its lenticular development involves some associated sandy beds, which are not certainly of New Richmond age, but may belong to the overlying dolomite member. At Point Douglas, Minnesota, there are 8-12 feet of conglomeratic sandstone overlying a slightly irregular surface of Oneota dolomite. Its content of cobbles and boulders of dolomite suggest wave agitation and shallower conditions of deposition than in the local basins to the east and west of this locality, which, incidentally, is near the axis of a minor anticline [32] and also the axis of an isopach low of the New Richmond sandstone (Pl. 50).

Exposures of New Richmond sandstone are rare in southwestern Wisconsin because of its slight thickness or because of its removal by post-Prairie du Chien and pre-Saint Peter or later erosion. At several places in La Crosse, Monroe, and Vernon counties, Wisconsin, the Saint Peter sandstone is known to rest on the New Richmond or in depressions in the Oneota. In southeastern Minnesota, as at Lanesboro, where the New Richmond is 44 feet thick, the member consists of massive white and slightly iron stained sandstone. At Preston, 4 miles southwest of Lanesboro, 4 feet of massive dolomite occur in the lower portion of the New Richmond. The occurrence of thin beds of shaly and cherty dolomite, interbedded with the sandstone, as at Lake City, Minnesota, and Lansing, Iowa, causes difficulty in distinguishing the New Richmond from the adjacent dolomite members. Beneath the surface, the New Richmond is identified by a predominance of sandstone, but beds of dolomite have been reported in it in Iowa [33] and both dolomite and chert in northern Illinois.[34]

[32] Trowbridge, A. C. Upper Mississippi Valley structure. Bull. Geol. Soc. Am. 45: 522-523, fig. 1. 1934.

[33] Norton, W. H. Deep Wells of Iowa. Iowa Geol. Surv. 33: 104-437. 1928.

[34] Needham, C. E. Contributions to the subsurface geology of northern Illinois, between the outcrops of the Saint Peter and Dresbach formations, with special reference to the

WILLOW RIVER (SHAKOPEE) DOLOMITE

The upper dolomite member of the Prairie du Chien at Burkhardt, Wisconsin, may be distinguished from the Oneota member by its thin bedded character (Pl. 51, compare a and b). Within the upper dolomite are several thin beds (2 inches to 1 foot and 6 inches) of sandstone and sandy dolomite which are distinct from the New Richmond sandstone at the base of the Willow River dolomite. There is a similar occurrence of thin sandstone beds within the Willow River at Cannon Falls, Minnesota. This member, as a whole, contains more sand than the Oneota dolomite. Shale and siltstone are important constituents in certain beds, as at Lanesboro and Preston, Minnesota, in northeastern Iowa, and at La Salle, Illinois. Chert occurs commonly in the Willow River, but nowhere in as great abundance as in the "upper cherty beds" of the Oneota (p. 432, this report). Oolites and glauconite are also present, but do not characterize any zone. There is some similarity, however, of the Cryptozoon reef structures to those of the Oneota. It may be generally stated that isolated exposures of Willow River dolomite may be distinguished, by field study, from Oneota dolomite.

SEDIMENTARY PETROLOGY

Approximately one thousand samples were collected from the Prairie du Chien sediments for laboratory investigation. Insoluble residues were prepared and petrographic studies were made. The writer plans to use the mineralogical analyses in a later report devoted to the sedimentary petrology of the formation.

Insoluble residues of samples from Minnesota River valley and from Lanesboro, Minnesota, have been studied by Tester and Couser.[35] Clement,[36] in 1933, studied insoluble residues from a few sections on Saint Croix River. The heavy accessory minerals below and above the Jordan-Oneota contact were studied by Graham,[37] in 1933, in sections on Minnesota River and on Mississippi River in southeastern Minnesota. Only such of these data as are necessary to substantiate the conclusions are included in the present paper.

New Richmond formation. Unpublished doctor's thesis. Northwestern University library. 1932.

35 Tester, A. C. and C. W. Couser. A petrographic study of the Prairie du Chien of the Minnesota River Valley, Minnesota. Unpublished manuscript. 1935.

36 *Op. cit.*

37 Graham, W. A. P. Petrology of the Cambrian-Ordovician contact in Minnesota. Jour. Geol. 41: 468-486. 1933.

Among the minerals of detrital origin are:

Garnet	Rutile
Zircon	Pistacite
Tourmaline	Titanite
Muscovite	Biotite
Common hornblende	Tremolite
Feldspars	Anatase
Magnetite or ilmenite	Quartz

Quartzite has also been introduced, but does not occur in abundance except where it has been derived from the quartzite formations in the Baraboo, Wisconsin, region. Abraded grains of chert have probably been derived both from distant sources and from reworking of chert deposited during the Prairie du Chien time. Tabular pebbles of dolomite occur commonly throughout the formation and are locally abundant in beds of conglomerate texture.

Among the minerals of secondary origin are:

Feldspars	Chert
Anatase	Chalcedony
Leucoxene	Pyrite
Quartz	Hematite
Galena	Limonite
Opal	

Calcite occurs as small veins and cavity fillings, and some dolomite is seen to be formed by recrystallization or direct precipitation, as within cavity fillings of residual clay. Siderite occurs in minute rhombs in the Oneota at Osceola, Wisconsin, and possibly in other sections. Both calcareous and siliceous oolites are common in dolomite and chert, with diameters of .75-1.5 mm. They either have no apparent nuclei or have grown around sand grains. A few siliceous monaxon and tetraxon sponge spicules have been observed from the Oneota.

Practically all of the minerals that have been described here have been found throughout the Prairie du Chien. An examination of the analyses of accessory minerals shows no great difference in their occurrences and relative abundance in the three members of the formation.

STRATIGRAPHIC RELATIONS

There is a gradual transition in lithology from the "Madison" beds of the Jordan sandstone throughout southwestern and southern Wisconsin, northeastern Iowa, and in the Mississippi valley region of southeastern Minnesota. At Stillwater, Minnesota, on Saint Croix River, the beds of alternating sandstone and dolomite are not present, and Oneota dolomite rests on the slightly irregular surface of Jordan sandstone. At St. Peter, Kasota and Mankato, Minnesota, Oneota dolomite overlies a more or less lenticular development of white shaly siltstone. Graham,[38] in 1933, described this irregular contact as having been produced by post-Oneota solution above the top of the Jordan. Stauffer and Thiel,[39] later in the year, redescribed the contact and agreed with Graham's interpretation. Graham,[40] in 1933, found that the Jordan-Oneota contact, on Minnesota River, and in certain sections along Mississippi River in southeastern Minnesota, is not located at the same horizon in the field as where changes occur in analyses of heavy minerals. There are conglomeratic beds at the base of the Oneota in southwestern Minnesota, northeastern Iowa, and southwestern Wisconsin which might have been easily produced by subaqueous erosion. Twenhofel and Thwaites,[41] in 1919, suggested that the "quartzite-like" beds in the upper portion of the "Madison" may have been due to pre-Oneota case-hardening resulting from exposure before Oneota deposition. The writer believes, however, that there is conformity between the Jordan and Oneota in the upper Mississippi valley, except at Stillwater, Minnesota, and possibly on Minnesota River, where Graham [42] recognized a break in sedimentation by both field and microscopic evidence. In 1924, Ulrich [43] believed the entire Oneota to be absent at Jordan, Minnesota, and probably also at Ripon and Butte des Morts in eastern Wisconsin, but as stated by Trowbridge and Atwater [44] the entire Prairie du Chien has been removed at Jordan by post-Prairie du Chien erosion. The writer has found no physical or mineralogical evidence to support the belief that the entire 113 feet of Prairie du Chien at Ripon and the more than 100 feet at Butte des Morts are equivalent to the upper dolomite member of western Wisconsin. If Ulrich's [45] correlations are correct, there would be a break at the Jordan-Oneota contact in western Wisconsin, represented by deposition of 2500 feet of "Lower Ozarkian dolomite" in Pennsylvania and Alabama, overlain stratigraphically by 2000 feet of "Middle Ozarkian dolomite" in the Appalachian region. The evidence for such a break in western Wisconsin would be entirely paleontological, because physical evidence is not only lacking in its favor, but rather indicates uninterrupted deposition, except for the production of brecciated and conglomeratic zones at the base of the Oneota, which occur within the Jordan and Oneota as well.

[38] Graham, W. A. P. Petrology of the Cambrian-Ordovician contact in Minnesota. Jour. Geol. 41: 471-473. 1933.

[39] Stauffer, C. R. and G. A. Thiel. Jordan-Oneota contact along the Minnesota River. Bull. Geol. Soc. Am. abstract. 1933.

[40] Graham, W. A. P. Petrology of the Cambrian-Ordovician contact in Minnesota. Jour. Geol. 41: 486. 1933.

[41] Twenhofel, W. H. and F. T. Thwaites. The Paleozoic section of the Tomah and Sparta quadrangles, Wisconsin. Jour. Geol. 27: 631. 1919.

[42] Graham, W. A. P. *Op. cit.*

[43] *Op. cit.*

[44] *Op. cit.*: 69-70.

[45] *Op. cit.* 83.

On the basis of meager faunas, Ulrich [46] placed the Oneota in the upper part of his proposed Ozarkian system and the "Shakopee" in the upper part of his Canadian system, thus recognizing a systematic break between the Oneota and "Shakopee" in the Upper Mississippi Valley, with the Lower and Middle Canadian missing between them. The New Richmond was considered as an introductory clastic phase of the "Shakopee." Where the New Richmond was thought to be absent, Ulrich cited physical evidences for location of the Oneota-"Shakopee" contact. At Stillwater, Minnesota, for example, the base of the "Shakopee" was placed at 60 feet above the base of the Oneota. His reasons for believing that the surface of the Oneota was eroded there before deposition of the "Shakopee" are as follows:

"(1) the relatively slight thickness of the lower formations, (2) the absence of the fossiliferous cherty zone, that is commonly present in the upper part of the Oneota at and to the south of Trempealeau, (3) the uneveness of the contact plane which shows irregularities of contour of a foot or more and corresponding dissection across sedimentary planes in distances of less than 10 feet, and (4) the presence of one to three inches of conglomerate with limestone and chert pebbles in a matrix of coarse quartz sand and grains of glauconite." [47] It was recognized that such a contact would be "affected and correspondingly obscured by secondary dolomitization." [48]

In criticism of the statements quoted from Ulrich above, the relatively slight thickness of the Oneota is thus assumed because he arbitrarily placed the top of the Oneota at only 60 feet above the top of the Jordan. The absence, at Stillwater, of the fossiliferous

[46] *Op. cit.* 100-104.

[47] Ulrich, E. O. *Op. cit.* 101.

[48] Ulrich, E. O. *Op. cit.*

upper cherty zone that is present in the upper Oneota south of Trempealeau does not imply non-deposition or removal of those beds by pre-New Richmond erosion. Careful and extensive field studies show that the "upper cherty beds" of the Oneota (see p. 432 of this report), as well as other lithologic zones in southwestern Wisconsin gradually lose their identity northwest of La Crosse and Trempealeau. Bedding planes with an unevenness of even more than one foot in distances of 10 feet, described in the Stillwater section, can be duplicated in many sections of the Prairie du Chien at horizons of no stratigraphic importance. Beds of conglomerate, one to three inches in thickness, with pebbles of dolomite and chert in a matrix of dolomite and quartz sand have been found by the writer at many horizons throughout the Prairie du Chien less than 10 miles from Stillwater, at Burkhardt, Wisconsin, and in most sections within the area of outcrops.

Field study of a large number of sections, involving the three members of the Prairie du Chien, shows no physical evidence for a significant unconformity within the formation. Local disturbances within the New Richmond sandstone, lying on a slightly eroded surface of the Oneota, as at Point Douglas, Minnesota, might be accounted for by wave agitation in a shallow portion of the depositional basin. That suggestion is substantiated by the fact that the New Richmond sandstone is thin near the Hudson anticline and increases in thickness in the structural basins described by Trowbridge immediately east and west of the anticline (p. 428 of this report).

The quartz sand in insoluble residues of the Prairie du Chien at Burkhardt, Wisconsin, increases from the lower portion of the Oneota to a maximum in the New Richmond sandstone and decreases more or less gradually from the base of the upper dolomite member toward the top. Local folds there involve the upper Oneota, New Richmond, and the basal beds of the upper dolomite alike. Except for the section described at Point Douglas, Minnesota, no irregularities have been observed on the surface of the Oneota where it is overlain by the New Richmond sandstone. Many sections, as at Lake City and Preston, Minnesota, demonstrate a gradual transition from the upper Oneota into the lower New Richmond. The writer has found that the mineral suites of the three members of the Prairie du Chien are strikingly similar. This would indicate a close relation between them as members of a formation rather than substantiate a systemic break between the lower and upper dolomite members. The writer, therefore, expresses the belief that there was continuous deposition throughout the Prairie du Chien in the Upper Mississippi Valley.

It is generally agreed that there is an erosional unconformity between the Prairie du Chien and Saint Peter formations. Trowbridge,[49] in 1917, described this unconformity in northeastern Iowa, and Trowbridge and Atwater,[50] in 1934, discussed it for the Upper Mississippi Valley. In many sections of southwestern Wisconsin, pre-Saint Peter erosion removed much or all of the upper dolomite of the Prairie du Chien, and in some places the Saint Peter sandstone rests on a very irregular surface of the Oneota. Subsurface data in southern Wisconsin and northern Illinois on thicknesses of the Prairie du Chien formation, when plotted on an isopach map (see Pl. 49), give a general concept of the amount of sediments removed from both the Prairie du Chien and from upper Cambrian sandstones before deposition of the Saint Peter sandstone.

CLASSIFICATION

PRAIRIE DU CHIEN FORMATION

The beds referred to the Prairie du Chien in this report are precisely the same as those to which the term was originally applied by Bain.[51] The geographic term was preferred to Owen's lithologic term, "Lower Magnesian" (see p. 422 of this report), as a regional term for the Upper Mississippi Valley. Where the entire thickness occurs, it was considered to include "(a) a dolomite at the base, 200 to 225 feet thick; (b) a sandstone in the middle, 15 to 130 feet, increasing to the southwest under cover; (c) a second dolomite at the top, approximately 40 feet in thickness."[52] In the bluff of the Mississippi River Valley, east of Prairie du Chien, Wisconsin, there is a complete exposure of the Prairie du Chien beds, consisting of 155 feet of dolomite below, overlain by 6 feet of sandstone and that in turn by 20 feet of dolomite. After an examination of representative sections of the Prairie Du Chien in the area of outcrops, a study of insoluble residues, a consideration of well records from geological reports and an examination of cuttings

49 Trowbridge, A. C. Prairie du Chien-Saint Peter unconformity in Iowa. Proc. Iowa Acad. Sci. 24: 177-182. 1917.

50 *Op. cit.*: 77-78.

51 Bain, H. F. Zinc and lead deposits of the Upper Mississippi Valley. U. S. Geol. Surv. Bull. 294: 17-19. 1906.

52 Bain, H. F. *Op. cit.*, p. 18.

from a few wells in Iowa,[53] the writer considers it advisable and practical to adopt Bain's original classification and to follow Trowbridge and Atwater [54] in classifying the term as a formation, consisting of three members.

This seems better than raising the Prairie du Chien to the rank of a group and the subdivisions correspondingly to formations. In such sections as at Stillwater and Hastings, Minnesota, stratigraphers disagree on the location of the Oneota-New Richmond and New Richmond-Willow River (Shakopee) contacts. Some even discount the New Richmond as a stratigraphic unit. Until the three units can be further subdivided by lithology and (or) fossils, the ranking adopted here should be retained. It is in harmony with the trend toward simplifying the classification of the lower Paleozoic sediments in the Upper Mississippi Valley.

ONEOTA DOLOMITE MEMBER

McGee's [55] term, Oneota, was generally accepted in and after the year 1892 for the lower dolomite unit of the sequence now known as Prairie du Chien. The writer adopts this well established term of McGee's for the beds of dolomite along the Upper Iowa River (old Oneota River), Iowa, and as the equivalent of Irving's Main Body of limestone, Wooster's Lower Magnesian proper, and Upham's Shakopee B limestone. In the Upper Mississippi Valley it is thus classified as the Oneota dolomite member overlying the Jordan member of the Trempealeau formation [56] and underlying the middle sandstone member of the Prairie du Chien formation.

NEW RICHMOND SANDSTONE MEMBER

Between the lower Oneota dolomite member and the upper dolomite member of the Prairie du Chien formation is a sandstone unit which is coextensive with them and which is not completely lacking in any place. Its thickness is 4 feet at Mankato, and 2-4 feet at Shakopee, Minnesota. Within the shoreward side of the outcrops in Wisconsin, it is 5-15 feet on Willow River and 5-10 feet in southwestern Wisconsin. In subsurface it is recognizable in most wells that have penetrated to the Oneota dolomite. There is, of course, difficulty in recognizing it in some wells where drilling records are

53 Courtesy, Iowa State Planning Board, Project 1044-C, 1934.

54 *Op. cit.* 21-80.

55 McGee, W. J. Pleistocene History of northeastern Iowa. U. S. Geol. Surv. 11th Ann. Rept. pt. 1: 331-333. 1891.

56 Twenhofel, W. H., G. O. Raasch, and F. T. Thwaites. Cambrian strata of Wisconsin. Bull. Geol. Soc. Am. Manuscript in press. 1934.

not adequate, and where its lithology does not allow a sharp distinction from the adjacent members. Where the sandstone is thin in Minnesota River valley and in Wisconsin, it might be easily penetrated in some wells without recognition. Quartz sand is an important constituent of the Prairie du Chien throughout, and within the dolomite members it locally predominates in certain beds as lenses, which the writer thinks, can in all cases be distinguished from the middle sandstone member. Wooster's choice of the type section of the New Richmond sandstone was unfortunate, because on Willow River it varies greatly in thickness within short distances, which is not typical of the unit throughout most of its extent in outcrops and in subsurface. Near the town of New Richmond, its lenticular development and poor exposure may cause it to be confused with the associated dolomite beds. Thwaites [57] was unable to distinguish the New Richmond sandstone from sandy beds of the Oneota in a deep well at New Richmond. At the upper Burkhardt dam on Willow River, however, the New Richmond sandstone unit is 5 feet thick and serves to delimit the upper part of the Oneota dolomite and the lower part of the upper dolomite member. In a discussion of the thickness of the Prairie du Chien (p. 428 of this report), attention was called to the coincidence of a minor syncline and an isopach high of both the New Richmond sandstone (Pl. 50) and the entire Prairie du Chien formation (Pl. 49) east of Burkhardt, Wisconsin. The suggestion of a local and more or less constricted basin of deposition in that area might account for the rapid increase in thickness of the New Richmond from 5 feet at Burkhardt to 10 feet between New Richmond and Jewetts and nearly 15 feet east of Jewetts on Willow River, the last of which occurs near the axis of the isopach high.

Perhaps it would be clearer to discard the poorly defined term, New Richmond, in favor of another geographic term chosen at a better exposure of the middle sandstone unit, as for examples, the sections at Lanesboro and Preston, Minnesota. Since the New Richmond was first applied, however, its stratigraphic position has been generally recognized, and the term has become well established in literature. It therefore seems advisable to follow the recent classification of Trowbridge and Atwater [58] and the suggestion of Wilmarth [59] in retaining the term New Richmond for the middle sandstone member of the Prairie du Chien formation.

57 Personal communication to the writer. 1933.

58 *Op. cit.*: 72-73, 79.

59 Wilmarth, Grace. Communication to the writer, Nov. 19, 1934.

A log of the J. A. Wilder well in the southeast part of Shakopee was published by Winchell [61] in 1888, and interpreted by Stauffer [62] in 1934, as follows:

LOG OF J. A. WILDER'S WELL AT SHAKOPEE

(River fill)	
Soil	2 feet
Yellowish stratified clay	5 feet
Sand and gravel, interstratified, coarsest below	38 feet
(Shakopee)	
Hard limestone	61 feet
(New Richmond)	
Quicksand and sandstone, plenty of water	2 feet
(Oneota?)	
Hard, cherty limestone	4 feet

That neither Winchell nor Stauffer knew the curb elevation of the J. A. Wilder well is demonstrated by their comparison of the "*New Richmond?*" (Stauffer) sandstone with a sandstone bed that was thought to occur, but not actually seen, at about river level in Shakopee.

The curb of the Wilder well is 905 feet above sea level. At an elevation of 860 feet, the top of the Prairie du Chien was entered. Below it, the drill penetrated 61 feet of dolomite and 2 feet of sandstone, which the writer ascribed to the upper dolomite and middle sandstone members, respectively, of the Prairie du Chien formation. Between the base of the sandstone at 797 feet in the Wilder well and the base of the dolomite at 671 feet in the City well, there is a thickness of 126 feet of beds ascribed by the writer to the Oneota dolomite member. A tabular summary of the Prairie du Chien formation at Shakopee is as follows:

	Thick (feet)	Elev. (feet)
Curb, J. A. Wilder well		905
Clay, sand and gravel	45	860
Willow River dolomite		
Dolomite	61	799
New Richmond sandstone		
Sandstone	2	797
Oneota dolomite		
Dolomite	4	793 (T.D.)
Unrecorded	61	732
Dolomite and sandstone, exposed	7	725

61 Winchell, N. H. Geology of Minnesota. Final Rept. 2: 125. 1888.

62 Stauffer, C. R. Type Paleozoic sections in the Minnesota Valley. Jour. Geol. 42: 350. 1934.

ERRATA

Since this paper was printed, Stauffer has learned that the original curb elevation of the city well at Shakopee was 12 feet below the present curb, or at an elevation of 713 rather than 725 feet; and also that the curb elevation of the J. A. Wilder well is 817 feet rather than 905 feet as printed in this paper.[1] The writer accepted this erroneous elevation for the Wilder curb from a determination made several years ago by engineers of the city of Shakopee, who placed the Wilder curb 180 feet above the present curb of the city well.

Considering these two corrections, the upper and lower parts of the general section at Shakopee work out from well data as follows:

J. A. Wilder Well	*Thickness*	*Elevation*
Clay, sand and gravel	45 feet	772-817
Dolomite	61 "	711-772
Sandstone	2 "	709-711
Dolomite	4 "	705-709 T.D.
Railroad cut and city well		
Dolomite	4 feet	728-732
Sandstone	2 "	726-728
Dolomite	1 "	725-726
Present curb city well 725.		
Dolomite excavated	12 "	713-725
Original curb city well 713.		
Dolomite	58 "	655-713
Jordan sandstone	112 "	543-655

The main difficulty now is in correlating the section in the Wilder well with that in the city well and the exposures near it. It is clear that the upper and lower parts of the section overlap. If the 2-foot sandstone of the Wilder well, at elevations of 709-711 feet, is identified with the 2-foot sandstone exposed in the railroad cut near the city well, elevation 726-728 feet, the general section might be interpreted as follows:

Willow River dolomite	61 feet
New Richmond sandstone	2 "
Oneota dolomite	71 "
Total Prairie du Chien	134 feet

1 Personal communication from G. M. Schwartz to A. C. Trowbridge, dated October 28, 1935.

Willow River, the entire dolomite member and its contacts with the New Richmond sandstone below and the Saint Peter sandstone above are exposed. It would thus be confusing to describe the type section of the Willow River dolomite (Wooster) as the type section of the Shakopee. Trowbridge and Atwater,[64] in 1934, favored returning to Wooster's term Willow River if the Shakopee type section should be proved to belong to the Oneota dolomite. In spite of the firm establishment of the Shakopee in literature since 1874, it seems better to discard the term and to revive the term Willow River. That would not be as objectionable for replacement of Shakopee as a newly proposed name, since it was introduced only 8 years later (1882), and has not been entirely disused since that date. The term, Willow River, is therefore adopted for the upper dolomite member of the Prairie du Chien formation in the Upper Mississippi Valley with a detailed description of the exposure at the upper Burkhardt dam on Willow River for the type section, as follows:

Location: SW¼ sec. 2, T. 29 N., R. 19 W., below new dam on Willow River, 1 mile above Burkhardt, St. Croix County, Wisconsin.

The entire thickness of the Willow River dolomite is exposed between the top of the dam and the water level by the power house below the dam. The 5 feet of beds assigned to the New Richmond member were exposed at the dam in 1931 but are now below water level. However, they are exposed about 200 yards down stream and almost continuously to the lower Burkhardt dam.

Top. Elevation 913 feet.

	Ft.	In.
21. Sandstone; base of St. Peter		
Willow River dolomite		
20. Dolomite; buff, light brownish; medium to coarse crystalline; bedding, massive; conglomeratic, few scattered pebbles dolomite	1	3
19. Sandstone; brown, buff; medium grained; relatively firm; cement dolomitic, 20-40%; conglomeratic, small pebbles, 2% =; cross-bedded		6
18. Dolomite; buff, greenish; lithographic to medium grained; shaly, greenish, concentrated along bedding surfaces of thin beds; conglomeratic, pebbles of dolomite locally concentrated; sandy, lenticular, near top; bedding, thin to massive, 1-4 inches	2	
17. Dolomite; gray, buff to greenish; fine to medium crystalline, locally coarse; shaly, greenish, concentrated along bedding surfaces; sandy, 2-30%; conglomeratic, some beds with abundant granules and small pebbles of light buff dolomite; oolitic (calcareous), dissolved out of some beds to leave minute pores; gastropods, few, ½ inch in diameter	6	10
16. Sandstone; brown, buff; relatively firm; cement, dolomitic, content variable, 5-45%; medium grained; conglomeratic, few small pebbles of dolomite; thin bedded		1
15. Dolomite; buff; medium crystalline; relatively firm; minutely porous where calcareous oolites were dissolved; oolitic, abundantly; sand, 5-15%; bedding, thin, 2-4 inches	2	
14. Sandstone; grayish white to buff; fine to medium grained; shaly, greenish, disseminated and in thin seams; dolomitic, 20-35% of stratum, as cement and as thin dolomite beds alternating with sandstone; bedding, very thin, ¼ inch	2	
13. Dolomite; buff; firm; fine to medium crystalline, variable with beds; sandy, 0-20%; some beds minutely porous, may represent dissolved oolites (calcareous); conglomeratic, few small pebbles dolomite; gastropods, occasional, 5 mm. in diameter	4	4
12. Sandstone; gray, greenish; medium grained; shaly, greenish, thin seams; very thin bedded; interbedded with Dolomite; buff; fine to medium crystalline; lenticular; grades laterally into sandstone; beds involved in wavy structures with relief of 2 feet in horizontal distance of 20 feet	1	8
11. Dolomite; buff; medium to coarse crystalline; relatively firm; sandy, thin and discontinuous lenses; glauconitic; conglomeratic, some thin beds locally brecciated and with tabular pebbles of dolomite; zone with major wavy structure with relief of 5 feet in horizontal distance of 20 feet; gastropods, few, 10 mm in diameter	3	2
10. Dolomite; buff; medium to coarse crystalline; bedding, 6-10 inches; minutely porous; sandy, 0-10%; gastropods, 2-30 mm, abundant		11
9. Sandstone; gray; firm to friable; cement dolomitic; shaly, greenish; thin laminations; very thin bedded		2-4
8. Dolomite; buff, grayish; medium to coarse crystalline; relatively firm; minutely porous; sandy, 5-20%		6
7. Sandstone; white, greenish; fine to medium grained; thin bedded; shaly, greenish, disseminated and in thin seams; relatively firm, cement dolomitic; bedding wavy		6-9
6. Dolomite; gray; firm; medium crystalline; brecciated, possibly mud cracks and crevices later filled with dolomite; sandy, irregular concentrations, 6-10%		8
5. Dolomite; buff, grayish; firm; texture variable; very conglomeratic, granules, pebbles and cobbles of light buff dolomite, 20% =; sandy, medium grained, 20% =	1	5
4. Dolomite; buff, grayish; fine to medium crystalline; bedding, thin, wavy; conglomeratic, at top, 80% of bed; Sandstone; white to greenish; medium grained; shaly, greenish, thin seams and disseminated through sandstone; dolomitic; relatively firm; 20% of bed	1	

[64] *Op. cit.*: 45, 72.

3. Dolomite; buff, grayish; fine to medium crystalline; sandy, 2-20%, variable with thin beds; shaly, greenish, locally concentrated on bedding surfaces; conglomeratic, thin beds with scattered pebbles of dolomite; bedding thin, slabby; gastropods, abundant on some bedding surfaces	4	4
2. Dolomite; buff, brownish to grayish; bedding irregular and thin; medium crystalline; sandy, 5-25%; conglomeratic, scattered pebbles of dolomite; gastropods, abundant on some beds	2	
Total	36	8
New Richmond sandstone		
1. Sandstone; massive; exposed in 1931, but now below water level	3	

Paleozoic Stratigraphy and Structure in the Minnesota River Valley

by

CHESTER W. COUSER

Contents

INTRODUCTION

Type sections of the Saint Lawrence, Jordan, Shakopee, and Saint Peter formations or members occur on Minnesota River between its mouth at Fort Snelling and New Ulm. Other formations or members, mostly described before 1900, occur here also. Although the strata in this area have long been known not to be exactly horizontal, no detailed structural studies have been made previously. The purpose of this paper is to present the results of a restudy of these type sections and of other exposed sections in the Minnesota River valley and of structural plane table mapping of the same area and thus to contribute to the solution of the several stratigraphic and structural problems in the upper Mississippi Valley.[1]

Since this paper was completed and submitted for publication but before it was sent to the printer, a paper by Stauffer [2] has appeared, which in some sense is duplicated by the present investigation. However, as the conclusions and interpretations of the present writer in regard to a number of important stratigraphic points differ somewhat from those of Stauffer, and as all known sections, both surface and subsurface, whether type sections or not, and structure as well as stratigraphy are included, this paper is being sent to press without change, except for the insertion of this paragraph and some minor revision of phraseology, punctuation, etc.

STRATIGRAPHY

GENERAL STATEMENT

In this paper the formations are classified and named according to a scheme which has been tentatively agreed upon for the states of Wisconsin, Illinois and Iowa and which best expresses the writer's opinions concerning the divisions in the Minnesota valley. The classification used (Table I) is that tentatively proposed by

1 Trowbridge, A. C. and G. I. Atwater. Stratigraphic problems in the upper Mississippi Valley. Bull. Geol. Soc. Am. 45: 21-80. 1934.

Trowbridge, A. C. Upper Mississippi Valley Structure. Bull. Geol. Soc. Am. 45: 519-528. 1934.

2 Stauffer, C. R. Type Paleozoic sections in the Minnesota valley. Jour. Geol. 42: 337-357. 1934.

Trowbridge and Atwater [3] for the upper Mississippi Valley, as modified by Twenhofel, Raasch and Thwaites [4] for Wisconsin and by

Table I

Stratigraphic Section in the Minnesota River Valley [5]

System	Series	Formation	Member	Lithology	Thickness (feet)
	Mohawkian	Platteville		Limestone	30
Ordovician	Chazyan	St. Peter Unconformity		Sandstone	165
		Prairie du Chien	*Shakopee	Dolomite	150
			New Richmond	Sandstone	
			Oneota	Dolomite	
		local unconformity			
Cambrian	St. Croixan	Trempealeau	Jordan	Sandstone	110
			Lodi	Siltstone, sandstone, shale limestone	30
			St. Lawrence	Dolomite	15
		local unconformity		(?)	
		Franconia		Sandstone, greensand, limestone, shale	145
		local unconformity			
			Galesville	Sandstone	70
			Eau Claire	Sandstone, shale	190
			Mt. Simon	Sandstone	115
		Unconformity (?)			
Cambrian?	Acadian (?) Waucobian (?) Keweenawan (?)	"Red Clastic"		Red sandstone, shale	50-1300
Algonkian	Huronian	Sioux		Quartzite	

* This is the Willow River (Shakopee) of Powers.

Trowbridge through Norton [6] for Iowa.

The Red Clastics and Dresbach formation and all of the Franconia but its uppermost beds are not exposed at the surface but are recorded in wells. All the exposures in the Minnesota River valley are located and numbered on figure 1.

[3] *Op. cit.*: 79.

[4] Twenhofel, W. H., G. O. Raasch and F. T. Thwaites. Cambrian strata of Wisconsin. Bull. Geol. Soc. Am. In press.

[5] Adapted from: Trowbridge and Atwater, *op. cit.*; Twenhofel, Raasch and Thwaites, *op. cit.*; and Norton, *op. cit.*

[6] Norton, W. H. Deep wells drilled in Iowa, 1928-1932. Iowa Geol. Survey: 36. 1935. In press.

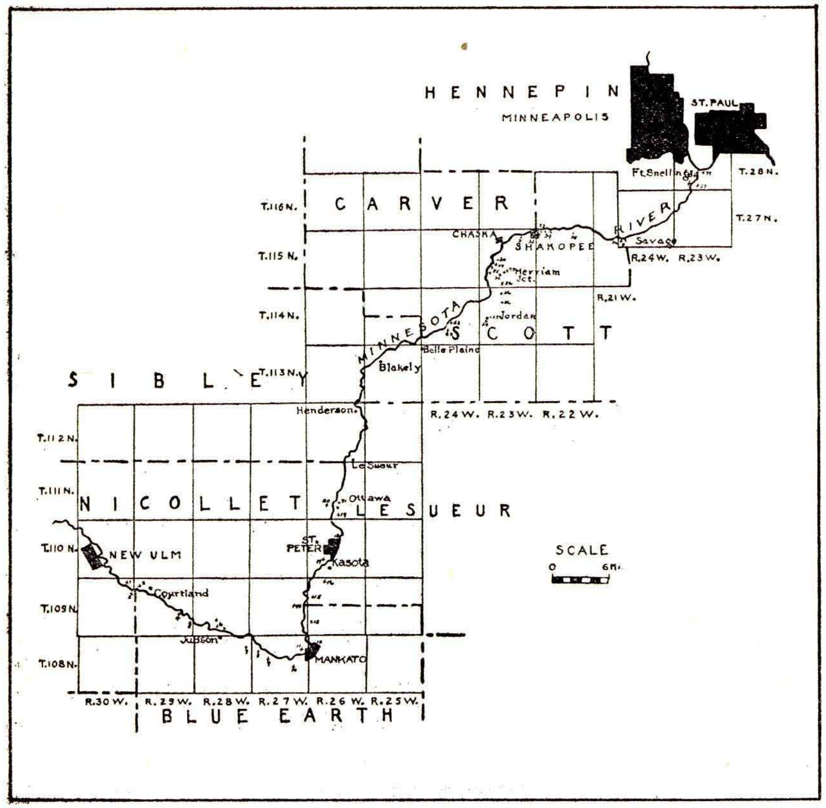

Fig. 1. Map of the Minnesota River valley from Fort Snelling to New Ulm. Numbers refer to exposures.

Exposure No.	Explanation
1	New Ulm quartzite. West-central Sec. 2, east-central Sec. 1, T. 109 N., R. 30 W.
2	Cretaceous shales. NE¼ Sec. 12, T. 109 N., R. 30 W., and NW¼ Sec. 7, T. 109 N., R. 29 W.
3	Cretaceous (?) sands. NE¼ Sec. 16, NW¼ Sec. 15, T. 109 N., R. 29 W.
4	Cretaceous (?) sands. SE¼ Sec. 23, T. 109 N., R. 29 W.
5	Franconia or St. Lawrence. SE¼ Sec. 25, T. 109 N., R. 29 W.
6	Franconia and St. Lawrence. East-central Sec. 33, SE¼ Sec. 28, SW¼ Sec. 34, T. 109 N., R. 28 W.
7	Jordan. NW¼ Sec. 12, T. 108 N., R. 28 W.
8	Jordan, South-central Sec. 7, T. 108 N., R. 27 W.
9	Jordan-Prairie du Chien contact. Central Sec. 17, T. 108 N., R. 27 W.

10	Jordan-Prairie du Chien contact. NW¼ Sec. 23, T. 108 N., R. 27 W.
11	Jordan-Prairie du Chien contact exposed for several miles along river road from Mankato toward Judson.
12	New Richmond in quarry NW¼ Sec. 7, T. 108 N., R. 26 W.
13	Fossiliferous upper Jordan, SW¼ Sec. 30, T. 109 N., R. 26 W.
14	Jordan-Prairie du Chien contact well exposed along river road from St. Peter to near Mankato.
15 and 16	Almost continuous exposures of Prairie du Chien in quarries.
17	Jordan-Prairie du Chien contact exposed on both sides of the river southwest of St. Peter.
18	Fossiliferous upper Jordan underneath new highway bridge NE¼ Sec. 21, T. 110 N., R. 26 W. (Exposure is now covered.)
19	Jordan-Prairie du Chien contact. White Rock quarry. SW¼ Sec. 34, T. 111 N., R. 26 W.
20	Jordan. Between Secs. 28 and 29, T. 111 N., R. 26 W.
21	Jordan-Prairie du Chien contact. Schwartz farm NW¼ Sec. 27, T. 111 N., R. 26 W. Other isolated exposures of Jordan and Prairie du Chien are found in the vicinity of Ottawa.
22	St. Lawrence. Type section. NE¼ Sec. 28, T. 114 N., R. 24 W.
23	Franconia-St. Lawrence contact. SE¼ Sec. 21, T. 114 N., R. 24 W.
24	St. Lawrence-Jordan contact in the bed of Sand Creek, below the breweries in Jordan.
25	Isolated exposures of Jordan at the type locality.
26	Isolated exposures of Jordan along Sand and Van Oser Creeks. Secs. 21, 28, 29 and 33, T. 115 N., R. 23 W., and Secs. 4 and 9, T. 114 N., R. 23 W.
27	Prairie du Chien. Upper St. Louis quarries, north-central Sec. 28, T. 115 N., R. 23 W.
28 and 29	Jordan-Prairie du Chien contact. East-central Sec. 20, SW¼ Sec. 21, and central Sec. 29, T. 115 N., R. 23 W.
30	Prairie du Chien. Lower St. Louis quarries, west-central Sec. 21, T. 115 N., R. 23 W.
31, 32, 33, 34, 35	Exposures in vicinity of Shakopee. (See text).
36	Prairie du Chien. Although not naturally exposed at the surface the Prairie du Chien is uncovered in many shallow excavations in the vicinity of Savage.
37, 38, 39	Platteville and St. Peter. Exposed on both sides of the river in the vicinity of Fort Snelling. Secs. 33, 32, 28, 21, T. 28 N., R. 23 W.

ALGONKIAN

Huronian

SIOUX

The Paleozoic rocks of the Minnesota River valley rest unconformably on a quartzite basement, the contact being somewhat

obscure. The easternmost exposure of the quartzite, which has long been correlated with the Sioux quartzite, is 3 miles west of Courtland, Nicollet County (1, fig. 1). The rock is thick-bedded and purple or reddish.

CAMBRIAN (?)

On the 1932 map of Minnesota no Paleozoic sediments appear in the Minnesota River valley east of a point midway between Judson and Courtland. West of this point the sediments are mapped as Cretaceous (2, 3, and 4, fig. 1). The Cretaceous rocks consist of red sandy shales and a few calcareous beds. Sandstones in this area have also been assigned to the Cretaceous.

The westernmost exposure of Cambrian rocks found by the writer occurs in the SE¼ of Sec. 25, T. 109 N., R. 29 W. (5, fig. 1). The strata exposed probably belong in the Franconia formation. Unless overlapped by younger Cambrian strata or buried beneath the Cretaceous sediments, the Red Clastics and Dresbach formation would be expected to appear at the surface between the westernmost Cambrian and the easternmost pre-Cambrian, a distance of about 7 miles. Within this area sedimentary rocks are exposed at a number of places of which some have been assigned previously to the Cambrian, some to the Cretaceous and some have been left in doubt.

Because of the stratigraphic position of these strata and the similarity of their heavy minerals to those of neighboring Cambrian beds, the writer believes that some of them may be of Cambrian age. However, the Cretaceous sea, advancing from the west over exposed Cambrian sediments may have reworked heavy minerals and reincorporated them within the Cretaceous deposits.

On the structure section (fig. 2) these beds of uncertain age are placed in the Cretaceous.

Red Clastic Series

With the possible exception of the exposures already mentioned, the Red Clastics are not exposed in the Minnesota River valley. They are recorded, however, in many wells. The total thickness in the Minnesota River valley is not known. The available data from wells are given in Table II.

Table II

Wells Showing Thicknesses of Red Clastic Sediments [7]

Location of Well	Thickness in Feet
Lake Crystal	50
Minneopa Falls	260+
Mankato	1300+
Henderson	200+
Minneapolis	1140+

In addition to the wells listed, wells at Jordan, Merriam Junction, Chaska and Shakopee are reported to have reached the Red Clastics. The Red Clastics are red shales, sands and sandy shales.

CAMBRIAN SYSTEM

Saint Croixan Series

DRESBACH FORMATION

The Dresbach formation in the upper Mississippi Valley consists of three members, a lower sandstone (Mount Simon), a shaly and sandy member (Eau Claire), and an upper sandstone (Galesville) (Table I). It is difficult to recognize the Red Clastic-Dresbach contact and the contacts between members of the Dresbach in drillings and the thicknesses assigned to the Dresbach formation and its members may vary considerably. Table III shows thicknesses of the Dresbach formation and its members at several places in the Minnesota River valley.

Table III

Wells Showing Thicknesses (in feet) of the Dresbach Formation and Its Members

Location of Well	Mt. Simon	Eau Claire	Galesville	Dresbach
Mankato	115	240	65	420
Merriam Junction	Mt. Simon & Eau Claire	272+	60	332+
Shakopee	98	173	95	366
South Minneapolis	130+	150	70	350+

The above data were obtained from the logs of the Shakopee well (p. 467), the Mankato well given by Upham,[8] and from the following well logs which have been interpreted by the writer.

7 Hall, C. W., O. E. Meinzer and M. L. Fuller. Geology and underground waters of southern Minnesota. U. S. Geol. Survey, Water-Supply Paper 256: 141, 150, 200, 340, 341, 344. 1911.

8 Upham, Warren. Geology of Blue Earth County, Minnesota. Geol. and Nat'l Hist. Survey. Final Report 1: 423. 1882.

Well log of C. St. P. M. and O. R. R., well at Merriam Junction water tank. Completed March, 1930. Elevation of well site—758 feet. Authority—Chief Engineer

	feet
Drift	
Clay and gravel	5
Limestone	3
Boulders and gravel	14
Clay and sand	17
Trempealeau:	
Jordan	
Soft sandstone	32
Hard sandstone	75
Lodi and St. Lawrence	
Gray shale	15
Limestone	24
Franconia:	
Green shale	145
Dresbach:	
Galesville	
Sandstone	60
Eau Claire and Mt. Simon	
Gray shale	10
Brown sticky shale	18
Green shale	22
Brown shale	30
Gray sandstone	15
White sandstone	120
Yellow sandstone	25
Pink sandstone	20
Red shale	12
	662

Well log of C. M. and St. P. R. R., well at South Minneapolis. Drilled April, 1917. Authority—Chief Engineer

	feet
Drift	
Sand and gravel	16
Hard pan and boulders	39
Platteville:	
Limestone	41
Shale and sandstone	8
St. Peter:	
Sandstone	106
Shale	15
Shale and sandstone	30
Prairie du Chien:	
Shakopee	
Hard rock	40
New Richmond	
Sandstone	5
Oneota	
Hard rock	70
Trempealeau:	
Jordan	
Soft sandstone	56
White shale and sand	24
Coarse sandstone	10
Lodi and St. Lawrence	
Shale and sand	40
Franconia:	
Shale	145
Dresbach:	
Galesville	
Sandstone	70
Eau Claire	
Shale	90
Sandstone	39
Shale and sandstone	21
Mt. Simon	
Sandstone	55
Red and yellow sand	35
Red sandstone	20
Yellow sandstone	10
Red Sandstone	5
Yellow sandstone	5
	995

Lithologically the formation in this area does not appear to be different from that elsewhere in Minnesota and in Wisconsin.

FRANCONIA FORMATION

Although Berkey,[9] in 1897, first named and described the Franconia formation as distinct from the Dresbach beneath and the Saint Lawrence above, it was not so recognized by Hall, Meinzer and Fuller [10] and has only recently been reassigned the rank of a separate formation in Minnesota.[11] In the present paper the Franconia includes beds consisting chiefly of sandstones and greensands that lie stratigraphically under the Saint Lawrence dolomite and over the Galesville sandstone. This is believed to be the original usage of Berkey and it is the present usage in Wisconsin and Iowa.[12]

In the Minnesota River valley the average thickness of the formation as defined above is about 145 feet. In the well at Ottawa, logged below and interpreted by the writer, the lower 131 feet are assigned to the Franconia. The base was not reached with the drill.

Well in Ottawa near river on Section line between Secs. 28 and 33, T. 111 N., R. 26 W. Well site elevation—747 feet

Well starts in Jordan which is exposed just north of the well site

Trempealeau:	Feet
Jordan	
Soft sandstone	40
Hard, white sandstone	20
Lodi and St. Lawrence	
Hard rock and shale	60
Franconia:	
Green shale, penetrated	131+
	251

The exposures of this formation in the Minnesota River valley are few. In the SE¼ of Sec. 21, T. 114 N., R. 24 W., Scott County (23, fig. 1) there are exposed about 5 feet of thin-bedded, brownish, glauconitic, sandy shale and dolomite, conglomeratic at the top, which is overlain by 5-7 feet of thick bedded Saint Lawrence dolomite. A short distance away in the NE¼ of Sec. 28, T. 114 N., R. 24 W. (22, fig. 1) is the type section of the Saint Lawrence where

9 Berkey, C. P. Geology of the St. Croix Dalles. Am. Geologist 20: 373. 1897.

10 *Op. cit.*: 47, pl. VI.

11 Stauffer, C. R. The Jordan sandstone. Jour. Geol. 33: 700. 1925.

12 Ulrich, E. O. Notes on new names in table of formations and on physical evidences of breaks between Paleozoic systems in Wisconsin. Wisconsin Acad. Sci., Arts and Letters 21: 77, 78. 1924.

Winchell [13] described 14½ feet of Saint Lawrence dolomite. This original Saint Lawrence section probably included the thin-bedded, glauconitic, shaly beds that underlie the dolomite in Sec. 21. Ulrich [14] considered these beds beneath the dolomite to represent the unnamed basal shale member of the Trempealeau formation. Such may be the case but they strongly resemble the uppermost beds of the Franconia elsewhere and have the same relations to the Saint Lawrence dolomite. In the opinion of the writer they belong in the Franconia and not in the Trempealeau. The Franconia-Trempealeau contact is between the Franconia and the Saint Lawrence dolomite and is placed at the base of the conglomeratic zone.

The Franconia is again exposed one-half mile north of Judson in Sec. 33, T. 109 N., R. 28 W., Nicollet County (6, fig. 1), where the Franconia-Saint Lawrence contact is exposed in the valley of the creek which enters the Minnesota River in the center of the section. The contact beds are similar lithologically to those described at Saint Lawrence.

TREMPEALEAU FORMATION

The Trempealeau formation consists of three members: the Saint Lawrence dolomite, the Lodi shale and the Jordan sandstone (Table I).

Saint Lawrence member. — The type section of the Saint Lawrence is at an abandoned town of that name 4 miles southwest of Jordan in Scott County. The quarry at Old Saint Lawrence (22, fig. 1), the type section, was described by Winchell.[15] A thickness of 14½ feet of beds was exposed at that time. The quarry is now partly filled with debris and the section exposed includes about 10 feet of thick-bedded, dark gray, glauconitic dolomite (Saint Lawrence) overlain by about 1 foot of thin-bedded, buff-colored dolomite (Lodi).

The only other exposures of the Saint Lawrence beds in the Minnesota River valley are in Nicollet County across Minnesota River from Judson, Blue Earth County, in Secs. 33, T. 109 N., R. 28 W., Sec. 28, T. 109 N., R. 28 W. (6, fig. 1). Most of these were described by Upham.[16]

13 Winchell, N. H. Geology of the Minnesota Valley. Minn. Geol. & Nat'l. Hist. Survey, 2nd Ann. Rept.: 153. 1873.

14 *Op. cit.*: 88.

15 *Op. cit.*: 153.

16 Upham, Warren. Geology of Sibley and Nicollet Counties. Minn. Geol. and Nat'l. Hist. Survey, Final Report 2: 160-161. 1885; Geology of Blue Earth County. Minn. Geol. and Nat'l. Hist. Survey, Final Report. 1: 425-426. 1882.

Lodi member. — Between Saint Lawrence and Jordan, the Lodi member is concealed but in the bed of Sand Creek below the breweries in the town of Jordan the contact of the Lodi with the Jordan is exposed (24, fig. 1). This contact was mentioned by Winchell [17] in his report on the type section of the Jordan. Here the Lodi is sandy near the base of the Jordan member. The exact line of contact is difficult to determine because of the gradual lithologic change in the upper Lodi beds. The contact is placed where the composition of the rock seems about equally divided between sand and calcareous material.

The complete thickness of the Saint Lawrence and Lodi members in the type locality of the Saint Lawrence may be found from the difference in elevation of the Franconia-Saint Lawrence contact at Saint Lawrence and the Lodi-Jordan contact at Jordan, after correction for dip, if any. The difference in elevation is 26 feet. According to the best available data the beds in this locality strike in a direction N. 93° E. The line connecting the Franconia-Saint Lawrence contact at Saint Lawrence and the Lodi-Jordan contact at Jordan is almost an east-west line; therefore, the amount of dip between these points may be ignored. Therefore, the Saint Lawrence member appears to be about 10 feet thick and the Lodi member about 16 feet thick. However, 39 feet of Lodi and Saint Lawrence were penetrated in a well at Merriam Junction a few miles to the northeast (p. 459).

The only other exposures of these members are found near Judson, Blue Earth County, where a few feet of the Lodi are exposed above the Saint Lawrence dolomite.

Because it is difficult in well logs to determine the Saint Lawrence-Lodi and the Lodi-Jordan contacts it is not possible to give exact subsurface thicknesses to the Saint Lawrence and Lodi members in the Minnesota River valley. Wells which have penetrated the Trempealeau show thicknesses for the Lodi plus the Saint Lawrence of 40 feet at South Minneapolis, 39 feet at Merriam Junction, 60 feet at Ottawa and 40 feet at Mankato. On the 1932 map of the Minnesota Geological Survey a thickness of about 130 feet is assigned to the Saint Lawrence. The difference between this figure and the figures given above is probably to be accounted for by the fact that the Minnesota geologists include some of the Franconia (of this paper) in the Saint Lawrence.

17 *Op. cit.*: 149.

Jordan member. — Alexander Winchell,[18] who named and described the type section at Jordan, Scott County, Minnesota, assigned a thickness of 51 feet to the formation in the type locality. Stauffer [19] repeated the original section in his later study. Hall and Sardeson [20] estimated that the formation is 35-40 feet thick at the type locality. The thickness of 51 feet for the type section was believed too great by N. H. Winchell [21] who thought that some of the beds in the type section were repeated. This the writer has found to be the case.

It was understood by Winchell when he defined the Jordan that only the lower beds are exposed at the type locality. The upper Jordan beds are exposed a few miles north of Jordan along Van Oser Creek. Plane-table work has shown that the uppermost bed of Jordan exposed at Jordan is at Foss's Mill, just east of the highway bridge, which is at an elevation 41.2 feet higher than the Lodi-Jordan contact in the bed of Sand Creek below the breweries.

The upper beds of the Jordan along Van Oser Creek four miles northeast (26, fig. 1) are about 25 feet thick, consist of sandstone, and are exposed below the Prairie du Chien dolomite. Between the beds at Jordan and the exposures on Van Oser Creek a considerable thickness of Jordan is concealed. After correction has been made for dip between these points it has been found that this concealed interval includes about 40 feet of Jordan.

Therefore, to study the complete type section of the Jordan two localities must be visited, i. e., the section at Jordan where the lower 41.2 feet of the member are exposed and the beds exposed along Van Oser Creek, about 25 feet thick. Between these two sections about 40 feet of beds are concealed. The thickness of the Jordan in the type locality is thus about 106 feet. The contact with the Prairie du Chien in this area is well exposed west of Merriam Junction (28 and 29, fig. 1). Here the upper 3 feet of the Jordan is dark brown to red, medium to coarse grained, thin-bedded, poorly cemented and is overlain by thick-bedded, dark gray to brown sandy dolomite of the Prairie du Chien.

Lithologically the Jordan is quite uniform. It is almost a pure quartz sandstone, mostly light colored but in places darker colored

18 Winchell, Alexander. Report of a geological survey in the vicinity of Belle Plaine. Senate Document, St. Paul, 1872.

19 *Op. cit.*: 705.

20 Hall, C. W. and F. W. Sardeson. Magnesian Series of the northwestern States. Bull. Geol. Soc. Am. 6: 176. 1895.

21 *Op. cit.*: 149.

because of iron. It is poorly cemented in the lower part and more tightly cemented in the upper part. The upper part is also somewhat coarser than the lower beds.

Wells which have penetrated the Jordan member show thicknesses of 90 feet at South Minneapolis and 107 feet at Merriam Junction. The average thickness of the member in the Minnesota River valley is probably about 100 feet.

In the area around Saint Peter and Kasota (13 and 18, fig. 1), sands that have previously been considered as upper Jordan contain gastropods which resemble those found in the Oneota. These fossiliferous beds have been mentioned by Stauffer [22] who believes them to represent reworking of the upper Jordan in Oneota time. Stauffer, and later Graham,[23] place the fossiliferous sands in the Oneota. Some silt which is white or bluish-white in color separates these sands and the Oneota dolomite at Ottawa, Saint Peter, Kasota and Mankato (14, 17 and 19, fig. 1). From about an inch in thickness on the Schwartz farm in the NE¼ of Sec. 27, T. 111 N., R. 26 W., at Ottawa (21, fig. 1), Le Sueur County, it thickens to the southwest and at Mankato (10 and 11, fig. 1) it is several feet thick. This silt may continue northward and explain the spring horizon a little above river level at Shakopee. At Saint Peter and Mankato this silt has been squeezed up into crevices of the Oneota due to solution and slumping of the dolomite.[24] Although formerly believed to be of Cretaceous age this clay is a part of the early Paleozoic section.

The contact of the Jordan with the Oneota on Minnesota River is one of slight unconformability. Graham,[25] Trowbridge and Atwater,[26] and Stauffer and Thiel [27] have discussed this unconformity.

ORDOVICIAN SYSTEM

PRAIRIE DU CHIEN FORMATION

The Prairie du Chien formation in the Minnesota River valley consists of three members, the Oneota dolomite, the New Richmond sandstone and the Shakopee dolomite (Table I). All this was included in the Shakopee formation of the early Minnesota reports.

22 *Op. cit.*: 706-707.

23 Graham, W. A. P. Petrology of the Cambrian-Ordovician contact in Minnesota. Jour. Geol. 41: 470-471. 1933.

24 Graham, W. A. P. *Op. cit.*: 471-472.

25 *Op. cit.*: 485-486.

26 *Op. cit.*: 76-77.

27 *Op. cit.*

Nearly all exposures of the formation have been described in the several county reports and only such new data as the writer has procured are presented. The distribution of the exposures of the formation is shown on Fig. 1.

Only three sections of the Prairie du Chien were studied in detail, i. e., at Mankato, at Merriam Junction and at Shakopee. The results of a textural and mineralogical study of the samples of these sections are presented in a separate paper.[28]

Mankato section. — Extensive quarrying is being carried on in the rocks of this formation at Kasota and Mankato and in the area between these towns (15 and 16, fig. 1). At these places the rock is thin to thick-bedded, brown dolomite.

The New Richmond is exposed along the road about midway between Mankato and Kasota and again in a quarry in the north-central part of Sec. 7, T. 108 N., R. 26 W., (12, fig. 1) in the northern part of Mankato. At this place about 60 feet of Oneota dolomite was measured above the Jordan contact. In the quarry the following section is exposed:

	Feet
3. Thin-bedded, dark gray to brown Shakopee (Willow River) dolomite. .	2-3
2. White, friable, thin and cross-bedded, sandstone with occasional shaly partings, New Richmond	2-3
1. Thin to thick-bedded, dark gray to brown, Oneota dolomite. At the top is thin-bedded and contains *Cryptozoa*	30-40

Across from Sibley Park and at other places in and near Mankato (9, 10 and 11, fig. 1) the contact of the Jordan and Oneota is exposed.

Merriam Junction section. — At and near Merriam Junction 5 miles northeast of Jordan and 5 miles southwest of Shakopee there is a famous section of dolomite that has been interpreted differently by different workers. The lower 20-30 feet of the formation, consisting of thick-bedded, dark gray to reddish brown, sandy dolomite and a few shaly seams, is exposed in abandoned quarries on the east side of the river and forms the valley wall in the west-central part of Sec. 21, T. 115 N., R. 23 W. (30, fig. 1). Between these quarries and the upper Saint Louis quarries on the east side of the R. R. tracks in the north-central part of Sec. 28, T. 115 N., R. 23 W. (27, fig. 1), a few old shafts expose thin-bedded, light brown or buff colored dolomite which is wavy in places, and in

28 Tester, A. C. and C. W. Couser. The Petrography of the Prairie du Chien of the Minnesota River valley. Manuscript in preparation.

places is interbedded with more massive layers. In some places the beds are cherty and shaly. These upper beds are oolitic at the top and farther east beyond the quarry contain large Cryptozoon masses. These peculiar fossils have been described by Winchell.[29] The top of the upper quarries is almost exactly 100 feet above the Jordan-Oneota contact in the base of the lower quarries. Winchell [30] believed the lower beds at Merriam Junction to be Oneota and the upper beds Shakopee which had been eroded back along the less resistant New Richmond. Stauffer and Thiel [31] have recently concluded that the strata are all of Oneota age with the exception of the upper few feet which are of Shakopee age.

The writer believes that all the dolomite beds exposed at Merriam Junction are equivalent in age to parts of the Oneota elsewhere. His reasons are: (1) the Oneota has a thickness of about 90 feet at Twin Cities [32] and probably attains an equal thickness at Merriam Junction although it does thin somewhat up the river, (2) no New Richmond is exposed and its presence between the lower and upper quarries as believed by Winchell is doubted, and (3) the structure is well known in this area and the New Richmond and Shakopee could hardly occur here, unless they replace the Oneota.

Shakopee section. — Almost all the published information on the rocks at Shakopee comes from a study of a single exposure, that in the quarry near the western boundary of the town. The writer found the rocks at Shakopee to be exposed at several places: (1) east along the south bank of the Minnesota River from Faribault Springs at the eastern boundary of the town, in the NE¼ of Sec. 6, T. 115 N., R. 22 W., and in the north-central part of Sec. 5 (34, fig. 1); (2) at the Schroeder quarry in the eastern part of Shakopee in the NW¼ of Sec. 6, T. 115 N., R. 22 W., (33, fig. 1); (3) along the R. R. tracks west of the city water works and east of the highway bridge; (4) along highway 5 in the west part of Shakopee (32, fig. 1), an exposure occurs also on Eagle Creek in the NE¼ of Sec. 3, T. 115 N., 23 W.; (6) in several excavations and cellars on the hill in the southern part of the town, and, (7) near the old brewery

29 Winchell, N. H. *Cryptozoon minnesotense*. Minn. Geol. and Nat'l. Hist. Survey, 14th Ann. Rept.: 313-315. 1886.

30 *Op. cit.*: 329; also, preface to vol. 2 of the Final Report, p. xvii. 1886.

31 Stauffer, C. R. and G. A. Thiel. The limestones and marls of Minnesota. Minn. Geol. Survey, Bulletin 23: 31. 1933.

32 Winchell, N. H. Geology of Ramsey County. Minn. Geol. and Nat'l. Hist. Survey, Final Report 2: 364. 1885. Sardeson, F. W. U. S. Geol. Survey Folio 201, Minneapolis-St. Paul: 5. 1916.

along the railroad tracks 1½ miles west of Shakopee (31, fig. 1). A small exposure occurs also on Eagle Creek in the NE¼ of Sec. 3, T. 115 N., R. 22 W., 4 miles east of Shakopee (35, fig. 1).

The maximum thickness of rock exposed at one place at Shakopee is in the Schroeder quarry. Here about 25 feet of rock are exposed. The rock consists of yellowish-brown, irregularly-bedded dolomite. The bedding is so wavy that some beds cannot be traced twenty feet horizontally. Sandy or shaly zones are common. A few beds of almost pure limestone are interbedded with the sandy dolomites. In places in the exposure east of Faribault Springs the beds are fossiliferous and oolitic and contain beds or more properly lenses of sandstone.

The best known exposure at Shakopee is in the west quarry. Sardeson [33] states: "fossils were found by me on the quarry dump, and also in the quarry wall under the main sandstone stratum." There are 21 feet of beds now exposed in the west quarry.

A log of a recently drilled well, located about midway between the two quarries, as interpreted by the writer, is given below.

Log of Well at City Water Works in Shakopee. Elevation of Well Site —725 feet

Rock	Thickness (feet)	Depth (feet)
Prairie du Chien		
Limestone	58	58
Trempealeau		
Jordan and Lodi		
Sandstone	146	204
St. Lawrence and		
Franconia		
Sandy limestone	133	337
Dresbach		
Galesville		
White sandstone	95	432
Eau Claire		
Sandstone and sandy limestone	173	605
Mt. Simon		

ERRATA

The figure 667 should be 655. See errata on page 445 for explanation.

plane table data that the strata in the area of Merriam Junction, Shakopee and Savage dip slightly northeast which would increase this figure to about 41 feet. This fact of the proximity of the beds at Shakopee to the top of the Jordan as shown in the city well led Trowbridge and Atwater [34] to express the view that the type section of the Shakopee might be of Oneota age.

This conclusion is favored by the writer. It seems clear that there are no beds equivalent to the New Richmond and Oneota beneath the dolomite exposed at Shakopee and above the Jordan sandstone that outcrops at Merriam Junction and is recorded in wells and test borings at Shakopee. According to the city well and other drillings which check it, not more than 38-41 feet of dolomitic beds are concealed above the Jordan sandstone (p. 467). By allowing for known dip it is computed that in the exposures east of Faribault Springs not more than 35 feet of dolomite can be concealed between the lowest exposed dolomite and the top of the Jordan sandstone. If there were anything like a normal thickness of New Richmond and Oneota beneath the beds exposed at Shakopee, there would have to be a syncline or other depression in the top of the Jordan, but surface and subsurface determinations prove that no such depression exists (fig. 2). It would be extraordinary if there were 90 feet of Oneota above the Jordan and beneath the Shakopee at Minneapolis 20 miles northeast of Shakopee and 90 feet of Oneota in the same position at Merriam Junction 5 miles southwest of Shakopee (p. 465) and no Oneota or at least less than 41 feet of Oneota in this position at Shakopee. As pointed out by Trowbridge and Atwater [35] this would mean that Winchell, who first used the term Shakopee for all of the dolomite and sandstone that directly overlie the Jordan and underlie the Saint Peter, was fortunate enough to have selected a place in which the dolomite correlates with a dolomite that overlies the New Richmond except in this one place.

Sardeson,[36] on the basis of the fossils he found, said the rock at Shakopee is of Shakopee age. Powell [37] when shown fossils collected from the exposure east of Faribault Springs, also believed the rock to be of Shakopee age.

34 *Op. cit.*: 71.
35 *Op. cit.*: 71.
36 *Op. cit.*: 114.
37 Powell, L. H. Personal communication to A. C. Trowbridge.

CHAZYAN SERIES

SAINT PETER FORMATION

The Saint Peter formation lies unconformably on the eroded surface of the Prairie du Chien. The name of the formation was given from the exposures at Fort Snelling (37, 28 and 39, fig. 1) at the mouth of the Minnesota River (earlier called the Saint Peter River), first described by Carver.[38] The formation was named and described by Shumard [39] in Owen's report of 1852.

The only other possible exposures of Saint Peter in the Minnesota River valley are [40] at the top of the Asylum quarry at Saint Peter, Minnesota, and in Rapidan township, Blue Earth County, along Maple River.[41] The rock at Saint Peter is now covered and Hall and Sardeson [42] later concluded that the rock on Maple River is Jordan.

The type section has been studied by Sardeson.[43]

The writer found the Saint Peter-Platteville contact underneath the north end of the Mendota Bridge to be at an elevation of 778 feet. Excavations for one of the piers of the Mendota Bridge struck the Prairie du Chien-Saint Peter contact at an elevation of 613 feet making a thickness of 165 feet for the Saint Peter in the type locality. Due to the erosional unconformity at its base, the thickness of the Saint Peter varies greatly within short distances.

MOHAWKIAN SERIES

PLATTEVILLE FORMATION

The Platteville formation lies conformably on the Saint Peter in the area near Fort Snelling. The contact is marked by the presence of several feet of bluish or greenish shale, the Glenwood, which is the basal member of the Platteville. The exposures in the vicinity of Minneapolis and St. Paul have been described by Sardeson.[44]

38 Carver, J. Travels through the interior part of North America in the years 1766, '67 and '68, p. 59. Dublin, 1779.
39 Shumard, B. F. Report of a geological survey of Wisconsin, Iowa and Minnesota by D. D. Owen, p. 481. 1852.
40 Winchell, N. H. The Geology of Carver and Scott Counties. Minn. Geol. and Nat'l. Hist. Survey, 2nd Ann. Report, p. 132. 1873.
41 *Idem.*: 133.
42 Hall, C. W. and F. W. Sardeson. Magnesian Series of the northwestern States. Bull. Geol. Soc. Am. 6: 176. 1895.
43 Sardeson, F. W. St. Peter sandstone. Minn. Acad. Sci. 4: 64-88, 1895; U. S. Geol. Survey, Folio 201, Minneapolis-St. Paul. 5-6. 1916.
44 *Op. cit.*: 6.

STRUCTURE

In the Minnesota River valley the strata dip toward a syncline which has been described by others.[45]

It is obvious that the rocks dip in a generally easterly direction from New Ulm where the pre-Cambrian rocks outcrop, to Minneapolis where pre-Cambrian rocks of equivalent age occur several thousand feet beneath the surface, and where the youngest rock at the surface is basal Galena dolomite. The regional dip cannot be determined accurately either in direction or amount. Several estimates made from the determination of the elevations of three points at the same stratigraphic horizon indicate that on the average the regional dip is about N. 71° E., in direction and about 16 feet per mile in amount.

The general easterly dip of the beds is complicated however by small and presumably local folds. Winchell [46] recognized an anticlinal axis in the vicinity of Belle Plaine and Hall [47] mentioned an arch in the pre-Paleozoic rocks in Rice, Goodhue and Dakota counties.

By determining the elevations of as many contacts as possible from exposures and wells the writer has prepared a section along Minnesota River from New Ulm to Fort Snelling (Fig. 2). As this section follows the river around the big bend at Mankato and all of its minor bends, the line of the section does not follow the line of true dip. It does not give a true picture of the structure, therefore, but does show the relations of the rock formations to the river.

No contacts were obtainable from either exposures of wells between Saint Lawrence and Ottawa and the structure in this part of the section is based on interpolation. Also, accurate data are not available between Judson and New Ulm, chiefly because the strata are obscured by Cretaceous sediments, and no claim is made to accuracy in this part of the section. The Red Clastics and Dresbach formation may be overlapped by younger beds or their outcrops may simply be covered by Cretaceous sediments.

45 Hall, C. W., O. E. Meinzer and M. L. Fuller. Geology and underground waters of southern Minnesota. U. S. Geol. Survey, Water-Supply Paper 256: 32-33. 1911.

Trowbridge, A. C. and G. I. Atwater. Stratigraphy and structure of the upper Mississippi Valley. Abstract. Bull. Geol. Soc. Am. 42: 219-220. 1931.

Trowbridge, A. C. Upper Mississippi Valley structure. Bull. Geol. Soc. Am. 45: 519-522. 1934.

46 Winchell, N. H. Geology of the Minnesota Valley. Minn. Geol. and Nat'l. Hist. Survey, 2nd Ann. Rept.: p. 86. 1873.

47 Hall, C. W. Underground waters of eastern United States. U. S. Geol. Survey, Water-Supply Paper 114: 229. 1905.

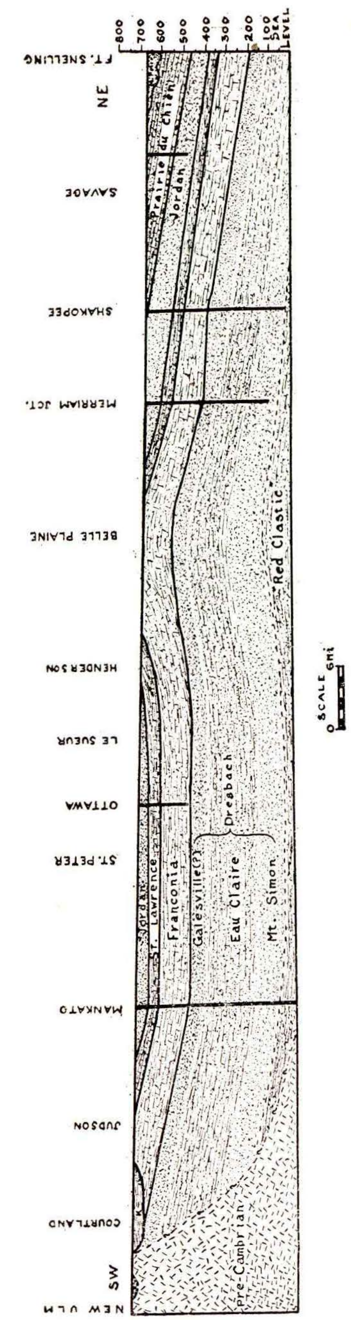

Fig. 2. Structure section along Minnesota River from New Ulm to Fort Snelling.

The synclinal axis that appears in the section crossing the river in the neighborhood of Saint Peter, due to the fact that the section is not straight, is apparent but not real. The facts are that the river flows down the dip and then in making the sharp turn at Mankato turns and flows nearly parallel with the strike of the strata. An anticlinal axis crosses the valley in the neighborhood of Belle Plaine. Because adequate control away from the river on either side is not obtainable, it is not possible to determine the strike or pitch of this fold.

CONCLUSIONS

The Red Clastics are present in the Minnesota River valley but this investigation does not contribute to the solution of the problem of age. The Dresbach formation in the Minnesota River valley is divisible with some uncertainty into three members, the Mount Simon, Eau Claire, and Galesville. The pre-Franconia strata near Judson are probably overlapped by Franconia and are covered by the Cretaceous. In the type locality of the Saint Lawrence this member appears to be about 10 feet thick and the Lodi member about 16 feet thick. In the type locality the Jordan is 106 feet thick but only the lower 41 feet are exposed at Jordan. The Jordan is separated from the Oneota on Minnesota River by a slight unconformity. The type section of the Shakopee is probably of Oneota age. The general eastward dip of the strata between New Ulm and Twin Cities is modified by an anticline at Belle Plaine.

Paleozoic Stratigraphy and Structure on Saint Croix River

By

George M. Clement

Contents

INTRODUCTION

Problems of stratigraphic classification, correlation, and nomenclature in the Upper Mississippi valley are apparent. Several classifications have been proposed and used, which differ one from another in important particulars. Recently another has been suggested tentatively by Trowbridge and Atwater [1] in the hope of clarifying some of these problems. This classification, after having been revised somewhat as indicated by Couser (p. 454 of this bulletin), harmonizes with the conclusions reached by the present writer and is adopted for use in this study.

The lower Saint Croix valley is the type locality of the Saint Croixan series and of the Franconia formation and contains several well known sections which have been differently interpreted by different stratigraphers. There are also structures in this area which have been known to exist but have not been studied in detail until now.

The purpose of this investigation was to make a new and detailed study of the rock formations and their structure in this classic area and, if possible, to solve the several problems involved, or at least to contribute to their solution.

The study involved detailed field work in which the plane-table and stadia alidade were used and the several formations were sampled, analytical work on these samples in the sedimentation laboratory, and library work in which the mass of literature bearing on this area was reviewed or abstracted.

The writer is indebted to Dr. A. C. Trowbridge for directing the field work and for making many suggestions in the preparation of the manuscript, and to Dr. A. C. Tester for assistance in the laboratory. Thanks are due also to Mr. Donald Laird and to Mr. John Mulroney who assisted the writer in the field, and to Mr. E. H. Powers, who described the valley of Willow River, adjacent.

STRATIGRAPHY

GENERAL STATEMENT

The general columnar section is shown on p. 454. Rocks that are exposed at the surface or are recorded in wells and are known to

[1] Trowbridge, A. C. and G. I. Atwater. Stratigraphic problems in the Upper Mississippi valley. Bull. Geol. Soc. Am. 45: 21-80. 1934.

be of Upper Cambrian age lie unconformably on Keweenawan rocks which are probably mostly pre-Cambrian although the upper part may be Cambrian. Between the two is the Red Clastic Series which is probably equivalent to the upper part of the Keweenawan and which may be of Lower or Middle Cambrian age. Trowbridge and Atwater [2] have given a more nearly complete discussion of the relative ages of the Red Clastic and Keweenawan Series than is possible to give in this paper. More recently a separate paper on this same subject has been prepared by Atwater and Clement.[3] All the formations shown on the chart, except the Red Clastics and the Mount Simon, appear at the surface.

In this paper the rock formations are described and classified as they occur in this particular area. No attempt is made to solve the problems that may arise elsewhere.

The outcrops of the rocks of different ages are shown in figure 1.

MIDDLE CAMBRIAN (?)

Red Clastics

As indicated on the map (fig. 1), the Keweenawan rocks are exposed discontinuously from Conglomerate Point near Franconia, Minnesota, to Saint Croix Falls, Wisconsin, and beyond. South of Conglomerate Point the surface of the Keweenawan slopes off into a deep trough, the axis of which extends from the southwest tip of Lake Superior to southern Minnesota under Minneapolis and Saint Paul, and which contains the Red Clastic Series. The Red Clastic rocks, which are not known to outcrop, were penetrated in the Saint Croix valley by three wells.

ERRATA

After this bulletin was printed a paper appeared[1] in which previous interpretations of the log of the old deep well at Stillwater were corrected, following further planetable work in the field and restudy of the original samples. For corrections of the section printed herein, see the article referred to.

1 Stauffer, C. R., Burch, E. P. and Schwartz, G. M., A Reinterpretation of the Stillwater Deep-well Records. Jour. Geol. 43:630-638, 1935.

Log of Well of C. St. P. M. and O. Ry. at Shop Yard, Hudson, Wisconsin [5]

	Thickness	Depth
Elevation		670
Pleistocene		
Glacial drift	104	104
Dresbach		
Galesville sandstone	16	120
Eau Claire sandstone with shale	90	210
Mt. Simon sandstone	240	450 T.D.

Log of Well at Water Works South Hudson, Wisconsin [6]

	Thickness	Depth
Elevation		705
Pleistocene		
Glacial drift	50	50
Dresbach		
Galesville or Eau Claire		
Gray sandstone	50	100
Eau Claire		
Limestone	45	145
Mt. Simon		
Sandstone	247	392
Red Clastic Series		
Red shale and streaks hard rock	125	517
Red rock	40	557
Red shale and rock	365	922
Rock and shale	130	1052 T.D.

The Red Clastics as shown in the logs are 2262 feet thick in the Stillwater well, and at least 660 feet in the south Hudson well. The Railroad well at Hudson records the depth to the Red Clastic series, as the drilling stopped when that rock was reached.

Except for these wells, the Saint Croix area produces no evidence that can be used in determining the age or relationship of the Keweenawan trap and the Red Clastic Series. The Red Clastics, however, are younger than the main mass of Keweenawan trap.

CAMBRIAN SYSTEM

Saint Croixan Series

DRESBACH FORMATION

According to the classification used in this paper (p. 454), the Dresbach is the oldest formation of the Saint Croixan Series and

[5] Adapted from Weidman, Samuel and A. R. Schultz. The underground and surface water supplies of Wisconsin. Wis. Geol. Nat. Hist. Surv. Bull. 35: 550. 1915.

[6] Log supplied by McCarty Well Company to A. C. Trowbridge.

is divided into Mount Simon, Eau Claire and Galesville members. This formation is exposed in windows in glacial drift.

Mount Simon member. — The Mount Simon member does not outcrop in the immediate valley of the Saint Croix but is exposed on the Willow River about two miles from Hudson, Wisconsin, and is recorded in the deep wells at Hudson and at Stillwater. From these well records it appears to be about 245 feet thick. The outcrops on Willow River are not more than 40 feet below the base of the Eau Claire member. The rock is composed of friable, cross-bedded, well-sorted, medium-to-coarse grained, unfossiliferous sandstone and granular gravel, and some shale. The laboratory analyses are shown in Table I.

Eau Claire member. — The Eau Claire member is exposed (14, fig. 1) in the Willow River valley near Hudson, where the total thickness of the member is from 90 to 146 feet. Peterson [7] described the section near Little Falls Dam, four miles east of Hudson. This exposure shows the typical thin-bedded, friable, fine-grained, fossiliferous sandstone and interbedded shale.

Adjacent to the river channel one mile south of Taylors Falls five feet of white shale appear above the Keweenawan trap. (Section 1.)

Section 1 (2, fig. 1)

One Mile South of Taylors Falls, Minnesota

Lithology	Thickness in feet	Elevation
Pleistocene		
Glacial gravel	50	800-850
Franconia		
Upper member (unnamed)		
Sandstone, white, medium-to-thin-bedded, some glauconite; predominantly quartz and authigenic feldspars; trilobites abundant in lower beds, becoming less abundant near the top	19	781-800
Sandstone, thick, dark brown; white in fresh exposures; speckled with green and brown glauconite; few fossils.	45	736-781
Intermediate member (unnamed)		
Green, friable, glauconitic sandstone with interbedded shales and limestones near the top; top marked by numerous springs.	16	720-736
Concealed	19	701-720

[7] Peterson, Eunice. The Dreshbach formation of Minnesota. Buffalo Soc. Nat. Sci. 14: 33-34. 1929.

Dresbach formation		
Eau Claire member		
Shale, dark pyritiferous, with numerous fossils.	10	691-701
Shale, white-to-gray, fossiliferous. (This shale is nearly 50 feet thick in the St. Croix Falls tourist park	5	686-691
Level of St. Croix River		686

The Eau Claire member is very fossiliferous; the most numerous forms collected are *Linguella phaon, L.* (*Lingulepis*) *acuminata, Lingula pinnaformis, Anomocarella* sp., *Obolus polita, Hyolithes primordialis* and *Ptychoparia chippewaensis.* On the basis of these fossils this bed is correlated with the upper part of Peterson's Willow River section and with the rocks which outcrop in the Tostevin Quarry at Dresbach, Minnesota. Laboratory analyses of samples are shown in Table I.

In the field, the Eau Claire member can be differentiated from any other shaly member by the abundance and kind of its fossils. In the laboratory the member at Taylors' Falls is identified by (1) the difficulty in disaggregating the grains, (2) the gray silty nature of the particles, (3) the presence of 5 per cent or more of pyrite, (4) the absence of feldspars, and (5) the presence of fossil shell fragments.

Galesville member. — The Galesville (?) member is even less widely distributed along the Saint Croix than the Eau Claire although exposures occur in the city of Hudson and along the south side of Lake Mallalieu (16, fig. 1) as well as in Secs. 7, 8, and 12, T. 29 N., R. 19 W. (14, fig. 1). Although the Hudson section was described in detail by Wooster,[8] it is redescribed below, because some of the beds, especially in the upper part of the section, are better exposed now than they were in 1882.

Section 2

South Hudson, Wisconsin (17 fig. 1)

Lithology	Thickness in feet	Elevation
St. Lawrence		
Wide bench, probably made by the St. Lawrence member, although no rock was identified positively as St. Lawrence.	10.1	922.9-933.0
Franconia		
Upper greensand member		
Medium-to-fine quartz sand, with much glauconite,		

8 Wooster, L. C. The geology of the Lower Saint Croix District. Geol. Wis. 4: 113, 114. 1882.

incoherent and shaly in places; concealed, except in a few places.	100.0	822.9-922.9
Intermediate member		
Limy beds, 2 to 6 inches thick, interbedded with greensand; few trilobites.	17.8	805.1-822.9
Greensands, fine-to-medium sandstone, with some green shale; glauconite very prominent.	35	770.1-805.1
Ironton member		
Buff calcareous sandstone; medium-grained quartz sand with some glauconite; numerous fragments of *Obelella polita*.	15	755.1-770.1
Dresbach formation		
Galesville member		
Brown medium-grained, friable quartz sandstone.	25.5	629.6-755.1
Concealed.	41.6	668.9-729.6
Level of St. Croix River.		668.0

On Willow River the member is 37 feet thick. Northward from Hudson, glacial drift and structural conditions conceal this member so that it is not exposed again except at Franconia, where only 5 feet of coarse sandstone separates the underlying trap from the Franconia formation.

Section 3

Franconia, Minnesota (3, fig. 1)

Lithology	Thickness in feet	Elevation
Pleistocene		
Glacial drift	77	823.0-900.0
Franconia		
Upper member		
Thick, white, fine sandstone; numerous trilobite remains; *Ptychoparia diademata* Hall and *Prosaukia misa* Hall are most abundant.	10.0	813.0-823.0
Sandstone, cross-bedded layers, very fine and thin; tobacco brown in color; numerous trilobites.	2.0	811.0-813.0
Sandstone, thick, white; very fine sand grains; a few calcareous brachiopod shells; a few trilobites; forms a cliff.	27.0	799.0-806.0
Middle member		
Sandstone, glauconitic; very fine grained; calcareous shaly beds near the top; forms a slope.	26.0	753.0-779.0
Ironton member		
Sandstone, white, coarse-to-medium, cross-bedded, with about 5 per cent to 10 per cent glauconite and numerous broken calcareous shells of *Obelella polita*.	20.0	733.0-753.0

Concealed.	6.0	727.0-733.0
Dresbach		
Galesville member		
Sandstone, quartzose; very hard, coarse-to-medium grained; cemented with iron oxide; samples show about 4 per cent leucoxene; unfossiliferous.	5.0	722.0-727.0
Concealed.	5.0	717.0-722.0
Keweenawan		
Diabase, dark in color	32.4	684.6-717.0
Level of St. Croix River		684.6

In the samples of the Galesville at Franconia, leucoxene makes up 70 to 80 per cent of the 1/8 to 1/32 millimeter grades, but only 4 per cent of the total sample. (Table I). A few grains of unaltered ilmenite and a few grains of ilmenite showing alteration to leucoxene clearly indicate that the leucoxene was derived from the ilmenite *in situ*. As this mineral is very scarce in other horizons this zone may well be called the leucoxene zone.

Samples of the Galesville at Hudson differ widely from those at Franconia; at Hudson the Galesville more closely resembles the Franconia than the equivalent member at Franconia. Euhedral authigenic feldspars, in the finer grades, link this member at Hudson to the Franconia. Indeed the beds exposed at Hudson listed as Galesville may well belong in the Ironton.

In the field, the Galesville at Franconia can be determined from other sandstones by (1) stratigraphic position, (2) the silification and casehardening of the surface, and (3) the absence of glauconite and fossils. In the laboratory, the sizes and shapes of the grains alone do not differentiate this member from other sandstones, but it is recognized by (1) quartz grains having a secondary growth which are absent in the higher formations, (2) the presence of leucoxene in the Galesville and its absence elsewhere, and (3) the relative absence of authigenic feldspars which are found in the Franconia formation.

The Galesville at Hudson is tentatively differentiated from the overlying Franconia by (1) the absence of fossils, (2) the scarcity of glauconite, and (3) the contrast between the friable white sands of the Galesville and the brown oxide cement of the higher formation.

Undifferentiated Dresbach. — At Conglomerate Point, south of Franconia (5, fig. 1), 50 feet of conglomerate composed of angular boulders of diabase and basalt as large as 2 feet in diameter, cemented with fine silty material, is exposed above the Keweenawan trap. Resting unconformably on this conglomerate is 5 feet of typical Ironton sandstone, which indicates that this angular material is probably Dresbach in age, but it may represent any or all of the members.

FRANCONIA FORMATION

Lying unconformably on the Dresbach, or on older rocks where the Dresbach is missing, is the Franconia formation (p. 454). This formation was named by Berkey [9] for the rocks which outcrop in the Saint Croix river valley near the village of Franconia, Minnesota. Berkey's original section is quoted as follows:

Basal Sandstone Series. (Modified from Norton.)	3. Franconia sandstone (100 feet).			The St. Croix Formation (Winchell.)
	2. Dresbach shales (150 feet)	Obolella polita zone	Greensands and shales	
		Lingulepis pinnaformis zone	Calcareous and pyritiferous shales	
	1. The lowest formation of this series is not exposed in the dalles area, but it includes the lowest sandstone beds and possibly also the "Hinckley sandstone," (0 to 1,000 feet).			

Practically all geologists working in the Upper Mississippi valley now include in the Franconia the coarse arenaceous shaly greensands and coarse sands (*Obelella polita* zone). The formation in the type locality now includes three distinct members, as follows:

	Feet
3. Upper heavy beds of white-to-cream sandstone containing numerous impressions of trilobites	92
2. Intermediate beds of greensand interbedded with shale and a few thin calcareous beds near the top	26
1. Ironton member. Coarse-grained, cross-bedded, glauconitic sandstone. *Dicellomus politus* = *Obelella polita* zone	20
Total	138

Although the sands of No. 3 are not abundantly glauconitic in the type section at Franconia, their equivalents in practically all other sections in Wisconsin, Minnesota, and Iowa contain numerous beds and lenses of greensand.

Numerous sections of the Franconia, distributed along the Saint

[9] Berkey, C. P. Geology of the Saint Croix Dalles. Am. Geol. 20: 373. 1897.

Croix from Afton, Minnesota, to Saint Croix Falls, Wisconsin, differ from one another and from the type section, but there is a general similarity both in character and in sequence of beds. Three miles north of the type locality, in the new road cut south of Taylors Falls (2, fig. 1), the upper part of the Franconia is well exposed. The greensand member, the top of which is here marked by springs, contains more and heavier limy beds and more shale than does the same member in the type section. In the river channel, the Ironton member of the Franconia is concealed by talus, but the fossiliferous Dresbach shales are exposed at the proper level. At Hudson, Wisconsin, (Section 2) approximately 35 miles south of the type locality, the same three members may be identified, although only the Ironton noticeably resembles the corresponding member of the type section. The intermediate member is much thicker (53 feet) and is composed of 35 feet of typical greensand and 18 feet of limy beds with a trilobite fauna near the top. The upper bed is approximately as thick as in the type section (100 feet), but differs in composition and in color. Whereas the type is white-to-cream, here the member is so heavily charged with glauconite that it is called the upper greensand. Sections between Afton and Taylors Falls show all transitions between the above two, yet each has its distinguishing characteristics. The thickness of the formation varies along the Saint Croix from 138 to 160 feet and increases toward the south.

The general mineral content of the Franconia is varied. In some places it is characterized by the presence of much glauconite which is responsible for the bright-to-dark-green color of the formation. Many of the sands are micaceous, especially in the vicinity of the type section. Above the southernmost trap on the Wisconsin side of the Saint Croix near Franconia, there are seams of intraformational conglomerate composed of pebbles of trap, some as large as 6 inches in diameter, interbedded with micaceous sandstone, but at the same level across the river in the type section there are coarse grits only. Laboratory analyses of sixteen samples taken are shown in Table I.

More than 30 per cent of the grains of the upper zone are authigenic feldspars which consist of euhedra of adularia, albite, microcline and oligoclase, listed in the order of abundance. The sizes of the grains vary from 1/2 to 1/256 millimeter; the majority are in the grades below 1/8 millimeter. In the grades 1/8 to 1/16 millimeter and below, more than 50 per cent of the sample is composed of the authigenic feldspars. Only the grains in the larger sizes show signs of wear. Most of the euhedral grains have nucleii which in some cases extinguish at the same angle as the outer growth; in other grains the nucleii apparently are absent. The reasons for their absence in some grains may be (1) reabsorption by the new growth, (2) such orientation as to have the same extinction angle as the secondary growth, or (3) the absence of dust, which when present, outlines the nucleii. In occasional grains the twinning bands cross the secondary growth at the same angles as they do the nucleus. Muscovite is the mineral next most abundant, making up as high as 10 per cent of the sample, thus affording the sandstone a good cleavage.

In summary: The basal bed of the Franconia may be distinguished from the underlying Galesville at Franconia by (1) the frosted and pitted quartz grains in contrast with the grains showing secondary growth in the Galesville; (2) the high percentage of coarse grains of glauconite in the Franconia, and its absence below; (3) the absence of leucoxene in the Franconia; (4) the presence of numerous shell fragments in the basal bed, and their absence in the other sandstone. This last characteristic serves as an index to the member in many places. The intermediate bed may be differentiated from all other sandstone having a similar texture by its high glauconite and feldspar content. The upper member, like the intermediate bed, is remarkable for its fine sands and differs from all other similar sandstones by an extremely high percentage of authigenic feldspars. Just as high a percentage in the same sizes may be found in the residue of the Saint Lawrence and of the Prairie du Chien, but considering the whole sample the percentage is far below that of the Franconia.

TREMPEALEAU FORMATION

The third division of the Saint Croixian series, the Trempealeau formation, rests on the Franconia. In most places along the Saint Croix, this formation consists of three members: (1) a lower dolomite, the Saint Lawrence, (2) an intermediate yellow-to-green silty member, the Lodi, and (3) an upper sandstone member, the Jordan. The Trempealeau exposures are distributed irregularly along the Saint Croix from Afton, Minnesota, to a point two miles south of Franconia.

Saint Lawrence member. — In the greater part of the area, the Saint Lawrence member, 10 to 15 feet in thickness, lends itself readily to mapping because of its greenish color and the distinct bench that it forms. From Marine to the "Soo" Draw Bridge the river flows parallel with the strike and this bench stands approximately 100 feet above the river level.

Lodi member. — This member lies directly on the Saint Lawrence dolomite member and can be distinguished in most places from it by its yellow calcareous siltstones and thin-bedded limestones in contrast with the heavier bedded dolomite beds of the Saint Lawrence (Section 4). But at Afton (Section 5) and at Osceola (Section 6) the Saint Lawrence and Lodi members are so similar as to prevent recognition separately. Analyses of samples taken every five feet fail to show any sharp line of demarcation; the beds having the stratigraphic position of the Lodi have as great calcareous content as the lower beds, although the grains of quartz are much smaller.

Section 4

One Mile South Osceola, Wisconsin

Lithology	Thickness in feet	Elevation
Trempealeau		
Jordan member		
White to yellow medium-grained cross-bedded sandstone	40	746-786
Lodi member		
Green siltstone with thin beds of dolomite, makes cascades in stream	17	729-746
St. Lawrence member		
Gray dolomite, some interbedded green siltstone, makes falls in stream	15	714-729
Franconia		
Upper member		
Fine white to cream, micaceous sandstone	26	688-714

Section 5

Afton, Minnesota (18, fig. 1)

Lithology	Thickness in feet	Elevation
Oneota		
Thick-bedded dolomite, bedding masked by secondary dolomitization	26	924-950
Trempealeau		
Jordan member		
Thick-bedded, yellow-to-white, coarse-to-medium sandstone; makes a cliff	121	803-924

St. Lawrence and Lodi members		
Green dolomitic silt with interbedded thin dolomite beds; some green shale; members not differentiated; fucoids and fragments of trilobites	31	772-803
Franconia		
Medium-to-fine sandstone with some interbedded shales near the top; heavily charged with glauconite	55	717-772
Concealed	41	676-717
Level of St. Croix River		676

Section 6

Osceola, Wisconsin (6, fig. 1)

Lithology	Thickness in feet	Elevation
Pleistocene		
Glacial drift	10.0	902.0-912.0
Prairie du Chien		
Oneota member		
Sandy dolomite; thick-bedded; reddish-to-purplish	4.0	898.0-902.0
Sandstone; brown; upper 2 inches green	3.0	895.0-898.0
Dolomite; in beds 2 to 3 feet thick; partings distinct; buff colored	26.0	869.0-895.0
— Unconformity —		
Trempealeau		
Jordan sandstone		
Sandstone; irregularly-bedded; medium-grained; brown	10.0	859.0-869.0
Sandstone; cross-bedded; white, with a few iron oxide stains	8.0	851.0-859.0
Sandstone; hard; medium-grained; with ferruginous cement	30.0	821.0-851.0
Concealed	24.0	797.0-821.0
St. Lawrence and Lodi members		
Siltstone; interbedded with thin calcareous beds; green; many fucoids; forms cascades; members not differentiated	45.0	752.0-797.0
Franconia		
Upper member		
Sandstone, medium-to-fine; white-to-greenish; some beds glauconitic	39.6	712.4-752.0
Concealed	30.0	682.4-712.4
Level of St. Croix River		682.4

It is unusual to find the Lodi exposed in its entire thickness because of the slumping of overlying materials or because of removal by erosion. In some places numerous springs mark the

position of the top. The combined resistance of the materials in the Lodi silts and the underlying dolomite in contrast to the friable sandstones of the underlying and overlying formations produce many falls and cascades.

The minerals of the two members are similar. The Saint Lawrence, where it is best developed between Marine and the "Soo" Draw Bridge, is coarser in texture and is more highly charged with glauconite than is the same member at Afton; otherwise the insoluble residue is much the same. In the Afton section, the material in the two members is very similar, consisting of more than 90 per cent of pitted and frosted quartz grains, mostly curvilinear, although the lower grades are angular. Glauconite is prominent in many of the samples, making up as much as 2 per cent of the size 1/4-1/8 millimeter, and as high as 30 per cent in sizes below 1/16 millimeter. The remainder consists of authigenic and detrital feldspars in sizes below 1/8 millimeter, and adularia, albite, microcline and oligoclase.

The mineral assemblages of the Saint Lawrence do not differ from the Prairie du Chien so greatly in species as in proportion. The Saint Lawrence can be differentiated from the Prairie du Chien by (1) solubility (an approximate average of 50 per cent, while the Prairie du Chien averages over 90 per cent), (2) the lower feldspar content (approximately 5 per cent of insoluble residues in contrast with the 50 per cent of the Prairie du Chien), (3) the high percentage of glauconite (5 per cent in contrast to the few grains in the Prairie du Chien). (See Table I.)

The more sandy and shaly zones of the Lodi can be differentiated from similar zones in the Dresbach and the Franconia by (1) the silty nature of the Lodi, (2) the high solubility and (3) the large feldspar content. Sizes of the grains alone differentiate the Saint Lawrence and Lodi insoluble residues from the Galesville member and from the Jordan and the Saint Peter formations.

Jordan Sandstone member. — The Jordan sandstone, the uppermost member in the Saint Croixan Series (p. 454), is exposed in the high bluffs from Afton, Minnesota, to Osceola, Wisconsin. The Saint Croix river flows almost parallel to the strike of the strata in the northern part of the area. A section, four miles southwest of Osceola, was described in detail by Stauffer [10] in 1925. The section at Stillwater, typical of the area, was described in 1888 by

10 Stauffer, C. R. The Jordan Sandstone. Jour. of Geol. 33: 710. 1925.

Winchell.[11] (Section 7.) The Jordan varies in thickness from 72 feet at Osceola to 121 feet at Afton, and has an average thickness of 75 feet. The formation is incoherent, although in many places the rock, due to casehardening of the surface, appears quartzitic. Unusual concretions of casehardened sandstone, 4 to 6 inches in diameter, were seen in the new road cut at Osceola. The lower beds, and some of the upper ones, contain flat sandstone pebbles, interbedded in a sandy matrix. The lithologic character of the sandstone is remarkably varied, but in the almost perpendicular bluffs along the river south of Osceola, three distinct units can be recognized.

(3) brown ferruginous sandstone containing many hard beds,
(2) pure white sandstone,
(1) cross-bedded sandstone, stained with iron.

The Jordan lies conformably on the Lodi, as indicated by the many cases of complete transition, and is overlain unconformably by the Prairie du Chien dolomite throughout the Saint Croix valley. The unconformity is recognized by (1) the presence of 1½ to 2 feet of basal sandstone conglomerate in the Oneota, (2) the complete absence of the transition beds exposed at Red Wing and at other places only a few miles southeast of the area, (3) the relative thinness of the formation compared with the Jordan farther south and (4) the truncation of the Jordan beds by those of the Prairie du Chien as seen in the new road cut at Osceola.

Laboratory analyses of eleven samples taken from the Jordan are shown in Table I. The Jordan can be differentiated from the Galesville by (1) the pitted and frosted character of the grains in contrast to the secondarily grown grains of the Galesville, (2) the absence of leucoxene in the Jordan and its presence in the Galesville and (3) the relatively high percentage of zircon in the Jordan. It can be distinguished from the Franconia by its larger grains, and from the Saint Peter by the high degree of roundness and the mineralogical purity of the Saint Peter.

ORDOVICIAN SYSTEM

Prairie du Chien Formation

The Prairie du Chien formation is divided into the Oneota, the New Richmond and the Shakopee members. This formation outcrops along the Saint Croix river from the mouth at Prescott to

[11] Winchell, N. H. Geology of Washington County. Geol. of Minn. Final Rept. 2: 387. 1888.

Osceola, Wisconsin. Exposures are not continuous because of removal by erosion or cover by drift, but wherever exposed the rock forms conspicuous cliffs or bluffs along the river and cuesta ridges away from the river. The bluffs are 185-200 feet high. The entire thickness of the formation is present only in the southern part of the area.

The Oneota member is chiefly thick-bedded, tough, crystalline, dolomitic limestone, with a few lenses of sandstone, varying in color from grayish or dirty buff to light buff or drab. In artificial exposures the beds are thick and fairly regular and have distinct partings, but in natural exposures the bedding planes are lost through secondary dolomitization. Many of the beds contain numerous solution pores. For no great distance are any of the beds mapable units.

The Stillwater section (Section 7) is typical of the exposures in the southern part of the area and the Osceola section (Section 6) of those in the northern part.

Section 7

Stillwater, Minnesota (11, fig. 1)

Lithology	Thickness in feet	Elevation
Pleistocene		
Glacial drift	70	915-985
Thin-bedded calcareous shales and siltstones with many springs at the top	13	668-681
Level of St. Croix River		668.0

ERRATA

After this paper went to press, Stauffer discovered a fauna at Stillwater in dolomite 100 to 105 feet above the Jordan.[1] This is identified as a Shakopee fauna. Either the present writer is wrong in assigning all of the dolomite above the Jordan to the Oneota as usually defined, or the Shakopee fossils occur in this section stratigraphically below the New Richmond horizon.

[1] Personal communication from G. M. Schwartz to A. C. Trowbridge, dated January 8, 1936.

The New Richmond member is represented on Willow River about 5 miles from Hudson by two beds of sandstone 2 or 3 feet thick and lying about 120 to 130 feet above the base of the Oneota.

This outcrop is only about 6½ miles from the type locality. No sandstone was found in the upper part of the 126 feet of Prairie du Chien at Stillwater, which might be ascribed to the New Richmond.

Most of the fossils that are found in the Prairie du Chien are very poorly preserved. Cryptozoons are common; gastropods of the genus *Ophilita* also are abundant, and *Hexactinellidae* sponge spicules were found in beds 33, 50, and 70 feet above the base of the Oneota at Stillwater.

The mineral assemblage in the different parts of the Prairie du Chien formation varies considerably in species, shape and size. Samples were taken at regular intervals of five feet in the Osceola and Stillwater sections, but in all the other localities the unusual beds only were sampled. In some of them chert occurs in the form of geodes, layers and oolites. Laboratory analyses of samples are shown in Table I.

The minerals in the Stillwater section are noticeably different from those at Osceola. The most soluble bed in the section is 60 feet above the base of the formation. The dolomite has a soluble carbonate content varying from 80.2 to 99.12 per cent, and an average of 91.2 per cent. Some of the insoluble grains are as large as 1/2 millimeter in diameter, although most of them are less than 1/16 millimeter. The dominant mineral is authigenic feldspars, consisting of euhedral grains of adularia, albite, oligoclase and microcline, which compose 30 per cent to 60 per cent of the insoluble residue. The grains of feldspar range from 1/32 to below 1/256 millimeter in diameter. Curvilinear shaped quartz grains are next most numerous, and very fine clay makes up an appreciable part of some of the residues.

Studies of mineral suites from the Prairie du Chien of the Stillwater section do not indicate a stratigraphic break in the upper part or at 60 feet above the base as believed by Ulrich, but rather support the classification of all of the exposed beds as Oneota.

In 1924, Ulrich [12] proposed to place a systematic break within this dolomite by classifying the Oneota in his Upper Ozarkian and the Shakopee in his Upper Canadian. He believes the New Richmond to be a lens or a series of lenses at different horizons rather than a member or formation. Part of Ulrich's physical evidence for this proposed division lies in the Saint Croix area.

12 Ulrich, E. O. Notes on the new names in table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin. Trans. Wis. Acad. Sci. 21: 100-104. 1924.

His evidence for a physical break 60 feet above the top of the Jordan between the Oneota and the Shakopee at Stillwater is: "The relatively slight thickness of the lower formation [the Oneota], (2) the absence of a fossiliferous cherty zone that is commonly present in the upper part of the Oneota sections at and to the south of Trempealeau, (3) the unevenness of the contact plane which shows irregularities of contour of a foot or more and corresponding dissection across sedimentary planes in distances of less than ten feet, and (4) the presence of one to three inches of conglomerate with limestone and cherty pebbles in a matrix of coarse quartz sand and grains of glauconite." [13]

In addition to taking samples every five feet for laboratory analyses, the writer carefully examined the Stillwater section to determine the possibility of a physical break within the Prairie du Chien formation. The writer found no more evidence in the field for placing the contact between the Oneota and the Shakopee 60 feet above the Jordan than at any other level. That is, the Oneota has about the same thickness at Stillwater as on Willow River and almost as great a thickness as at Dresbach, Prairie du Chien, and elsewhere on the Mississippi River. The lenticular character of the cherty zones in the Prairie du Chien renders the presence or the absence of such zones of doubtful value for purposes of classification in the Saint Croix area. The unevenness of the bedding at the 60-foot level is duplicated at many different horizons in the Prairie du Chien. Many such irregularities of contour — due to truncation of cryptozoan reefs and diastems — indicating even greater breaks than the one at Stillwater can be observed along the railroad cut west of Point Douglas, at Hastings and elsewhere, in different stratigraphic positions. If such evidence were to be so used, there would be scores of great unconformities in the Prairie du Chien. If there is a break between two systems at the 60-foot level, it will have to be determined on paleontological evidence, for physical evidence seems to the writer to indicate the contrary.

Saint Peter Sandstone

South of Stillwater, the Saint Peter sandstone directly underlies the steep slopes of erosion remnants that are capped by Platteville limestone. These flat-topped hills stand approximately 100 feet above the surrounding country. Following is a typical section:

13 *Op. cit.*: 101.

Section 8

North of Prescott, Wisconsin, in Secs. 25, 26, and 36, T. 27 N., R. 19 W. (20, fig. 1)

Lithology	Thickness in feet	Elevation
Pleistocene		
Glacial drift	15	1045-1060
Platteville limestone		
Thick-bedded, broken, buff-colored, fossiliferous, dolomitic limestone	7.5	1037.5-1045.0
Fossiliferous dolomitic limestone	5.5	1032.0-1037.5
Glenwood shale member; green shale	4.0	1028.0-1032.0
St. Peter		
Thick-bedded, ferruginous sandstone	2.0	1026.0-1028.0
Loose, friable, white sandstone	8.0	1018.0-1026.0
White sandstone; makes a distinct bench	5.0	1013.0-1018.0
Friable sandstone; mostly concealed	120.0	893.0-1013.0
Prairie du Chien		
Bedded dolomite, with coarse quartz sand	2.0	891-893
Bedded dolomite; only partly exposed; lowest rock seen near river level is close to contact with the Jordan	185.0	796-891

The basal portion of the formation is concealed in most places, making difficult an actual measurement of the thickness, but from several measurements in the field and from well records, the Saint Peter south of Hudson is known to be 130 to 133 feet thick.

Trowbridge,[14] describing an unconformity beneath the Saint Peter in Iowa, found that the thicknesses of the Prairie du Chien and Saint Peter formations vary reciprocally, but sum up to about 300 feet, and stated that the buried erosional surface under the Saint Peter has a relief as great as any similar surface in the Paleozoic in the Mississippi valley. However, on Willow River only a few miles from the Saint Croix, Powers[15] traced this same contact for 1½ miles and found a relief of only 4 feet. So far as can be determined the thicknesses of the two formations do not vary greatly from place to place in the Saint Croix river region, and their combined thicknesses amount to as much as 322 feet. It is possible that there is no important unconformity between the Prairie du Chien and the Saint Peter formations in this particular area.

14 Trowbridge, A. C. Prairie du Chien-Saint Peter unconformity in Iowa. Proc. Iowa Acad. Sci. 24: 177-182. 1917.

15 Powers, E. H. Paleozoic stratigraphy and structure in the valleys of Willow and Apple Rivers, Wisconsin. Unpublished thesis, Univ. of Iowa. 1932.

Much of the Saint Peter sandstone is somewhat cross-bedded, and near the top there are several hard layers cemented with iron. Many of the weathered faces are yellowish-to-reddish, but the fresh exposures are white, excepting the few ferruginous beds near the top.

The formation consists of bedded, white, friable, saccharoidal, quartzose sandstone. Most of the grains are frosted, highly polished and curvilinear, but some are sub-rounded. Mechanical analyses are shown in Table I. The few heavy minerals which were seen under the petrographic microscope were not separated from the light minerals.[16]

Platteville Formation

In the Saint Croix area the Platteville limestone occurs only on the tops of erosional remnants south of Stillwater. Only 10-17 feet of the lower part of the limestone and 2-4 feet of the basal Glenwood shale member are known anywhere within this region (Section 8), the younger beds of the formation having been eroded from the tops of the hills.

The green Glenwood shale probably represents transition from the Saint Peter sandstone to the Platteville, which in this region consists of blue-to-gray, fossiliferous, thin-bedded dolomitic limestone.

Decorah Shale

If there were any rocks younger than the Platteville deposited in this area, they have been removed by erosion, except for traces of the Decorah shale. No exposures of this shale have been found in place along the Saint Croix, but in the faulted area near the "Soo" Draw Bridge, Peterson[17] reports "float" made up of slabs of Decorah.

STRUCTURE

As has long been known, the Paleozoic strata in this general region dip gently from the pre-Cambrian high of northern Wisconsin toward the axis of the Lake Superior syncline of Minnesota. The general regional dip is about 15 feet per mile in a southwest direction.

16 As this paper goes to press, a paper by Thiel appears (Sedimentary and petrographic analysis of the St. Peter sandstone, Bull. Geol. Soc. Am. 46: 559-614. 1935).

17 Peterson, Eunice. Block faulting in the Saint Croix Valley. Jour. Geol. 35: 368-374. 1927.

Local structure was first noted by one of Owen's[18] party who sketched a large fault on the Saint Croix south of Afton, and another on the Mississippi near Hastings. In 1888, Winchell[19] re-described the Hastings fault, but interpreted the Afton structure as an anticline, stating: "There is a sudden upward swell in the limestone [Prairie du Chien], both in its lower and its upper surface, running from this point [meaning Hastings], toward the central part of Afton and hence to Hudson. This anticlinal axis can be traced through the central part of Dakota County into the township of Waterford, where it becomes lost in the drift." In the same report, Winchell[20] noticed that the heavy dolomite beds on the Hastings side of Mississippi River show displacement in relation to the beds on the opposite side, but could not locate the fault zone.

In 1915, Weidman and Schultz[21] attributed the structure between Hudson and Burkhart to faulting. In 1919, Peterson[22] mapped and described block faulting near the "Soo" Draw Bridge (8, fig. 1). In 1931, Trowbridge and Atwater[23] thought there must be a fault with a throw of 300 to 400 feet between Stillwater and Hudson, but they had not studied at that time the structure further than this. In 1931, Thwaites[24] quoting Karges[25] described two faults with a horst between them in the lower Saint Croix area. Powers,[26] in 1932, after detailed mapping in the Willow River valley concluded that the structure is anticlinal, and that the evidence of faulting is lacking.

After completion of the field work on which the present paper is based, Trowbridge[27] mapped this structure as an anticline, called it the Hudson anticline, and named the syncline east of it the River Falls syncline and the syncline west of it the Twin City syncline.

18 Owen, D. D. Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. Map Section 1 S. 1852.

19 Winchell, N. H. Geology of Washington County. Geol. of Minn. 2: 382-383. 1888.

20 *Op. cit.*: 382.

21 Weidman, Samuel and A. R. Schultz. Water supplies of Wisconsin. Wis. Geol. and Nat. Hist. Survey 35: 546. 1915.

22 *Op. cit.*

23 Trowbridge, A. C. and G. I. Atwater. Stratigraphy and structure of the Upper Mississippi valley. (Abstract) Geol. Soc. Am. 42: 220. 1931.

24 Thwaites, F. T. Buried Pre-Cambrian of Wisconsin. Geol. Soc. Am. 42: 734-739. 1931.

25 Karges, B. E. Faulting in the Paleozoic sediments near Hudson, Wisconsin. Unpublished thesis, Univ. of Wisconsin. 1930.

26 *Op. cit.*

27 Trowbridge, A. C. Upper Mississippi Valley structure. Bull. Geol. Soc. Am. 45: 519-528. 1934.

After detailed mapping of the region, using the base of the Prairie du Chien as a datum, the writer concludes that the dominating local structure is an anticline with a N. 25½° E. axis passing through Hudson and Afton (structure map, fig. 1), and pitching sharply to the southwest. The northern end of this anticline is covered by drift, but the structure was mapped for nearly twenty miles on the east side of the Mississippi River. On the crest, the datum is fully 500 feet above the normal levels. Because of thick deposits of glacial drift the anticline cannot be traced far to the northeast, but a closure of 100 feet is indicated northeast of Hudson fig. 1). The width of the anticline at Hudson and Afton is between five and six miles. The maximum dip to the east near the Little Falls Dam on the Willow River is 400 feet per mile or more than 4°, and the greatest dips in the south part of the area near Afton and along Trout Creek are somewhat less than that.

The fault at Hastings which trends S. 68° W. intersects the anticlinal structure at a high angle. The total displacement of this almost vertical normal fault could not be definitely determined on account of secondary dolomitization of the Prairie du Chien, but measurable beds show throw of more than 100 feet. As Winchell[28] stated, the Prairie du Chien on the Hastings side of the river is much lower than it is on the Point Douglas side; a fact which indicates that there is a fault in the valley between these two points. Glacial drift and river alluvium make it impossible to locate the fault, and the outcrops to the north and east of this location throw no light on the problem.

On the southeast flank of this anticline, the strata dip to the southeast and south, into the River Falls syncline, at the rate of 100 to 400 feet per mile. North of the anticline, the area has the normal regional dip of approximately 50 feet per mile, and the strike of the strata is almost parallel to Saint Croix River. The only interruption of this normal dip is near the "Soo" Draw Bridge which has been described by Peterson.[29]

CONCLUSIONS

Study of the Saint Croix area throws little if any light on the age of the outcrops of the Keweenawan traps or of the rocks of the Red Clastic Series. Neither has this investigation revealed much concerning their relationship to each other, except that the Red

28 *Op. cit.*: 382.

29 Peterson, Eunice. *Op. cit.*: 368-374.

Clastics are younger than the Keweenawan trap in this particular region.

The Saint Croixan Series can best be divided into three formations: Dresbach, Franconia and Trempealeau. Each of these can be recognized in the field, and their contacts are sharp enough to serve as datum planes in field mapping.

The members of the Dresbach in the Saint Croix area are as easily recognized in the field as is the formation itself, and in a given section, they can be separated in most actions by mechanical analyses and petrographic studies.

The Franconia, like the Dresbach, is divided into members, but the upper two do not have similar lithologic characteristics over an area large enough to warrant naming. In spite of this great variation, the members are distinguishable in the field in the sections in which they occur, and in the laboratory by the high per cent of authigenic feldspars and glauconite.

The members of the Trempealeau can be recognized in most of the Saint Croix area, but in some places the Saint Lawrence and Lodi are indistinguishable.

The writer failed to find evidence for a physical break 60 feet above the Jordan sandstone in the Stillwater section by means either of field or laboratory studies.

The Saint Peter and the Platteville formations are easily recognizable either in the field or in the laboratory.

The dominant structure in the Saint Croix area is the Hudson anticline, which has been thought recently to be a horst.

Mechanical analyses of the samples and a study of both the light and heavy minerals show that the different formations can be differentiated in a given section. It was found that authigenic feldspars and glauconite are very useful in distinguishing the various members; but the writer does not assert that the mineral assemblage found in the Saint Croix section can be used to recognize the different formations and members in sections occurring outside of this area.