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STUDIES OF SUB-SURFACE GEOLOGY IN WISCONSIN, 1923-1957

by

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ILLUSTRATIONS

STUDIES OF SUB-SURFACE GEOLOGY IN WISCONSIN, 1923-1957

F. T. Thwaites

Introduction. Study by the writer of subsurface geology in Wisconsin began about 1912. In 1923 a discussion of results was published. (Thwaites, 1923) At that time the total sample collection included only about 8000 specimens. Today it is well over 100,000. At the time the first report was published many of the major correlations of the concealed formations had been reached but the additional data now available has not been simply duplication; it has confirmed and greatly strengthened the early conclusions. During this work many maps of the structure of the rock formations were drawn and a few were published.(Thwaites, 1935) Maps showing variation in thickness of the formations (isopach maps) were constantly revised; only a few were published. (Thwaites, 1935) Many cross sections were drawn and some were included in the report of 1923.

Changes in correlations. In 1923 and previously the late E. O. Ulrich was making studies of the surface geology of Wisconsin. His work was almost wholly based on fossils collected at widely-separated localities. It is now clear that he duplicated some formation names, for he concluded that the same formation at different localities was not the same. These correlations affected mainly the Trempealeau formation at the top of the Cambrian. Such names as "Devils Lake sandstone", "Mazomanie sandstone", and "Mendota dolomite" were then used but have since been discarded. Ulrich admitted many of these errors to the writer privately but did not retract his opinions in print. The surface work of Wannemacher, Twenhofel and Raash (1934) cleared up many debatable points. The above fact should be kept in mind in comparing this report with that of 1923 in which the writer disclaimed responsibility for Ulrich's correlation (Thwaiter, 1923, p. 531). A detailed study of surface geology was made in 1916-1921 by Thwaites and Twenhofel in the vicinity of Sparta but was not all published. The full manuscript is in the files of the Wisconsin Geological Survey. Other surface studies will be mentioned in the present report. Ulrich published a short paper (Ulrich, 1934) giving some of his older conclusions. A full bibliography of reports on both surface and subsurface geology of Wisconsin and adjacent states since 1923 is given at the end of this report.

Nature of information. The data from which subsurface geology is studied consists of cuttings from holes drilled with cable (percussion) tools. These cuttings were at first taken at irregular intervals where the driller concluded that there a change of material exists. As time went on and the value of the information was appreciated by drillers and engineers the sample interval was decreased. Most samples are now taken at intervals of 5 feet. During this time the percentage of wells where samples were taken has steadily increased. This is due not only to education in the value of the information but also to the efforts of the Bureau of Sanitary Engineering of the State Board of Health. At the present time they endeavor to have samples collected from all municipal wells and from all wells, regardless of depth, which produce 100,000 gallons of water per day or more.

Accuracy of samples. Some geologists may still cling to the old idea that cuttings from cable tool holes are so contaminated by cavings that they are worthless. Were this true it would be difficult, if not impossible, to drill with such tools. The principal source of error is not the method of drilling but the manner in which samples are taken by the driller or inspector.

Differences in amount of washing, depending in part on just how the samples are collected, are an important source of error.

Washing affects the relative amounts of coarse and fine sand grains and shale content. Washing, which is in large part unavoidable, can make a silty, non-water-bearing gravel look like a clean deposit which should be developed for water. Washing may make a sample of a succession of thin shale and dolomite layers appear to be all dolomite. Shale partings in sandstone may be lost in the same manner. But the greatest cause of error is neglect to take a sample every time the hole is cleaned out by bailing. Later the driller may fill several sample bags from the same material. This error may often be detected by too great similarity of samples. If correctly and conscientiously taken few samples are exactly the same as those above and below. In former times many drillers took their samples from the pit into which cuttings are dumped and they therefore showed only the finest of the cuttings which settled on top. This kind of error appears to be uncommon today. It is true that in an uncased hole some fragments which have fallen from higher up than the level of drilling occur in samples. Such "strays" can often be detected by the fact that they are larger than normal cuttings and some have been rounded more or less by abrasion with the true cuttings. All things considered, cuttings provide reasonably accurate information. In some cases comparison with nearby outcrops has confirmed the accuracy of the cuttings.

Collection of cuttings is more difficult in drift than in the rock formations.

Caving is much greater if the hole is open, and in driving pipe through sand it is common to have the sand rise inside the pipe far above the position at which it actually occurs. Formerly some drillers refused to take cuttings from the drift and it was not until recently that their value was appreciated. Methods for taking reliable samples from gravel still await development. Probably to dump the entire contents of the bailer into a pail or banell shows the silt-clay content best.

Geographic distribution of data. Most of the well samples thus far obtained come from the southeastern part of the state, which is the most densely populated region where contact with drillers and engineers is easy. The north-central part of the state has few deep wells because of the presence of impeneable rock close to the surface. Few samples are available from holes drilled for mineral exploration, including some attempts to find oil.

Objectives of study. The first well records were collected solely to increase knowledge of geology. As time passed the practical value of records in the steadily increasing search for ground water led to seeking much more information on well construction and results of tests. Results of pumping tests are given in terms of "specific capacity", that is gallons per minute perfoot of lowering of the water surface. The static water level in wells when drilled is also recorded. Areas where flowing wells could be found were mapped but the universal availability of electric current for pumping has greatly diminished the value of natural flows some of which were formerly used to furnish power to hydraulic rams. Information on relative yield from different formations is very incomplete. In giving results of tests it is necessary to rely on the statements of drillers and not on personal observation. The following effort is devoted to geology only.

Examination of samples. On receipt samples are dried and placed in two ounce glass bottles previous to examination. In the case of drift and sedimentary rock cuttings inspection with a hand lens is usually adequate. Cuttings from crystaline rocks are examined either with a binocular microscope or with a petrographic microscope in thin section where chips large enough to make a section are present. The fear has always been present that because of the necessity of using hydrochloric acid in examination of cuttings to test for carbonate might injure a microscope, hence its use was reduced to a minimum. The sluggish action of almost all calcarous materials in Wisconsin, including the cement in sandstones, shows that dolomite is much more abundant than calcite or true high calcium limestone. Considerable washing of samples is required to determined true colors. Color charts were not introduced until 1955 but those available are not complete for some of the rock colors, particularly blue-grays. Besides, some of the names used in the charts are too cumbersome to be used in the typed sections. Colors recorded are in general those of dry rather than wet cuttings.

Well logs. On completion of examination of the cuttings graphic logs are made of almost all wells. These are made directly from the handwritten description of samples on which changes of material and formation boundaries are marked. The logs are made on tracing paper and descriptions typed in abbreviated form with the use of the "carbon back" method in order to make impressions dense enough to make Ozlid prints. The graphic section is made with India ink and uses standard symbols for the different kinds of rock. Copies are supplied free of charge to U.S. Geological Survey, State Board of Health, well owner, driller, and engineer. The data on construction and test results are shown. The construction log is shown at the right and is as nearly as possible to scale. Locations are given by section, township, and range. The Survey files are open to public inspection, Ozlid copies of logs can, with few exceptions, be supplied for 10 cents a sheet postpaid by Wisconsin Geological Survey, Science Hall, Madison 6, Wisconsin.

Order of discussion. In the following report the formations are discussed form the top down because that is the order in which they are penetrated in drilling a well.

QUATERNARY: PLEISTOCENE and RECENT (DRIFT)

Introduction. On account of the difficulty of collecting samples noted above study of the unconsolidated surficial materials has lagged considerably behind that of the sedimentary rocks. All but the southwestern part of the state has been glaciated. The unglaciated area is called by the somewhat misleading name of "Driftless Area". Although ice did not invade this area, streams, lakes, and the wind brought in material from adjacent glaciated regions. Unconsolidated materials due to prolonged weathering and decay of the underlying bed rock occur to considerable thicknesses (several tens of feet) in the Driftless Area. Such material of local derivation is termed "Surface" on the logs of wells. The term "drift" applies to all unconsolidated (locally semi-consolidated) material deposited either directly by glacial ice or reworked by water mainly derived from its melting ("melt-water"). Some material was redeposited by the wind ("loess"). Much of this has been altered by weathering into "soil". Deposits of glacial streams are called "outwash". Material laid down in lakes is often referred to as "lacustrine" or "glacio-lacustrine". Many of the lakes were enclosed on one side by the glacial ice. The margin of the ice did not remain in any one position long. Either melting changed it or a renewal of snow and ice accumulation caused the front of the glacier to readvance. As a result the sucession of materials of different origins is extremely confused in the drift. Lake, stream, and vegetable deposits are buried by direct ice deposit or glacial "till". Extensive testing with the drill is needed to determine the extent, nature and water-bearing quality of the drift at any locality. Deposition by streams, lakes and vegetation has continued since the glacial ice all melted away. These deposits are referred to as "Recent" or "Postglacial". They are present in many stream beds and in almost all swamps and marshes. Both glacial drift and related deposits are called "Pleistocene". The Pleistocene and Recent are often lumped under the name "Quaternary".

Character. The most important practical problems in testing the drift are to determine: (a) its quality for foundations of buildings, and (b) its water-bearing quality. The testing of foundations is now called "Soil Mechanics" and requires taking of cores for determination of compression, weight of unit volume moisture content and other qualities which indicate the probable behavior of the material when a load is placed on it. Only a few such shallow test borings have been reported to the Survey. Unless some serious problems are encounted the services of a geologist are rarely called upon. For water development, the main problem is to distinguish till from sand and gravel. The perfection of removal of the finer clay and silt portion of the till in the process of its reworking by water varies greatly and is hard to determine. Sand and gravel deposits occur on top of, and buried under, till as well as along valleys in the Driftless Area which carried glacial streams. Outwash deposits have considerable horizontal extent which in many instances can be determined only by test drilling, or possibly by geophysics. Deposits of streams where they entered a lake are called deltas. They are limited in horizontal extent and have bedding inclined about 25 degrees from horizontal. Hence adjacent test holes vary greatly in amount and character of the sand and gravel.

More confusing are small masses of sand and gravel which were plowed up by moving ice from older deposits and transported for some distance. In the Kettle Moraine of eastern Wisconsin gravel is very abundant although not all of it was washed clean by the glacial waters. Such poorly-washed gravel with many angular stones is well illustrated in the log of the well at the State Radio Station on Lapham Peak near Delafield and is exposed in an abandoned railroad cut southeast of Whitewater. Beach gravel formed on lake shores is distinguised by small, well-sorted pebbles in thin layers. Such deposits are commonly only a few feet thick and may contain much clay. Till is distinguished from lake clay by the presence of a considerable percentage of sand and pebbles which ar disclosed by washing. Tills reflect the nature of the source rock. Those of sandstone regions contain much sand and those on dolomite contain comparatively little fine material for they are made chiefly of broken-up ground up bed-rock. Where the ice advanced over lake clays the clay-silt content of the till is very high. The red "Valder" till of northeastern Wisconsin is of this character. The relative amount of stratified or assorted material in the drift depends upon the sand and stone content of the till as well on amount of waterwashing. Lake clays which contain layers of sand and fine gravel may be easily confused with till which has a high clay-silt content. Some cuttings of lake clay display two colors, pale red and light grey suggesting that they are varved. For the most part clay that is show winter and summer layers, samples make more lumps than do till cuttings; many stones can be seen without washing of the latter. None of the till in the state seems to be entirely free of dolomite flour. Even in regions formerly regarded as free of such sediment the lake clays are highly calcareous suggesting mechanical concentration of rock flour along with the clay. Deposition of carbonate by organisms is improbable in cold lakes of glacial time. Clays on the shore of Lake Superior contain carbonate but the source of the carbonate content of the northern drift is not definitely known. Carbonate rocks occur at Limestone Mountain, west of l'Anse, Michigan, as well as near Lake Temiskaming, and Hudson Bay, in Canada. There may be unknown remnants of Paleozoic strata in the basin of Lake Superior. One peculiar feature of some areas in the northern part of the state disclosed by well logs is the absence of any till. These assorted deposits rest directly on the bed rock. The disposition of the till which was present in the ice is unknown.

Distribution. Glacial drift of significant thickness is present mainly in the area of Wisconsin drift which was the product of the last stage of glaciation. In north-central Wisconsin around Wausaw and Neilsville the drift is mostly thin except in valleys. The same remark applies to the area of older drift west of Janesville and Beloit. In the Driftless Area of southwestern Wisconsin outwash is confined to the valleys. Deposits of glacial lakes are found along the margins of the Great Lakes and in central Wisconsin in Juneau and Adams counties on both sides of the Wisconsin River.

Thickness. Records furnished by drillers generally place the thickness of the drift as the depth to which it was necessary to line the hole with pipe. Cuttings, however, demonstrate that in many localities pipe was driven some distance into soft bed rock formation. Such decay may be a relic of the preglacial weathered zone but in some places it extends so deep that such an explantion is difficult. At Summit, southwest of Madison, pipe was driven 320 feet from the surface; indubitable drift extended only to 142 feet. On the other hand, drift sand and small pebbles are abundantly found mingled with dolomite cuttings in some places far below the top of the bed rock. The question is are these due to (a) careless sampling, (b) a leak under the drive pipe, or (c) drift between layers of the rock such as was seen at Ripon (Thwaites, 1921).

Definite solution of these possibilities is impossible with data available. Leaks under the drive pipe or casing may be very troublesome for they allow sand to enter the well. If the sand pumped from a well contains grains of dolomite, feldspar, or hornblend its recognition as drift is easy. In the Driftless Area leakage of river-transported sand may be discovered in some wells by glauconite where it is not present in the adjacent bed rock. In places where the well passed through stream-washed sand derived from rock similar to that found lower down in the hole determination of the true depth to solid rock is extremely difficult. In some cases the presence of chert pebbles in the transported surface material is decisive for there is no chert in the Cambrian Sandstones. Examples of this difficulty occur in all the wells at Camp McCoy near Sparta. In many areas of Cambrian sandstone the rock is so weakly cemented that it is hard to stop the drive pipe which tends to follow down the drill in to the rock. Cement forced into the rock might harden it enough to furnish a safe seat for the drive pipe. In many places an inner liner into the rock may be cemented both to the drive pipe and rock, thus making a permanent connection. Some wells have caved in under the bottom of the casing many years after they were drilled. In these instances the evidence furnished by the geologist from sample examination is invaluable for location of the caving formation and for repair. Other unconsolidated formations include loess and weathered dolomite. The depth to which the bed rock is weathered in the unglaciated area has been underestimated by most geologists. In many places it is very hard to place a definite limit to the solid rock.

Few wells which pass through very thick drift deposits are recorded by samples. The deepest drift reported is 525 feet at Superior (Weidman and Schultz, p. 317), 484 feet at Black Creek (Thwaites, 1943, p. 117-118), 439 feet at Delavan, 450 feet west of Brillion, 412 feet at Gillett (Thwaites, 1943, p. 118) and 372 feet at Madison, this last is supported by a partial set of samples. In general the experience of the writer is that the thickness of the drift has been exaggereated in the past. In the Driftless Area the outwash is over 200 feet thick in some wells.

Division of different ages of drift. Comparatively few well records in Wisconsin show undoubted evidence of more than one age of drift deposition separated by an interval of soil formation aside from the clear-cut occurence of red Valders till on older gray till. Only a few wells near Fontania have disclosed "gumbotil" which is so abundant in Illinois and Iowa. Most buried soil profiles show oxidation and in places leaching of carbonate. Correlation of the concealed drifts is problematical for we do not have such uniform layers of drift as those of Illinois (Horberg,

Table 1

Equivalence of geologic names

Pleistocene Old	1956
Wisconsin	Valders till Two Creeks Forest Bed Wisconsin Cary till* Tazewell till Iowan-Shelbyville till Farmdale till**
Pre-Wisconsin	Brady soil Sangamon and Loveland interval Illinoian till Yarmouth interval Kansan till Aftonian interval Nebraskan till

* Subdivision into Port Huron till and Cary till suggested
** Correlation not proved

1953). In a few localities, for instance near Portage and along Wisconsin River, the lower part of the sand and gravel is semi-cemented which may possible be due to its greater age.

Postglacial or Recent sediments. Few water wells penetrate an important thickness of postglacial "recent" sediments. Foundation tests in some of the valleys which enter Lake Michigan have given important confirmation of Hough's (1953, 1955) conclusion that the water of that lake was very low prior to the Nipissing level. Considerable thicknesses of marl, which is formed in relatively warm water, occur along with sand and fine gravel. These are the fillings of old valleys eroded during the low stage and filled during the rise of the lake level due to postglacial uplift of the land to the northeast. In the boring at Jones Island, Milwaukee, it seems likely that only 5 feet of red clay just above the bed rock is of glacial age. Marls are easily distinguished from lake clay of glacial times because of the content of calcium carbonate which is in many cases shells; carbonaceous organic matter is also present.

Well logs showing more than one age of drift.

Log of well at Buena-Vista Park, Fontana, Wisconsin

SW¼NE¼ sec. 14, T. 1N., R. 16 E.

	Depth, feet	Thickness, feet
Till, gray, dolomitic (Cary or Tazewell)	21	21
Clay and sand, gray (outwash)	6	27
Gravel, stony	8	35
Clay, grey	30	65
Sand, coarse, some fine	5	70
Gravel, sand, best gravel 78-86 (outwash)	27	97

Till, gray (Tazewell)	46	173
Gumbotil, dark gray (Illinoian)	11	184
Till, gray, (Illinoian)	9	193

Partial log of City Well No. 6, New London, Wisconsin

Pershing and Wyman Sts.

Clay or till, pale red, weathered (Valders)	5	5
Clay, sandy, yellow-gray, dolomitic (Early L. Oshkosh)	10	15
Till, gray dolomitic (Cary)	5	20
Clay, snady, yellow-gray, dolòmitic (pro-Cary lake)	10	30
Clay, snady, rusty brown, weathered (pre-Cary soil)	5	35
Clay, gray, sandy, dolòmitic (pre-Cary)	10	45
Till, gray, dolomitic (pre-Cary)	5	50
Sand and gravel (pre-Cary delta)	115	165

The pre-Cary drift may be either Tazewell or older.

Log of well at Waterstreet Resort, Baraboo, Wis.

SE NE¼ sec. 13, T. 11 N., R. 6 E.

Silt, light brown-gray, weathered	5	5
Sand and gravel (Cary delta-moraine)	210	215
Gravel, fine, sandy, yellow-brown (pre-Cary soil)	5	220
Sand, medium to very coarse, light gray (pre-Cary)	9	229

Log of test hold, Baraboo waterworks

SW¼NE¼ sec. 12, T. 11 N. R. 6 E.

No samples	25	25
Sand, meduim, gray, some pebbles, dolomitic	90	115
Sand, medium, to fine, gray to dark brown, weathered; vegetal remains, partly extinct forms	20	135
Sand, medium, gray, dolomitic	20	145
Clay, dark gray, dolomitic, some organic matter	5	150

Sand, fine to coarse, light gray, mainly local	20	200
Sand, fine to coarse, local pebbles	10	210

The weathered zone with plant remains suggests top of a pre-Cary drift.

Partial log of Avoca Oil Co. well, No. 1 Faulk, Avoca, Wis.

Sec. 8, T. 8 N., R. 2 E.

Sand and gravel, no samples to 30 (Cary outwash)	135	135
Sand, medium to very coarse, local	10	145
Sand, coarse to fine, light gray, glacial (pipe driven to 154)	10	155
Sand, medium to fine, light gray, local, firm	20	175
Sand, medium to fine, light gray, some drift, firm	40	215
Bed rock (sandstone)		

The firm sand may possibly be of pre-Wisconsin age.

Logs of other drift wells.

Log of test well, Armour and Co., Milwaukee, Wis.

NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 31, T. 7 N., R. 22E.

Marl, gray (postglacial)	5	5
Till, gray, dolomitic (Cary)	45	50
Silt, sandy, gray, dolomitic (lake deposit)	10	60
Gravel, fine, much silt (beach?)	5	65
Till, light gray, dolomitic	85	150
Gravel, fine, silty, water at 60'	10	160
Sand, very coarse, water at 75'	15	75
Gravel, fine, partly cemented (pre-Cary beach)	25	200
Sand and gravel, fine, dry (beach)	10	210
Till, gray, dolomitic	20	230
Clay, gray, dolomitic (lake deposit)	5	235

Till, gray, dolomitic	7	242
Bed rock, water at 100'		

The above log illustrates the complexity of glacial drift and that all beds of sand and gravel do not contain water.

Postglacial filling of Milwaukee River Valley, Milwaukee, Wis.

Log of test hole No. 1, Jones Island, center sec. 33, T. 7 N., R. 22 E.

Elevation about 10 feet above Lake Michigan

Fill and boulders, no samples	7	7
Sand, fine to small pebbles, silty, light gray (beach)	19.5	26.5
Marl dark to light gray (estuarine postglacial deposit)	37.4	63.9
Sand, fine, light gray, fragments of shells	20.1	84
No samples, sand, coarse, to gravel, fine	14	98
Sand, fine to medium, some silt, gray	5	103
Clay, silty, light gray, dolomitic	2	105
Sand, medium to fine, light gray, dolomitic	11.2	116.2
Clay, gray, dolomitic interbedded with gravel, sandy	10.1	126.3
Sand, and gravel, fine, much silt	42.7	169
Clay, red, dolomitic, sandy (Valders till?)	5	174
Bed rock		

Partial log of Well No. 1, Oscar Mayer and Co., Madison, Wis.

SW¼ sec. 31, T. 'N., R. 10 E.

Till with boulders (Cary)	5	5
Quicksand, no sample	5	10
Gravel, coarse, no sample	10	20
Till, no sample	26	46
Sand, silty, yellow-gray	6	52
Gravel, coarse to fine (no water)	36	88

Sand, medium, pebbles, gray, dolomitic	10	98
Sand, very fine, gray, dolomitic (quicksand)	34	132
Clay, gray, sandy, dolomitic	93	225
Sand, medium, gray, dolomitic	5	230
Clay, gray, dolomitic	120	350
Gravel, coarse, many sandstone pebbles	22	372
Bed rock		

Gravel layers are probably delta deposited in a (Cary or pre-Cary) glacial lake. The bottom gravel may have been deposited in early glacial time by a local stream.

MISSISSIPPIAN

Introduction. The youngest bed rock formation definitely known in Wisconsin is the black shale which was encountered beneath Lake Michigan in the Linwood Avenue tunnel of the Milwaukee waterworks. This formation was studied only on the dump for no geologist was allowed to enter the tunnel, it was correlated as Mississippian by its fossils. (Raasch, 1935)

Character. The name "Kenwood" was applied by Raasch in 1935 to this formation but the term appears to have been previously preempted (Wilmarth, 1938, pp. 1083-1084). The formation is described as black, brown, and green fossiliferous shale with layers of coal up to two inches thick. In lithology it strongly suggests the "Antrim" shale of Michigan which occupies a similar stratigraphic position.

Distribution. Notes by Raasch record the presence of the Kenwood formation in the Nunn, Bush, and Weldon well in Milwaukee but reexamination of the samples by the present writer shows that only glacially transported fragments are present in the drift at this location. The formation has never been found in any other wells in Milwaukee or elsewhere in Wisconsin and is apparently confined to the bed of Lake Michigan. There is no information on its thickness.

DEVONIAN

Introduction. Strata of Devonian age are found in Wisconsin along the Lake Michigan shore between Milwaukee and Sheboygan. The following section is given by Raasch (Raasch, 1935)

Milwaukee formation
North Point member — shale and siliceous dolomite, about 35 ft
Lindwerm member-shale, about 25 feet
Berthelet member-shaly dolomite once used as cement rock, about 21 feet
Total about 80 feet.

Thiensville formation
Dolomite, light brown to white, bituminous, about 65 feet

Lake Church formation
Ozaukee member-pyritiferous dolomite, about 27 feet
Belgium member dolomite, brown, bituminous, about 8 feet
Total about 35 feet

Grand total about 180 feet

Of the names proposed above Milwaukee and Thiensville have been approved by the U. S. Geological Survey. (Wilmarth, 1938, pp. 1134, 1378, 2138-2139)

Character. Most of the Devonian strata encountered in wells (Teller and Monroe, 1899; Teller, 1900; Cleland, 1911; Pohl, 1929) are dolomite. Color varies from very light gray through various shades of blue-gray and green-gray to brown. Little shale is recorded, slight shows of oil occur. Discrimination from the underlying Niagara dolomite is made mainly on the basis of color. The underlying formation is all light gray. The problem is complicated by the irregular surface of the Niagara below the Devonian.

Table 2

Devonian

Iowa	Illinois	Michigan	Wisconsin
Sheffiled Lime Creek	Absent	Traverse	Milwaukee Thiensville Lake Church
Shell rock Cedar Valley	Cedar Valley		
Independence	Independence		
Wapsipinicon	Wapsipinicon	Bell	
		Dundee Detroit River	

<u>Distribution.</u> The main area of Devonian strata is in the north part of Milwaukee where it extends over 5 miles inland from Lake Michigan. To the north it forms only a narrow strip along the lake shore. One of the most accesible exposures is in the bed of Milwaukee River is Estabrook Park, Milwaukee. Under Lake Michigan the Devonian appears to form two submerged ridges which trend northeast from Sheboygan and from Milwaukee respectively to the Dundee and Traverse limestone formations of Michigan.

<u>Thickness.</u> Little over 100 feet of Devonian strata is found in most wells. The log of the Shorewood well, however, seems to

show 271 feet although the exact lower limit is uncertain.

Because of the unconformable contact with the Niagara, as well as the fact that the top of the Devonian was eroded in pre-glacial time, it is not possible to present an isopach map showing thickness of the Devonian.

Partial log of abandoned well, Shorewood School, Milwaukee County, Wis.

SE corner sec. 4, T. 7 N., R. 22 E.

	Thickness	depth, feet
Drift	165	165
Milwaukee formation, 105 feet		
Shale, pink, dolomitic	10	165
Shale, gray, dolomitic	55	220
Dolomite, gray, shaly, pyritic	10	230
Dolomite, gray, shaly (cement rock)	30	260
Thiensville formation, 70 feet		
Dolomite, dark gray, shaly	20	280
Dolomite, light and dark gray	10	290
Dolomite, brown-gray	20	310
Dolomite, brown-gray; shale, blue-gray, dolomite	10	320
Dolomite, light gray	10	330
Lake Church formation (?) 106 feet		
Dolomite, shaly, light green-gray	10	340
Shale, green-gray, dolomitic	24	364
Dolomite, gray, layers shale, blue-gray	72	436

Total Devonian 271 feet

All of the Devonian strata in the above well were cased because of caving.

SILURIAN

Introduction. The Super-Niagaran strata Silurian of Wisconsin is an dolomite and does not display any of the upper Silurian evaporite formations of Michigan which contain salt and gypsum. A single outcrop near Waubakee (Sec. 29, T. 12 N., R. 21 E.) shows dolomite which was ascribed to the upper Silurian and termed "Waubakee" by Alden in 1906 (Wilmarth, 1938, p. 2285). Correlation is on the basis of fossils. Strata of this age have never been positively identified in other outcrops or in well cuttings from Wisconsin.

Niagara Strata. Almost all the recognized Silurian strata of Wisconsin are commonly included in the Niagara or Lockport group. The lowest part of this group termed "Mayville" is correlated by some geologists with the older Alexandrian Group, but will be here discussed with the overlying strata. Several attempts have been made from the time of the Chamberlin Survey on (Thwaites, 1923, p. 533) to subdivide the Silurian dolomites into separate formations, but in tracing these from place to place and in attempting to discriminate them in well logs difficulties arise (Karges, 1936) Hence it seems best to the writer to relegate these subdivisions to the rank of "members" in sub-surface geology. The following general column is that of Ehlers as given by Shrock (Shrock, 1939).

*Racine-dolomite, cherty   over 400 feet
Manistique dolomite
    Cordell or Upper Coral cherty dolomite, about 90 feet
    Schoolcraft of Lower Coral cherty dolomite, about 70 feet

* = name approved by U. S. Geological Survey (Wilmarth, 1938, p. 1763)

Burnt Bluff dolomite
Hendricks dolomite or transition beds, about 30 feet
Byron dolomite-fine-grained, little chert, about 100 feet

Mayville dolomite, locally cherty, about 100 feet

Grand total about 690 feet

Table 3

Illinois	Iowa	Michigan	NE Wisconsin	SE Wisconsin
Port Byron				
Racine	LeClaire	Racine	Racine	Racine
Waukesha (cherty)	Hopkinton	Manistique (cherty)	Coral (cherty)	Waukesha (cherty)
Joliet				
Kankakee (cherty)	Kankakee	Burnt Bluff	Byron	Byron?
Edgewood	Edgewood	Mayville	Mayville	Mayville?

* All Silurian strata in Wisconsin lumped as Niagara in subsurface

Character. Most of the entire Niagara group is very pure dolomite almost a theoretical dolomite $CaMg\ (CO_3)^2$ (Steidtmann, 1921). The average of 80 analyzis shows dolomite 94.3%, calcite 2.77%, with four which show an excess of magnesium. On solution with acid the residue is commonly chert rather than shale. The size of dolomite crystals varies considerably from almost a lithographic texture to nearly a millimeter in diameter. To distinguish grain size it is necessary to wash and then dry the cuttings and this has not been done for many wells. A quantative standard is lacking. The difficulty in tracing subdivisions is due in part to complete observation of grain size but is mainly because of the presence in the Niagara group of many reefs or bioherms (Shrock, 1939). The dolomite in and around these accumulations consists of (a) core rock which is cavernous and coarse-grained, with many fossils,

(b) flanking fine-grained dolomite with a dip up to 54 degrees, and (c) inter-reef horizontal fine-grained dolomite layers with few fossils. The flanking inclined strata cause much trouble in drilling for they deflect the drill from vertical. Subdivision of the sequence by insouble residues is most uncertain for chert varies in horizontal distribution. There seems to be three chert zones: basal Racine, lower Manistique or Waukesha and locally Mayville. Most of the chert is white colored and is conspicuously different from the light gray dolomite fragments. Red or pink dolomite is limited in horizontal extent and color is not a satisfactory means of subdivision. In some localities the red is confined to shale partings but in drilling this color clings to the dolomite cuttings making color determinations difficult. Partings of red shale were very prominent in the well at Pilgrim Heights, near Menomonee Falls. These were so abundant that very little water could be obtained from the Niagara at that locality. Where weathered the dolomite is yellow-gray.

Distribution. The outcrop of the Niagara dolomite group forms a wide cuesta in the eastern part of Wisconsin. The escarpment on the west side of this cuesta lies east of Lake Winnebago where it rises in abrupt slopes and cliffs to an elevation of nearly 400 feet above the lake. South of Mayville the escarpment is almost wholly lost beneath the drift. North of Green Bay it forms the western shore of the Door Peninsula. Portions of the escarpment are cut away by valleys, for instance just north of Lake Winnebago. Other parts are so straight that some have suggested faulting. It is apparent from subsurface study of structure that this is not the correct explanation but that glacial erosion controlled by jointing is more probable. East and southeast of the crest of the cuesta the land declines gently but at a smaller angle than the dip of the strata until it passes below the level of Lake Michigan. Isolated erosion remnants of the Niagara occur in southwestern Wisconsin where they make prominent hills or "mounds".

Thickness. The greatest recorded thickness of the Niagara dolomite is 735 feet at Manitowoc. Since the upper contact with the Devonian is an erosion surface it is not possible to prepare an isopach map even of a limited area. In most areas the thickness is less. South of Milwaukee the Niagara is quite thin and is possibly locally absent.

Well logs. The following logs show typical occurences of Niagara dolomite. Names of subdivisions are given at top where they could be distinguished.

Partial log of City Well No. 2, Kewaunee, Wis.

	Thickness	Depth, feet
Drift	56	56
Dolomite, medium grained, light gray (Racine)	175	231
Dolomite, light gray, medium grain; chert, white (Menistique)	45	276
Dolomite, medium grain, light gray	15	291
Dolomite, medium grain, gray	35	326
Dolomite, medium grain, light gray	25	351
Dolomite, medium grain, grey	25	376
Dolomite, medium ground, light grey	25	401
Dolomite, medium grain, gray and light gray	25	426
Dolomite, fine grained, gray and light gray (Byron)	20	446
Dolomite, fine and medium grain, light gray	85	531

Dolomite, fine grain, light gray	55	586
Dolomite, fine and medium grain, light gray	20	606
Dolomite, medium grain, light gray (Mayville)	60	666

Total Niagara 610 feet

Dolomite, light gray, dark gray, green-gray, black specks (Richmond)

Partial log of well of Wisconsin Malting Co., Manitowoc, Wis.

Drift	35	35
Dolomite, broken, light gray, black specks (Racine)	19	54
Dolomite, medium some fine grained, light gray	266	320
Dolomite, gray and light gray, medium grain	10	330
Dolomite, medium grain, light gray	10	340
Dolomite, medium grain, light gray; chert, white (Manistique)	30	370
Dolomite, medium grain, light gray	10	380
Dolomite, medium grain, gray and light gray	10	390
Dolomite, medium grain, light gray	90	480
Dolomite, medium grain, light and dark gray	10	490
Dolomite, medium grain, light gray	40	530
Dolomite, fine grain, light gray (Bryon)	20	550
Dolomite, fine grain, gray	10	560
Dolomite, part fine grain, dark and light gray	30	590
Dolomite, fine grain, light gray	10	600
Dolomite, fing grain, dark gray	30	630
Dolomite, medium grain, gray (Mayville)	20	650
Aolomite, medium grain, gray and light gray	30	680
Dolomite, medium grain, light gray	10	690

Total Niagara 655 feet

Shale, red, and iron ore, oolitic (Neda)

Partial log of Wisconsin Gas and Electric Co. well, Racine, Wis.

Drift	68	68
Dolomite, light gray, top 2 feet broken	142	210
Dolomite, light gay and red	30	240
Dolomite, light gray	20	260
Dolomite, light gray; chert, white (Waukesha?)	40	300
Dolomite, light gray (Mayville)	50	350
Total Niagara 282 feet		
Dolomite, dark blue, shaly (Richmond)	--	--

ORDOVICIAN (1)

(1) The line of division between Silurian and Ordovician has long been debated. Ulrich placed it at the base of the Richmond group. The controversy need not be discussed here, but this explains some older editions of the geologic map of Wisconsin. The usage in this report is now nearly universal.

Introduction. Neda formation According to the commonly used classification the Neda formation lies at the top of the Ordovician.

Table 4

Ordovician

Minnesota	Iowa	Illinois	Wisconsin Old	Wisconsin New
Maquoketa	Maquoketa	Maquoketa	Cincinnati	Richmond (Maquoketa)
Galena	Galena Decorah	Galena Decorah	Galena	Galena Decorah*
Platteville	Platteville	Platteville	Trenton or Platteville	Platteville
St. Peter	St. Peter	St. Peter	St. Peter	St. Peter
[illegible]				

	Shakopee	Shakopee	Shakopee		
New Richmond	New Richmond	New Richmond	New Richmond**	Lower Magnesian	Prairie du Chien
	Oneota	Oneota	Oneota		

* not shown on well logs

** Willow River or Root Valley

The name was applied first by Savage and comes from a small railroad station near the former mines south of Mayville. (Wilmarth, 1938, p. 1471) The name has been approved by the U.S. Geological Survey.

Character. The Neda formation consists of oolitic hematite with layers of red and blue-gray shale. Although formerly correlated as Silurian and equivalent to the Clintes formation Savage placed it in the Orodovician because of the presence of some fossils of that age, east of DePere, Wisconsin. At the base there is a conglomerate with pebbles of shale which have a polish of iron oxide. The ore is low grade, about 33% to 47% iron, Phosphorous is over 1%, silica occurs as concentric layers in the oolites between layers of hematite. Considerable dolomite is present. It is very fariable and cannot be smelted in blast furnaces unless mixed with other ore.

Distribution. The Neda ore area occurs in lenses which appear to strike northeast-southwest. In places these lenses are widely separated and in others they appear to lie side by side in series which trend northwest-southeast. The sides of the lenses are rather steep and a bed of ore several feet thick pincher out within a horizontal distance of little more than its thickness. Whether or not these sides of the lenses are erosional or depositional is not known. The Neda ore was found in the City well at Campbellsport (20 feet thick), the Thiel farm well near St. John (6 feet thick), the Wisconsin Malting Company well at Manitowoc (showing mixed with red shale) and the Caddy Vista well in Racine Co. (15 feet, red shale and ore). It has been reported by drillers in many other wells but not confirmed by sampling. Workman (1951) describes its extension in Illinois.

Thickness. The thickness of the Neda formation is very variable. The maximum reported is 55 feet in the old "Sheep Farm" well in southwest Manitowoc. (Thwaites, 1913) Test drilling near Mayville showed a maximum of little less. Most of the ore mined was not over 6 to 8 feet thick because of the danger of falls from a layer of harder ore at the contact with the Niagara dolomite above. The surface of the shale below the ore is very regular and smooth. It does not lie in valleys eroded in the shale. The layer of the overlying Mayville are draped over the ore lenses.

Richmond Group

Introduction. The Ordovician shale of Wisconsin is called "Cincinnati" in older reports. (Thwaites, 1923, p. 536) Later the name "Maquoketa, which was first used in Iowa in 1870, was applied in southwestern Wisconsin. Ulrich (unpublished) urged that the group term "Richmond" from a type locality in Indiana, be used since it is not at all certain that the shale of Wisconsin is all the same as that of Iowa. (Wilmarth, 1938, pp. 445, 1292, pp. 1809-1810) This name is in current use on well logs.

Character. The Richmond of Wisconsin is composed mainly of blue-gray dolomitic shale. Layers and lenses of dolomite occur in many sections. Most of these are blue-gray in color, some are light gray. Much of the dolomite is shaly. Some layers of brown-gray bituminous shale have been found. These smell strongly of petroleum when heated. In 1923 the writer attempted to subdivide the Richmond into a series of lithologic members but with the much greater number of well logs now available it is evident that this was premature. There seems to be much dolomite near the top of the formation in northeastern Wisconsin. The Shanty Bay campground well in Peninsula State Park, Door County, shows over 300 feet of shale and shaly dolomite below the Niagara. In many places the presence of dolomite beds at the top of the Richmond makes the location of the contact with the Niagara uncertain particularly in drillers' logs. Discrimination of thin dolomite layers is at best uncertain for in many cases the driller evidently collected the shale which stuck to the bit. In other instances too much washing removed the shale cuttings leaving a concentrate from a thin dolomite bed. Thin dolomite layers may be missed in examining cuttings because of mixture with the more abundant shale. The base of the Richmond group is clearly marked by an abrupt contact of blue-gray shale on light brown-gray dolomite. The drill hole is commonly carried a few feet into the underlying dolomite so that it is not reliable to place the bottom of the shale casing (shale liner) as the exact base of the formation. Correlation of the dolomite strata of the Richmond with those found in northern Michigan will not be attempted here. So far as Wisconsin is concerned, lateral variations in lithology of the group render any conclusions in respect to disconformable overlap at either the upper or lower contacts most uncertain. If the top is a buried erosion surface the evidence in Wisconsin is inconclusive.

Distribution. Shale of the Richmond group underlies in eastern Wisconsin little more than the outcrop area of Niagara dolomite from underneath which it projects only a few miles. In southwestern Wisconsin the shale formation is confined to the uplands, in many places to the isolated "mounds", which are caped with outliers of the Niagara. Surface exposures are rare everywhere, on account of the ease of weathering of the shale. Almost the only natural exposures are in the shore cliffs of Green Bay and in a few ravines near Green Bay.

Thickness. The variations of thickness of the Richmond group ar shown in the isopach map, figure 1. The range is from a minimum of 175 feet west of Milwaukee to 519 feet in well No. 1 at Algoma. The discrepancy between the two wells at Algoma is evidently the result of a normal fault which crosses well No. 2 just at the bottom of the Richmond. (figure 2) The thickest part of the group is in southern Door County. Small shows of oil in this rock have led to some drilling for oil in that vicinity.

Well logs. The following partial logs of wells show the variations in character of the Richmond group.

Partial log of well at Shanty Bay Campground, Peninsula State Park, Door Co.

	Thickness feet,	Depth, feet
Dolomite, light gray (Niagara)	—	150
Shale, blue-gray, green-gray, dolomitic; dolomite, gray (Richmond)	5	155
Shale, gray, dolomitic; dolomite, blue-gray, gray	5	160

Dolomite, blue-gray and gray	35	195
Shale, blue-gray, dolomitic; dolomite, blue-gray, gray	15	210
Dolomite, dark blue-gray to light gray; shale, blue-gray, dolomitic	15	225
Dolomite, gray, some blue-gray	10	235
Shale, blue-gray, dolomitic; dolomite, blue-gray	15	250
Shale, blue-gray, dolomitic; dolomite, gray	5	255
Dolomite, light gray, gray, blue-gray, pyritic	10	265
Dolomite, gray, some blue-gray	20	285
Dolomite, blue-gray	15	300
Dolomite, gray	10	310
Dolomite, gray and light gray	15	325
Dolomite, gray; gypsum, white	10	335
Dolomite, blue-gray and gray	5	340
Shale, blue-gray, dolomitic	5	345
Dolomite, blue-gray; shale, blue-gray, dolomitic	15	360
Shale, blue-gray, dolomitic; dolomite, blue-gray	15	375
Shale, blue-gray, dolomitic	5	380
Dolomite, blue-gray	10	390
Shale, blue-gray, dolomitic	15	405
Shale, blue-gray, dolomitic; dolomite, blue-gray	5	410
Dolomite, blue-gray to gray, blue specks	15	425
Shale, blue-gray, dolomitic	10	435
Shale, brown-gray, dolomitic, hard	5	440
Dolomite, dark brown-gray	10	450
Shale, blue-gray, dolomitic (bottom of hole)	2	452

Partial log of city well No. 2, Kewaunee, Wis.

Dolomite, light gray (Niagara)	--	666
Dolomite, light and dark gray, black specks (Richmond)	4	670
Shale, blue-gray, dolomitic	95	765
Dolomite, light gray to gray	15	780
Shale, blue-gray, dolomitic	20	800
Dolomite, gray, black specks	10	810
Shale, blue-gray, dolomitic	45	855
Shale, brown, dolomitic	5	860
Dolomite, gray and blue-gray, black specks	10	870
Shale, blue-gray, dolomitic	35	905
Shale, light brown, dolomitic	15	920
Shale, blue-gray, dolomitic	5	925
Shale, brown, dolomitic	55	980
Shale, blue-gray, dolomitic	30	1010
Shale, light brown, dolomitic	5	1015
Total Richmond 349 feet		
Dolomite, light gray (Galena)	--	--

Partial log of East Avenue city well, Waukesha, Wis.

Dolomite, light gray (Niagara)		150
Shale, pink, dolomitic; dolomite, light gray (Richmond)	5	155
Dolomite, light gray	15	170
Shale, blue-gray, dolomitic	20	190
Dolomite, blue-gray; shale, blue-gray, dolomitic	10	200
Shale, blue-gray, dolomitic	15	215
Dolomite, shaly, dark blue-gray	25	240
Shale, blue-gray, dolomitic	10	250
Dolomite, shaly, dark blue-gray	5	255

Shale, blue-gray, dolomitic	80	335

Total Richmond 185 feet

Dolomite, light gray (Galena)

Partial log of Well No. 2, Oak Creek Station, "isconsin Electric Power Co., on Lakeshore, south line of Milwaukee Co.

Dolomite, light gray, light pink, some green-gray (Niagara)	---	438
Shale, red, slightly dolomitic (Richmond)	22	460
Shale, blue-gray, dolomitic	10	470
Dolomite, blue-gray and light gray; shale, blue-gray, dolomitic	60	530
Shale, blue-gray, dolomitic	30	560
Dolomite, gray and dark blue-gray	10	570
Shale, blue-gray, dolomitic	15	585
Dolomite, gray and dark blue-gray	10	595
Shale, blue-gray, dolomitic	60	655

Total Richmond 217 feet

Dolomite, light gray (Galena)	---	---

Trenton and Black River Groups. (Mohawkian series).

Galena-Platteville dolomite and limestone (including Decorah)

Introduction. The Trenton and Black River groups in Wisconsin are almost entirely limestone and dolomite. Only a few thin layers of shale and sandstone occur. In the reports of the earlier geological survey of the state (Thwaites, 1923, p. 538) the name "Galena" was used for the upper part and the lower portion was named "Trenton". In 1905 the name Trenton was replaced by Bain by a local designation, "Platteville". (Wilmarth, 1938, p. 1679) Efforts were later made to introduce the term "Decorah" (Wilmarth, 1938, p. 538) for strata between the two units (Bays and Raasch, 1935)

Much attention has been given to details of this interval on account of their relation to lead and zinc mineralzation in southwest Wisconsin. The following section is used by the U. S. Geological Survey (Agnew, 1952).

Formation	Member	Lithology	Thickness, feet
Galena	Dubuque	Dolomite	40-42
	Stewartville	Dolomite	75-78
	Prosser	Dolomite	165
Decorah	Ion	Dolomite and limestone	20
	Guttenberg	Limestone	12-14
	Spechts Ferry	Shale ("oil rock")	1-3
Platteville	Quimbys Mill	"Glass rock" limestone and dolomite	8-12
	McGregor	Limestone and dolomite in thin layers	30
	Pecatonica	Dolomite in thick layers	20-22
	Glenwood	Shale and sandstone	1

There has been some differnce of opinion on parts of the foregoing secti n. (Bays, 1935, Kay, 1935) The detailed section abo ve is inapplicable to subsurface study in eastern Wisconsin where the entire sequence is dolomite. No limestone is known east of Sun Prairie in Dane Co. The Glenwood sandy member at the base of the Platteville is the only one which can be positively identified in the subsurface. It is much thicker up to 35 feet in eastern Wisconsin. Chamberlin (1877) divided the Platteville sequence in the vicinity of Beloit into descending: Upper Blue 15 feet, Upper Buff, 55 feet, Lower Blue 25 feet and Lower Buff 25 feet. It is not easy to connect this column with that above but the Lower Blue is probably the McGregor member of the Platteville and the Upper Blue the Decorah formation. In the subsurface the buff (yellow-gray) members are light to medium gray for the colors described from the outcrop are due to oxidation of the iron content. The blue tint is present at depth and appears to be original. It requires washing of the cuttings to distinguish these colors with certainty. The term "Glenwood" for the basal member (not included in Chamberlin's section) is unfortunate for the same name is used for one of the stages of glacial Lake Chicago. (Wilmarth, 1938, pp. 830-831) The Upper Blue of the Chamberlin section is recognizable in most well logs. It is probably Decorah but has not in named in the logs. The Lower Blue (MacGregor) is not recognized everywhere. The absence of this member may be due to (a) imperfect sampling, (b) replacement of blue by light gray strata for in many logs the only blue color is confined to spots in a light gray groundmass, (c) local replacement by the sandy Glenwood member, and possibly in some cases (d) incomplete washing of the samples. At one time the writer recognized a "Trenton stray sand" (Thwaites, 1923, p. 540) which is now regarded as a miscorrelation of a thin St. Peter sandstone. The Decorah shale is absent or rare in eastern Wisconsin.

<u>Character.</u> The dolomite of the eastern Galena-Platteville is medium-grained and except in the blue divisions, is light gray with a light brown shade in some sections. Attempts to subdivide the unit by insoluble residues have not succeeded. Chert is rare. The sand grains in the Glenwood member are in considerable part larger than those of the older St. Peter sandstone. The sorting of the sand is very poor. The Glenwood

must contain material brought from outside the region, (Cohee, 1948) the product of a marine transgression. The limestone members are predominantly blue colored. Discrimination from dolomite is not easy unless the sample is washed to remove all fine cuttings which effervesco readily even where they are dolomitic.

Distrib tion. The carbonate rocks of the Galena-Platteville are found in full thickness only where it is protected by the overlying Richmond formation. It is occurs (a) in a belt parrallel the Lake Michigan coast and (b) on high ridges and mounds of southwestern Wisconsin. With a reduced thickness these strata form the capping of many ridges from southwestern Wisconsin north to the vicinity of Viroqua and again in northwestern Wisconsin near River Falls. Eroded Galena-Platteville dolomite underlies the lowland west of the Niagara excarpment throughout east-central and southwestern Wisconsin. The formation is most commonly penetrated by wells in eastern Wisconsin.

Thickness. The thicknass of the Galena-Platteville is shown the isopach map, figure 3. It varies from a minimum of 179 feet at Denmark to a maximum of 368 feet at Kenosha. In much of northeastern Wisconsin it is about 200 feet. It is not known to what extent the variation is thickness is due to pre-Richmond erosion or to original differences in deposition.

Well logs. The accompanying logs of wells which penetrate the Galena and Platteville strata show the nature of these beds.

Partial log of well at U. S. Air Force Radar Station, Elkhorn, Wis.

	Thickness, feet	Depth, feet
Shale, blue-gray, dolomitic (Richmond)	—	470
Dolomite, light gray (Galena)	100	570
Dolomite, light gray; chert, white	15	585
Dolomite, light gray	50	635
Dolomite, light gray, blue spots	25	660
Dolomite, blue-gray, some light gray (Upper Blue, Decorah)	10	670
Dolomite, light gray (Upper Buff Platteville)	20	690
Dolomite, light gray and blue-gray (Lower Blue MacGregor)	15	705
Dolomite, light gray (Lower Buff)	15	720
Dolomite, light gray and gray	35	755
Sandstone, fine to medium-grained, light gray, dolomitic (Glenwood)	5	760
Dolomite, very light gray, green-gray	10	770
Sandstone, fine to medium-grained, light gray, dolomitic	10	780
Total Galena-Platteville 340 feet		
Sandstone, medium to fine-grained, light gray (St. Peter)		

Partial log of East Avenue well, Waukesha, Wis.

Shale, blue-gray, dolomitic (Richmond)		335
Dolomite, light gray (Galena)	160	495
Dolomite, blue-gray and light gray (Upper Blue, Decorah)	10	505
Dolomite, light gray (Upper Buff, Platteville)	45	550
Dolomite, light gray, light blue-gray (Lower Blue, McGregor)	10	560
Dolomite, gray and light gray	20	580
Sandstone, fine to coarse, light gray, dolomitic (Glenwood)	25	605
Total Galena-Platteville 270 feet		
Sandstone, fine to medium-grained, light gray (St. Peter)		

Partial log of City well No. 2, Kewaunee, Wis.

Shale, blue-gray, dolomitic (Richmond)		1015
Dolomite, light gray (Galena)	95	1110
Dolomite, light gray, blue specks (Upper Blue, Decorah)	25	1135
Dolomite, light gray (Upper Buff, Platteville)	10	1145
Dolomite, gray to light gray, some blue (Lower Blue, McGregor)	25	1170
Dolomite, light gray (Lower Buff)	55	1225
Dolomite, light gray, sandy; sandstone, fine to coarse-grained, light gray (Glenwood) Total Galena-Platteville 220 feet	10	1235

Sandstone, medium to coarse-grained; chert, pebbles white; shale green-gray (St. Peter)

Improbable occurence of oil. Oil is present in nearby states in strata which probably correspond to the Galena dolomite. In order to have any commercial accumulation in eastern Wisconsin below the protective cap of the Richmond shale it would be necessary to have: (a) a bituminous source rock, (b) enough fracturing to provide a reservoir and (c) a closed trap to retain the oil. There are some bituminous layers both in the Richmond of northeastern Wisconsin and in the Decorah of parts of southwestern Wisconsin ("oil rock"). The slight amount of water where the Galena dolomite is deeply buried indicates that there is little chance of a reservoir. A study both of well records and of outcrops in northeastern Wisconsin has failed to discover any closed structural traps. Every water well which penetrates this formation is a negative oil test for that locality. (Twenhofel, 1923) The chance of finding commercial production in the Galena of eastern Wisconsin appears exceedingly remote. Only one well has shown any bituminois residue (3 miles west of Chilton, Lot 114, Brothertown) which suggests the former presence of oil.

St. Peter sandstone.

Introduction. The St. Peters sandstone was first named by D. D. Owen in 1847 from outcrops near Fort Snelling, Minnesota, on what was then called the St. Peters River but is now known as the Minnesota River. The name changed to St. Peter, has been used consistenly ever sinse (Wilmarth, 1938, pp. 1884-1886)

Character. The St. Peter sandstone varies from medium to very fine grained, almost silty, sandstone. In the subsurface the color of the St. Peter is nearly everywhere light gray to white; small parts are pink. Dolomite cement is present in portions of the formation. Various shades of red, brown, and green are common on the outcrop and can be ascribed to weathering. Shale of red and green-gray color is present, particularly toward the base of the formation. The shale caves badly in drilling. Chert occurs as pebbles in the shale and in places as definite strata. The chert pebbles are little rounded and for the most part do not exceed an inch in diameter. They were formerly dug for road surfacing but are no longer used hence exposures of these basal beds are now rare. Parts of the basal sandstone are very well cemented by quartz almost a true quartzite which breaks under the drill into angular fragments. Some of these hard layers are red. In some records light gray dolomite appears to be interstratified with shale and sandstone but surface exposures which show the true relations are rare. The true St. Peter can be indentified and distinguished from lower sandstones b the presence of non-dolomitic shale and chert pebbles.

Distribution. The St. Peter sandstone outcrops in a belt of very irregular width which fringes the borders of the Platteville areas. This belt contains many cliffs and crags where unglaciated and is in strong topographic contrast with the smooth topography on the dolomites above and below. Outliers of St. Peter are very abundant and occur far from the borders of the Platteville beds. In the subsurface St. Peter is very irregular in distribution in some areas there is no St. Peter and to pass through the St. Peter horizon in a well and find no sandstone is not at all uncommon. The St. Peter appears to pinch out in northeastern Wisconsin near Peshtigo River.

Thickness. One of the distinguishing characteristics of the St. Peter is its extreme variation in thickness noted above. Although the maximum recorded thickness is almost 400 feet at Shullsburg thicknesses of over 100 feet are uncommon. The changes in thickness are unpredictable with present knowledge and hence no isopack map is possible. The strata underlying the St. Peter vary greatly in age. It has been found overlying every formation from Prairie du Chien down well into the Cambrian. On the section from Prairie du Chien to Milwaukee (figure 5) it is concluded from the well logs that the lower formations gradually disappear below the St. Peter which also increases in thickness. It is very difficult to distinguish the base of the St. Peter when it lies upon the Cambrian and some Cambrian strata may be erroneously included in it where there is no red shale or chert conglomerate to mark the true contact.

Pre-St. Peter unconformity. The relation of the St. Peter to the older strata has been debated for a long time. Some urge that they are conformable and others that a period of erosion intervened.

The following facts support the theory of an erosion interval prior to deposition of the St. Peter: (a) The red non-dolomitic shale and the chert conglomerate is explicable by surface weathering of the older dolomite, (b) it has been definitely proved that the St. Peter fills valleys in the older formations some of which cut through formations older than the Prairie du Chien, (c) portions of these valleys may contain dolomite beds interstratified with sandstone and shale, (d) in eastern Wisconsin there is a progressive overlap at the base of the St. Peter from the Galesville or Eau Claire members of the Cambrian Dresbach formation near Milwaukee to the Prairie du Chien near Madison. Throughout a large area in southeastern Wisconsin the St. Pete rests upon the Trempealeau formation, (figures 4 and 5) (e) it is difficult to explain the shales and cherts by subsurface weathering which is favored neither by the carbonate mineralization of the ground water in the St. Peter nor confirmed by evidence of subsurface openings or collapse due to solution.

The following facts favor conformity (Flint, 1956): (a) the bedding in the older Prairie du Chien dolomite in many exposures dips parallel to the base of the sandstone, (b) the contct below the St. Peter is gradational in many places and dolomite is interbedded with sandstone, (c) the irregular contact may be explained by reefs or bioherms of the older dolomite, such as form many hills on the present-day surface, (d) the apparent interbedding of dolomite and sandstone in the Linden well could be explained by overhang of a buried dolomite cliff. Such an overhang is present in a road cut southeast of Viroqua on U. S. highway 14.

Well logs. The following logs of wells show the deep valley-fill phase, possible interbedding with dolomite in another filled valley, and the eastern thin St. Peter phase.

Partial log of city well No. 3, Shullsburg, Wis.

	Thickness, feet	Depth, feet
Sandstone, fine to medium-grained, light gray, dolomitic (Glenwood member of Platteville)		290
Sandstone, fine to medium-grained, light gray (St. Peter)	10	300
Sandstone, medium to fine-grained, white	15	315
Sandstone, fine to medium-grained, light gray	25	340
Sandstone, fine to medium-grained, light pink	5	345
Sandstone, medium to fine-grained, light pink	10	355
Sandstone, fine to medium-grained, light pink	20	375
Sandstone, medium to fine-grained, pink	25	400
Sandstone, medium to fine-grained, light gray	10	410
Sandstone, medium to fine-grained, light pink	5	415
Sandstone, fine to medium-grained, pink	10	425
Sandstone, medium to fine-grained, pink	15	440
Sandstone, fine to medium-grained, light pink	10	450
Sandstone, medium to fine-grained, light gray and pink	10	460
Sandstone, fine to medium-grained, light gray, some pink	30	490
Sandstone, medium to fine-grained, light gray, some pink	60	550
Sandstone, fine to medium-grained, light gray and pink	15	565
Sandstone, medium to fine-grained, light gray	25	590

Sandstone, medium to fine-grained, light pink	10	600
Sandstone, fine to medium-grained, light gray and pink	15	615
Sandstone, fine to medium-grained, light gray	10	625
Dolomite, light gray; shale red and green-gray; some quartzite	20	645
Shale, red and green-gray; chert, yellow-gray; sandstone, fine-grained, light gray in part very hard; formation caves; bottom of hole	42	687

St. Peter penetrated 397 feet

Partial log of supply well, Linden, Wisconsin

Snadstone, fine-grained, gray, dolomitic (Glenwood member of Platteville)		210
Sandstone, medium to fine-grained, white (St. Peter)	35	245
Sandstone, fine to medium-grained, light gray	5	250
Sandstone, medium to fine-grained, white	20	270
Sandstone, fine to medium-grained, light gray	30	300
Sandstone, coarse-grained to silty, light gray	10	310
Shale, red, green-gray, gray	35	345
Dolomite, sandy, light gray	40	385
Dolomite, light gray; shale, red, green-gray	10	395
Shale, red and green-gray	30	425
Sandstone, medium to fine-grained, light gray, dolomitic	5	430
Dolomite, light gray; sandstone, fine-grained, gray, dolomitic	15	445
Sandstone, fine to medium-grained, light gray	25	470
Shale, red; chert, white	10	480
Sandstone, coarse to fine-grained, light gray; chert, white; shale, red	25	505
Shale, red and green-gray	10	515
Sandstone, medium to fine-grained, pink; shale, red	20	535
Shale, dark red mottled with green-gray	60	595

Total St. Peter 385 feet

Shale, pink, very sandy, very dolomitic, glauconitic (Franconia)	—	—

Partial log of well of Stokley-Van Camp, Inc., Appleton, Wis.

Sandstone, medium to fine, light gray, dolomitic (Glenwood member of Platteville)		115
Sandstone, fine to medium-grained, very light gray (St. Peter)	20	135
Chert, gray and pink-gray	5	140
Shale, red; chert, green-gray and pink	5	145
Chert, gray, yellow-gray and pink-gray; quatzite, light gray	40	185
Total St. Peter 70 feet		
Dolomite, very light gray (Prairie du Chien)	—	—

Prairie du Chien (Lower Magnesian) group.

Introduction. The youngest strata which underlie the St. Peter are a group of dolomite and sandstone beds long ago named "Lower Magnesian" by Owen (Wilmarth, 1938, p. 1228) The name "Prairie du Chien" was applied by Bain, of the U. S. Geological Survey in 1906 (Wilmarth, 1938, p.1726) when studying the southwest part of Wisconsin. The subdivision of the group into "Shakopee" dolomite, "New Richmond" sandstone, and "Oneota" dolomite in descending order was given by the Minnesota geologists (Wilmarth, 1938, pp. 1649, 1490, 1549) and has been widely used although it is unworkable in subsurface geology within Wisconsin as explained below. In 1935 Powers revived the name "Willow River" for the New Richmond sandstone.

Character. The dolomite of the Prairie du Chien group is for the most part light gray; some is red or pink. The sandstone layers are light gray with in places included chert most are highly dolomitic. Chert in the group is mainly white to light brown and is dense. Oolitic chert is most abundant near the base of the group for which it furnishes a horizon marker in many parts of Wisconsin. In some places it is found in a red dolomitic sandstone at the bottom of the group. Oolitic chert is confined to the group and hence is a diagnostic feature of the Prairie du Chien. The case for subdivision of the group into formations (or members?) is poor in Wisconsin. Powers (1935) concluded that he could map a definite New Richmond sandstone in other states but in Wisconsin this conclusion is open to doubt. A City well at New Richmond shows 4 or 5 sandstone layers in the interval between 20 and 170 feet depth of which a sandstone from 35 to 50 feet depth is probably the original New Richmond sandstone. City well No. 5 at River Falls has 3 sandstone layers in the interval from 70 to 165 feet depth. The top one probably is exposed in the gorge of the river. Powers (1935) suggests that this difficulty in indentification is due to the fact that Wisconsin is close to the shoreline of that time. In northeastern Wisconsin there are several sandstone layers some of which are known to pinch out lterally. (Thwaites, 1923, p. 543) Andrews (1955) reports evidence of a possible break in sedimentation at the base of a sandstone layer in western Wisconsin but the significance of this one exposure is unknown. Nothing has been discovered in well logs which is a relaible indicator of a division. Small showings of green-gray shale are found throughout the group but do not seem to mark definite horizons. Efforts to use insoluble residues failed. The difficulty lies mainly in the presence of reefs or bioherms away from which the strata dip at considerable angles. The problem of separating the Prairie du Chien from the overlying

Platteville dolomite is difficult where the St. Peter sandstone is absent. In some logs this contact may have been placed too high for the division was made on the basis of the blue-gray color of the Platteville. Such a division might erroneously place about 20 feet of the Lower Buff (Pecatonica) member of the Platteville in the Prairie du Chien. Where the St. Peter is absent some of the sandstones of the Prairie du Chien have been erroneously correlated as St. Peter by a number of geologists and much confusion has arisen from this fact. (Thwaites, 1934)

Distribution. Prairie du Chien strata occur in a U-shaped area surrounding the central lowland of Wisconsin. Throughout this area the firm dolomite caps many hills and makes the resistant formation of a prominent cuesta whose edge is much more dissected than is the glaciated Niagara escarpment. In the subsurface it was long ago discovered that the group is absent in much of the southeastern part of Wisconsin but it is impracticable to map the exact limits of this area. In much of the area the St. Peter sandstone lies on the Trempealeau dolomite which can be ditinguished from Prairie du Chien dolomite by the presence of much fine quartz silt and the absence of chert, as well as by the stratigraphic succession of lower formations.

Thickness. It is impossible to construct a reliable isopach map of the Prairie du Chien group because of its extremely variable thickness. However, if combined with the overlying St. Peter a map can be made (figure 6). The map shows a distinct convergence or thinning of the sum of the two formations toward the southeastern part of Wisconsin. The sum of the two formations reaches a maximum of at least 300 feet in western Wisconsin.

Well logs. The logs of the following wells illustrate some of the characteristics of the Prairie du Chien group of dolomite and sandstone.

Partial log of well of Platteville Milk Products Co., Platteville, Wisconsin

Shale, gray (St. Peter, total 65 feet)		225
Dolomite, light gray, some light pink; shale, little green-gray, (Prairie du Chien)	35	260
Sandstone, medium to fine-grained, light gray; dolomite, gray, sandy	10	270
Dolomite, light gray; some sand and shale, green-gray	10	280
Dolomite, light gray and pink; shale, green-gray	15	295
Dolomite, light gray, some pink; some shale, green-gray	35	330
Dolomite, light gray	25	355
Dolomite, light gray; chert, white	15	370
Dolomite, light gray, some light pink	20	390
Dolomite, light gray and pink; chert, white	10	400
Dolomite, light gray; some chert, white	35	435

Total Prairie du Chien 210 feet

Sandstone, fine to medium-grained, light gray, dolomitic (Trempealeau)

Partial log of well No. 3, Wisconsin State Prison, Waupun, Wis.

Shale, green-gray (St. Peter) (Total St. Peter 22 feet)		210
Dolomite, light gray (Prairie du Chien)	15	225
Dolomite, light gray; chert, white, oolitic [illegible]	10	235
Dolomite, sandy, light gray; shale, green-gray	10	245
Dolomite, light gray; chert, white	25	270

Dolomite, light gray	30	300
Dolomite, sandy, light gray	15	315
Dolomite, light gray; chert, white	5	320
Dolomite, light gray	10	330
Dolomite, light gray; chert, white, oolitic	5	335

Total Prairie du Chien 125 feet

Dolomite, light gray, sandy (Trempealeau)	—	—

Partial log of well of Liebmann Packing Col, Green Bay

Sandstone, fine to medium-grain, very dolomitic (St. Peter)		435
Dolomite, sandy, light gray; shale, green-gray (Prairie du Chien)	20	455
Sandstone, fine to medium-grained, light gray, dolomitic	10	465
Dolomite, light gray	10	475
Sandstone, fine to medium-grained, light gray, very dolomitic	20	495
Dolomite, light gray	10	505
Dolomite, light gray; some shale, green-gray	10	515
Sandstone, fine to medium-grained, light gray, dolomitic; shale, green-gray	5	520
Dolomite, light gray	30	550
Sandstone, medium to fine-grained, light gray, dolomitic; chert, white	15	565
Dolomite; light gray; chert, white	20	585
Dolomite, light gray	35	620
Dolomite, light gray, some purple-gray	5	625
Dolomite, light gray	15	640
Dolomite, sandy, light purple-gray	10	650
Dolomite, sandy, gray	15	665
Dolomite, sandy, pink; chert, gray, oolitic	10	675

Total Prairie du Chien 240 feet

Sandstone, fine-grained, light pink-gray, dolomitic (Trempealeau)

Partial log of Marinette County Farm well, Peshtigo, Wis.

Dolomite, blue-gray, sandy (Platteville)	—	155
Dolomite, light gray (Prairie du Chien)	20	175
Dolomite, part sandy, light gray; chert, white	25	200
Dolomite, light gray	5	205
Dolomite, sandy, light gray	5	210
Dolomite, light gray	15	225
Sandstone, fine-grained, much silt, light gray, very dolomitic	20	245
Dolomite, snady, light gray	10	255
Dolomite, light gray	30	285
Dolomite, sandy, purple, some light gray	10	295
Dolomite, sandy, light gray and gray	10	305
Dolomite, sandy, light gray and gray; chert, pink, gray, oolitic	5	310
Dolomite, light gray; some shale, green-gray	10	320
Dolomite, light gray; some chert, white	50	370
Dolomite, light gray, some light pink	30?	400
Dolomite, light gray; some chert, white	10	410

Total Prairie du Chien 255 feet

Dolomite, silty, dark gray (Trempealeau)	—	—

CAMBRIAN (St. Croix series)

Introduction. The name "St. Croix" was introduced by Walcott in 1912 (Wilmarth, 1938, p. 1872) but has not been widely used in Wisconsin.

Table 5

Cambrian above base of Franconia

Minnesota (Nelson, Berg)	Illinois	Iowa* Twenhofel	Wisconsin Old reports	Ulrich, Raasch	This report
Jordan	Jordan		Madison	Madison (Sunset Point)	?

		Trempealeau	Trempealeau	Mendota	Jordan * Norwalk		Jordan
St. Lawrence ***	Lodi Black Earth				Trempealeau	Lodi St. Law.	Trempealeau
Franconia	Reno (Mazomanie) Tomah Birknose Woodhill	Franconia	Franconia	Potsdam	Mazomanie ** Franconia		Franconia

* Ulrich placed the following above the Jordan: Madison, Mendota, Devils Lake, descending. It is now known that these were duplications of other names. Norwalk is the fine-grained phase of the Jordan.

** Ulrich regarded the Mazomanie as unconformable above the Franconia. Berg concludes that it interfingers with other members.

*** In some early Minnesota reports the name St. Lawrence included most of what is now called Franconia

It is with the divisions of the Cambrian and in respect to the controversy over Ulrich's proposed Ozarkian (Wilmarth, 1938, p. 1583) system that there is the most marked difference of nomenclature from the 1923 report by the writer. The studies by Ulrich (Ulrich, 1924, pl 82) resulted in giving formation names to certain units of the Cambrian which later work showed to be identical with formations already named and described The controversy (or series of controversies) is explained more in detail in the words by Wannenmacher, Twenhofel and Raasch (1934), by Twenhofel, Raasch and Thwaites (1935) and by Trowbridge and Atwater (1934). Suffice it to say here that it is now recognized that: (a) the Mendota dolomite of the region around Madison known in some papers as Black Earth (Wilmarth, 1938, pp. 1346-1347) is the same as the St. Lawrence dolomite of Minnesota which name has priority (Wilmarth, 1938, pp. 1878-1879; Trowbridge and Atwater, 1934, pp. 50-56), (b) the name Devils Lake (Wilmarth, 1938, pp. 604-605) sandstone, applied on the basis of fossils to certain strata exposed near Baraboo, is inapplicable since those beds belong to other formations, mainly the Franconia, (c) in taking the name Dresbach (Wilmarth, 1938, p. 631) from Dresbach, Minnesota to the Wiscons n side of Mississippi River it was moved to strata which are not well exposed at the type locality and to which Trowbridge later applied the name "Galesville" (not approved, Wilmarth, 1938, p. 792), (d) that in naming formations at Eau Claire, Wisconsin Ulrich ignored earlier use of formation names by Wooster (Twenhofel, Raasch and Thwaites, 1935, p. 1691), and (e) Mazomanie sandstone (Wilmarth, 1938, p. 1329; Trowbidge and Atwater, 1934, pp. 45-50) is simply a lithologic phase of the Franconia sandstone which had long been named (Wilmarth, 1938, p. 770) and (f) division of the Cambrian strata below the base of the Franconia into "formations" rather than "members" was premature in that the lines of divisions set up are not laterally persistant and cannot be traced throughout Wisconsin. (figure 7) In general it is clear that the confusion largely orginated from reconnaisance studies which set up a stratigraphic succession on the basis of fossils only instead of the basis of stratigraphy and lithology. We should expect that the faunal divisions would cross the litholgic units at a low angle (Berg, 1954). The strata of the entire Cambrian

Table 6

Cambrian below Francona* Potsdam or Dresbach where indivisible.

Minnesota			Illinois	Wisconsin			
Old	New			Old	Ulrich	Twenhofel	This report***
Unnamed		Galesville	Galesville	First Potsdam	Dresbach		Galesville
Dresbach	Dresbach	EauClaire Mt. Simon	Eau Claire	Eau Claire	Eau Claire	Dresbach*	Eau Claire
Hinckley**			Mt. Simon Fond du Lac	second Potsdam or Eau C. grit	Mt. Simon		Mt. Simon

* includes Galesville, Eau Claire, Mt. Simon members like Minnesota

** Hinckley now regarded as Keweenawan

*** Shown as formations on well logs and name Dresbach used only where indivisible section are lentivular and highly variable in detail. Only broad divisions can be distinguised as "formations". In the solution of the controversy over the Mendota dolomite subsuface geology had an important part. The log of the Conover well, near the railroad cut at Mendota, demonstrated that the Mendota dolomite, which is exposed on the shore of Lake Mendota a mile to the southwest, extends below the recognized Jordan sandstone in the cut instead of above it as the former correlation demanded (Twenhofel, Raasch and Thwaites, 1935, pp. 1705-1708), Kansas Geol. Society 1935, pp. 129-132, Raasch, 1935, pp. 310-311) agreement between the outcrop and well cuttings proved very close and this well log virtually settled that controversy.

Jordan and Trempealeau

Introduction. The name Jordan was applied by Winchell (Wilmarth, 1938, pp. 1055-1056). The name was derived from rather poor exposures near Jordan, Minnesota, along the Minnesota River. At first the underlying strata were named St. Lawrence from St. Lawrence, Minnesota (Wilmarth, 1938, pp. 1879-1880) but later Ulrich substituted the name Trempealeau for the sub-Jordan strata. This latter name was first used in print by the present writer (Wilmarth, 1938, pp. 2178-2179; Ulrich, 1934, pp. 72-85. Twenhofel, Raasch and Thwaites (Twenhofel, Raasch and Thwaites, 1935, p. 1705-1714) expanded the original usage to include all strata up to the Prairie du Chien dolomite under the name Trempealeau. This usage was followed in many well logs, and by the U. S. Geological Survey but the writer now desires to return to Ulrich's original usage and make the Jordan a separate formation. Reasons for this comprise: (1) the Jordan sandstone is a distinct unit sharply divided from underlying strata, (2) the Jordan is very important in topography for it is a cliff-maker, (3) the Jordan sandstone is an important aquifer in parts of western Wisconsin and adjacent states, (4) the Jordan is much thicker in western Wisconsin than the Trempealeau if we define the base of the latter as the original St. Lawrence dolomite member since called Black Earth and Nicollet Creek. It should be recognized that in eastern Wisconsin the entire sequence is much thinner and division of a separate Jordan formation is not everywhere practicable in well logs. In this case the Twenhofel usage of the name Trempealeau is preferable. Trouble is also encountered over the status of the Madison sandstone member at the top of the Jordan. Some attempted to trace this sparingly fossiliferous dolomitic sandstone over a wide area wheras others were not convinced that it is present except near Madison, Wisconsin, where it was long used as a building stone. Its discrimination is difficult in well logs. The following table presents the members here recognized.

Jordan formation

Madison or Sunset Point member-sandstone, fine-grained, dolomitic to 15 feet.

Jordan sandstone, fine to coarse-grained, generally non-dolomitic; the lower fine-grained portion called Norwalk by Ulrich (Wilmarth, 1938, p. 1517) to 120 feet

Trempealeau formation (as originally defined)

Lodi "shale", siltstone, thin-bedded, very dolomitic, red and yellow-gray at surface, red and blue-gray at depth to 50 feet

St. Lawrence or Balck Earth, Nicollet Creek or Mendota
dolomite, some sand and glauconite, not everwhere
discriminated to 15 feet

The table above shows a plausable reason for the extreme confusion of nomenclature: these strata are very variable in lithology and consequently in faunal assemblage. Some of the published sections depend entirely on fossils and are inapplicable to subsurface work where fossils cannot be found. From the standpoint of sedimentation the two formations represent (with the exception of the fine-grained Madison beds) the emergent phase of a cycle of marine invasion, that is the retreatal phase with sand grains for the most part increasing is size toward the top. There has been some dispute as to the proper base of the formation. The Minnesota survey long included much of the glacuconitic sandstone below which is now assigned to the Franconia formation. Ulrich included much less and limited the name Trempealeau by a few feet of glauconitic siltstone-conglomerate below the original St. Lawrence. According to Raasch (1951) the Trempealeau includes descending: Sunset Point (former Madison beds); Jordan, Lodi, St. Lawrence, and Arcadia. The reason for the change in name at the Madison was that the Madison limestone of the west is much better known for it is a thicker and more extensive formation. The name Madison sandstone, however, has priority in date of application. (Wilmarth, 1938, pp. 1263-1264). Nelson (1956) suggested more changes and listed in desending order: Sunset Point, Jordan, Lodi, Black Earth, excluding the basal greensand conglomerate. The change of name of the lowest member was justified by the former usage of St. Lawrence which was never clearly defined. Twenhofel attempted to return to the original usage of St. Lawrence. The name has priority in time of use over Mendota (Wilmarth, 1938, p. 1346). The names Black Earth (Wilmarth, 1938, p. 200) and Nicollet Creek were never extensively used. (Stauffer, Swartz and Thiel, 1939, pp. 1238-1239). There has been difficulty over the type locality of the Lodi (Wilmarth, 1938, p. 1206). Ulrich was not specific on this point but probably had in mind exposures at Lodi Mill Sauk County Wisconsin rather than at the village of Lodi, Columbia County. The status of the Madison or Sunset Point member is unsettled for it does not fit with the cyclic concept either in grain size, heavy minerals, or fauna. T e writer suggests that it is lagoon deposits behind sand bars and barriers.formed by the waves from the coarser sands below but still open to the sea.

Character. The Madison or Sunset Point member is about half dolomite where fresh. The heavy minerals are the same as the underlying Jordan but differ in relative amounts. The Jordan proper is fine to coarse-grained sandstone only locally cemented by dolomite. At depth this formation is light gray to white. On the outcrop the colors contain much red and yellow. The formation thickness greatly toward the west but no isopach was prepared for it was included in the Trempealeau on Figure 8. The Lodi member is sharply separated below. It consists of dolomitic siltstone, red and blue-gray at depth, yellow-gray and red on the outcrop. It was used as a building stone in early days and many quarries were then made. Later the material was used to surface roads including the sholders next to cement pavement. In the exposures there are many large openings along joints. Some have also been reported from wells. None of them shows much indication of solution but the origin is unknown. Throughout both Jordan and Trempealeau formations there are many layers of conglomerate. The pebbles are siltstone and dolomitic fine-grained sandstone in a matrix of coarser-grained sandstone. The layers are lenticular and do not appear to mark any important break in deposition. Glauconite is confined to small grains sparingly present in the Lodi. Larger particles are locally present in the St. Lawrence member.

The St. Lawrence (Mendota, Nicollet Creek, or Black Earth) member is fairly pure thick-bedded dolomite with some medium-grained quartz and glauconite grains. Although readily distinguished in outcrops where the strata have been weathered it is hard to separate from the Lodi member in sample cuttings. Down the dip away from the outcrop all of the Trempealeau formation becomes very dolomitic and the members can only be separated by insoluble residues. (Twenhofel, Raasch and Thwaites, 1935, p. 1710) These dolomitic strata were formerly confused with the Prairie du Chien (Thwaites, 1927, p. 22). The basal greensand conglemerate layer distinguised by Ulrich has been here included in the underlying formation (Ulrich, 1934, pp 89-90; Twenhofel, Raacsh and Thwaites, 1935, p. 1705)

<u>Distribution.</u> In surface distribution the Jordan and Trem-

pealeau strata outcrop in a narrow band around the eroded margin of the Prairie du Chien. No Jordan or Trempealeau can be found in the region around Milwaukee. Where these formations underlie the St. Peter the Trempealeau dolomite has been confused with the Prairie du Chien from which it differs in the presence of quartz silt and some glauconite and the absense of chert.

Thickness. The accompanying isopach map shows the thickness of the Trempealeau formation of Twenhofel, Raasch and Thwaites which varies from absence in eastern Wisconsin to a recorded maximum of about 200 feet to the west. Whether this variation is due to erosion or to differences in deposition is not certain. Probably both causes cooperated. The greater thickness in western Wisconsin is certainly due to the greater thickness of the Jordan member (or formation.)

Well logs. The following logs of wells show the nature of the Trempealeau formation. The top is fixed by the base of dolomite or sandstone with oolitic chert and the bottom by the sudden increase in amount of glauconite and quartz sand.

Partial log of city well No. 1, New Richmond, Wis.

	Thickness, feet	Depth, feet
Dolomite, light gray (Prairie du Chien)		247
Sandstone, medium-grained, light gray, dolomitic (Jordan)	18	265
Sandstone, medium-grained, white	15	280
Sandstone, fine to medium-grained, white, dolomitic	5	285
Sandstone, fine to medium-grained, white	10	295
Sandstone, fine to very fine-grained, light gray, d dolomitic	15	310
Dolomite, sandy, light green-gray (Lodi?)	25	335
Dolomite, sandy, dark gray (St. Lawrence?)	15	350
Dolomite, very sandy, green-gray, glauconitic	30	380

Sandstone, fine-grained, green-gray, dolomitic	20	400
Sandstone, very fine-grained, dark green, glauconitic, dolomitic (Franconia)	5	405
Total Trempealeau 158 feet		

Sandstone, fine-grained, green-gray, glauconitic, dolomitic (Franconia)

Partial log of well of Platteville Milk Products Co., Platteville, Wis.

Dolomite, light gray, pink; chert, white (Prairie du Chien)		435
Sandstone, fine to medium-grained, light gray, dolomitic (Jordan)	15	450
Siltstone, very dolomitic, gray (Lodi)	10	460
Sandstone, fine-grained, red, very dolomitic	5	465
Sandstone, very fine to fine-grained, gray, very dolomitic	10	475
Dolomite, some fine sand, much silt, purplish-red and gray	70	545
Dolomite, much quartz silt, glauconitic, purplish red and gray (St. Lawrence)	45	590
Total Trempealeau 155 feet		

Sandstone, fine-grained, silty, green-gray, dolomitic, glauconitic (Franconia)

Partial log of city well No. 4, Neenah, Wis.

Dolomite, sandy pink and gray (Prairie du Chien)		272
Sandstone, coarse to fine-grained, gray, dolomitic, pyritic (Jordan)	23	295
Sandstone, fine-grained, gray, very dolomitic	5	300
Dolomite, very sandy, glauconitic, red and gray (Lodi and St. Lawrence)	10	310
Total Trempealeau 38 feet		

Sandstone, fine-grained, green-gray, pink spots, glauconitic; shale, pink and green-gray, dolomitic, pyritic (Franconia)

Partial log of well at Marinette County Farm, Peshtigo, Wis.

Dolomite, light gray and light pink (Prairie du Chien)		410
Dolomite, much silt, dark gray (Trempealeau) (Lodi and St. Lawrence)	5	415
Dolomite, silty, dark gray, black specks	15	430
Sandstone, fine-grained, very dolomitic, light gray	5	435

Dolomite, sandy, light gray	10	445

Total Trempealeau 35 feet

Sandstone, fine to medium-grained, light gray, dolomitic (Franconia)

Franconia sandstone

Introduction. The name "Franconia" was first applied by Berkey in 1897 (Wilmarth, 1938, p. 770-771) to the lower part of the strata which are now included in that formation. For a long time the Minnesota geologists restricted the name to the strata which were first included and the overlying beds were placed in the St. Lawrence formation. (Kansas Geological Society, 1935) Several subdivisions or members have been proposed for the Franconia formation. Twenhofel and Thwaites (1919) distinguised in the Sparta-Tomah region of western Wisconsin the following lithologic subdivisions: Upper Greensand, Yellow sandstone, Lower Greensand, and Micaceous Shale. Twenhofel, Taasch and Thwaites (1935, p. 1697-1705) used a faunal subdivision, descending: Bad Axe, Hudson, Goodenough, and Ironton members. The last was added as the earlier classification had placed the basal beds in the underlying formation. The first classification is of local value only and that the second is mainly inapplicable to subsurface studies where fossils cannot be found. Ulrich (1934, p. 83) concluded that the thin-bedded fossiliferous Franconia of western Wisconsin is unconformably replaced by thicker-bedded dolomitic "Mazomanie" sandstone in eastern Wisconsin. Field work by the writer showed that this latter conclusion was an error due to poor exposures of the basal Franconia strata which resemble the Lodi beds of the Trempealeau. Berg (1954) divided the Franconia into descending: Reno, Tomah, Birknose, and Wood Hill members with the Mazomanie facies interf -gering the upper members. Of these the Tomah member is the micaceous shale (siltstone) of the first subdivision above. The Minnesota Survey (Stauffer, Schwartz, and Thiel, 1939) used descending: Bad Axe, Hudson, Taybors Falls (original Franconia) and Ironton. The proposed divisions are hard or impossible to use in the subsurface with the exception of the Ironton (Wood Hill) member.

Character. In the western and southern parts of Wisconsin the Franconia is characterized by its fine grain and glauconite content. The sandstones vary in color from light gray, in many places specked with glauconite making what drillers call "pepper and salt rock", through green-gray to red. The Birkmose, and Reno members are glauconitic and the Mazomanie facies much less so. The Tomah member is a siltstone, not a true shale or mudstone. In northeastern Wisconsin glauconite is not as abundant as it is in western Wisconsin and the lower part of the formation is in many places nearly free of it. Parts of this are dolomitic siltstone and are locally a true dolomite. Dolomite cement is present throughout the formation but is most conspicuous in the Mazomanie facies which outcrops in many prominent cliffs and crags for instance the Natural Bridge near Leland. On the weathered surface the Franconia appears much more sandy than in drill cuttings where silt and fine sand has not been removed by weathering. Berg (1954, p. 868) shows that the faunal subdivisions transgress the lithologic divisions at a slight angle. The Franconia is the trangressive part of a cycle of marine invasion. The

Franconia is here defined as the strata between the lowest dolomite or silty dolomite of the Trempealeau and the base of the poorly sorted Wood Hill (Ironton) member whose coarse sand grains form an invaluable marker in subsurface studies.

Distribution. The Franconia formation caps many bluffs in a U-shaped ared which surrounds the Central Plain of Wisconsin. This relationship is due to the dolomite cement plus the impermeable nature of the siltstone of the Tomah member (Micaceos Shale). This layer forms an important spring line in much of western Wisconsin. Franconia strata are absent in the vicinity of Milwaukee.

Thickness. The accompanying isopach map (figure 9) shows the thickness of the Franconia formation. The minimum is about 45 feet in southeastern Wisconsin and the maximum reaches almost 200 feet in the western part of the state. Little regularity in the changes of thickness can be discerned although it is possible that in many old records the top and bottom were not as accurately discriminated as they are now.

Well logs. The following well logs show strata correlated as Franconia.

Partial log of city well No. 1, New Richmond, Wis.

	Thickness, feet	Depth, feet
Sandstone, very fine-grained, dark green-gray, glauconitic, dolo itic (Trempealeau or possibly top of Franconia)		405
Sandstone, fine-grai ed, green gray, dolomitic (Franconia)	20	425
Sandstone, fine-grained, green, glauconitic, dolomitic	15	440
Sandstone, fine-grained, light gray, glauconitic, dolomitic	45	485
Shale, sandy, light green-gray, dolomitic	10	495
Sandstone, fine-grai ed, gray, glauconitic, dolomitic	15	510
Shale, sandy, green-gray, dolomitic, glauconitic	15	525

Sandstone, fine to coarse-grained, light gray, glauconitic, dolomitic	10	535
Shale, very sandy, gray	5	540
Sandstone, very coarse to medium-grained, gray	10	550

Total Franconia 145 feet

Sandstone, medium to fine-grained, light gray (Galesville)

Partial lög of city well No. 3, Viroqua, Wis.

Siltstone, light gray, dolomitic, glauconitic (Trempealeau)		355
Sandstone, fine-grained to silty, red, green-gray, glauconitic, dolomitic (Franconia)	10	365
Sandstone, fine-grained to silty, green-gray, shaly, glauconitic, dolomitic	40	405
Sandstone, fine-grained to silty, light gray, glauconitic, dolomitic	20	425
Sandstone, silty to fine-grained, green-gray, glauconitic, dolomitic	30	455
Sandstone, fine-grained to silty, gray, dolomitic, glauconitic	20	475
No samples	10	485
Siltstone, green-gray, dolomitic, micaceous (bottom of well)	10	495

Franconia at least 140 feet

Partial lög of well Nol 3, Wisconsin State Prison, Waupun, Wis.

Siltstone, sandy, light gray, glauconitic, dolomitic (Trempealeau)		400
Sandstone, fine to medium-grained, light gray, very dolomitic (Franconia)	45	445
Sandstone, silty to fine-grai ed, light gray, dolomitic	5	450
Sandstone, very fine-grained, pink, dolomitic	10	460
Sandstone, fine to medium-grained, pink, dolomitic	10	470
Sandstone, fine to coarse-grained, light gray, dolomitic	10	480

Total Franconia 80 feet

Sandstone, medium to fine-grained, white (Galesville)

Partial log of well at Marinette County Farm, Peshtigo, Wis.

Dolomite, sandy, light gray (Trempealeau)		445

Sandstone, fine to medium-grained, light gray, dolomitic (Franconia)	10	455
Sandstone, medium to fine-grained, light gray, dolomitic	10	465
Sandstone, fine to medium-grai ed, gray, dolomitic	25	490
Sandstone, fine-grained, light gray	15	505
Sandstone, medium to coarse-grained, light gray, dolomitic	10	515
Sandstone, medium to fine-grained, light gray, dolomitic	10	525
Sandstone, coarse to fine-grained, light gray	10	535

Total Franconia 90 feet

Sandstone, fine to medium-grained, light gray (Galesville)

Dresbach formation

Introduction. The differences in usage of the name "Dresbach", taken from the little village of Dresbach, Minnesota, northwest of LaCrosse, Wisconsin, have already been explained briefly. (table 6) In this report the name is used in the same way as did Twenhofel, Raasch, and Thwaites (1935, pp. 1691-1693) to include all Cambrian strata between the bottom of the coarse-grained, poorly-sorted Ironton (Wood Hill) member of th Franconia and the pre-Cambrian basement, The basement igneous and metamorphic rocks are overlain west of the Wisconsin arch by red sandstones (Red Clastic series of Minnesota) to which various ages have been asigned. (Trowbrige and Atwater, 1934, pp. 38-45) Subdivision of the Dresbach strata into three distinct formations descending: Dresbach, Eau Claire, and Mt. Simon has long been the practice in Wisconsin. Such a subdivision is impracticable in central Wisconsin where the entire sequence is sandstone (figure 7) and fixing the dividing lines of distinct formations is everywhere difficult. The sequence appears have resulted from a single episode of marine transgression where the Mt. Simon is the transgressive phase, the Eau Claire the deep water deposit and the Galesville is the emergent or recessive phase. The Eau Claire is confined mainly to the flank of the Wisconsin arch. The name "Galesville" (Wilmarth, 1933, p. 792) for was suggested by Trowbridge and Atwater. Only the fact of long usage of Dresbach kept the name, Galesville, from previous application in Wisconsin. Exposures of the Galesville strata in the cliff at Galesville, Wisconsin are much better than were ever present at Dresbach, Minnesota, and are more likely to be permanent. It seems to be high time to adopt the newer nomenclature as has been done in Illinois. (see table, p. 73). The names, Galesville, Eau Claire and Mt. Simon ar thus demoted to "member" status for subsurface geology and the word Dresbach is now used only where the sequence does not allow subdivision in the well log.

Galesville member

Introduction. The name "Galesville" was proposed by Trowbridge and Atwater in 1934 (Wilmarth, 1938, p. 792) and is synomomous with "Dresbach" as employed by Ulrich and by the Wisconsin Geological Survey in well logs made previous to 1955.

Character. The Galesville member of the Dresbach formation consists of coarse to fine-grained sandstone with local yellow brown to yellow-grey spots and stratas. Some of these may be due to decomposition of iron-bearing minerals, chiefly pyrite. Dolomite cement is rare. In most localities the sandstone is pure white and cliffs of this sandstone are very conspicuous below the gray strata of the Franconia. Locally the entire formation is red. This is the "first Potsdam sand" of well drillers. (Anderson, 1915, p. 100-101)

Distribution. Strata of Galesville age outcrop for the most part in cliffs and slopes where protected by a caprock of Franconia. Excellent exposures of this relation occur in many parts of central Wisconsin notably near Camp Douglas.

Thickness. The Galesville member is fairly uniform in thickness, around 75 to 100 feet. No isopach map has been prepared on account of the gradational lower boundary. The Galesville member is thin in southeastern Wisconsin. Will logs will be presented for the entire group.

Eau Claire member

Introduction. The name Eau Claire was originally applied to the strata by Wooster in 1878 (Twenhofel, Raasch and Thwaites, 1935, p. 1694, Wilmarth 1938, p. 657) It included shaly strata which are much finer-grained than the overlying Galesville and where weathered contain much more dolomite

Character. In the subsurface there are local thin dolomite layers. Many of the shales are silty especially in eastern Wisconsin. All shales are lenticuler and cannot be traced for more than a few hundred feet. Some shales are red and dolomitic; these have long been called "red Marl" by well drillers. The Eau Claire strata are perhaps the most fossiliferous rocks of the entire Cambrian sequence in Wisconsin; the only near rival is the Franconia. South of the Baraboo quartzite range the amount of shale appears to reach a maximum which thins in both directions as shown in the cross section. (figure 5) Strata of the above character are absent in central Wisconsin and are replaced by clean sandstone as may be seen at the Wisconsin Dells and in the high bluffs of Juneau and Adams counties farther north. Some sandstone beds of the Eau Claire member somewhat resemble the Galesville. Many of these sandstones have partings of shale or of pink to grey dolomite and most have a dolomite cement.

Distribution. Eau Claire strata underlie considerable areas of the Central Plain of Wisconsin. In places they form a distinct bench below the steeper slopes of the Galesville and they probably cap some bluffs.

Thickness. Owing to the gradational nature of the boundaries of the Eau Claire member it is very difficult to give an average thickness. The estimated range is 250 to 350 feet, althoug h some well logs have indicated at nearly 400 feet. It reaches 500 feet in Illinois (Weller, map. 1945)

Mt. Simon member

Introduction. The sandstone of the Mt. Simon member was named by Ulrich (Wilmarth, 1938, p. 1444), replacing the older name of Eau Claire grits used by Wooster (Twenhofel, Raasch and Thwaites, 1935, p. 1693) This is the "second Potsdam sand" of well drillers. (Anderson, 1919, p. 101)

Character. The Mt. Simon strata are relatively pure sandstone with little dolomite cement which is gradational below the Eau Claire member. The formation seems to have more coarse-grained sandstone in the west of Wisconsin than it does to the east. The individual layers pinch out laterally. The coarse beds nearly disappear east of Madison. Shale is not uncommon, especially south of the Baraboo quartzite area. The shale beds are lenticular and for the most part non-dolomitic unlike those of the Eau Claire member. Some are dark red, others green-gray or gray. It is clearly the transgressive member of a marine invasion. Conglomerate is uncommon except near to high spots of the underlying pre-Cambrian rocks.

Thickness. The Mt. Simon is 234 feet thick at its type locality near Eau Claire but thickens greatly to the southeast, especially in Illinois where it may be over 2000 feet (Weller, map, 1945) It appears to be absent in northeastern Wisconsin where the entire Dresbach formation is only about 200 feet thick. In northern Illinois (Templeton, 1951) found about 5400 feet of Dresbach in Illinois wells. He proposed to dividing the Mt. Simon part of this sequence into a number of members of which the lower ones do not extend into Wisconsin. The basal member is arkose or "granite wash". He also discussed the possible Keweenawan age of part of the formation, a correlation suggested in 1923 (Weller, map, 1945, Thwaites, 1923, pp. 554-555, Trowbridge and Atwater, 1934, pp. 31-38) Isopach maps, although attempted by some, are impracticable for the Dresbach formation or any of its members. (Kansas Geol. Soc. 1935, Foley, Walton, and Drescher, 1952, p. 29) The principal cause of uncertainty is the irregularity of the surface of the pre-Cambrian rocks. In much of eastern Wisconsin wells disclose that the entire Dresbach formation is fine-grained. This is probably due to the presence of undiscovered pre-Cambrian highs caused deposition in sheltered waters in the lee of islands. Discrimination of members is difficult in this area.

Well logs. The following logs, are at places where the wells have passed through the entire thickness of the Dresbach formation.

Partial log of Unit Well No. 10, Madison, Wis.

Sandstone, coarse to fine-grained, yellow-gray dolomitic (Franconia)		270
Sandstone, medium to fine-grained, white to light gray (Galesville)	110	380
Sandstone, fine to medium-grained, light grgy, dolomitic (Eau Claire)	5	395
Sandstone, fine to medium, white, dol mitic	10	395
Sandstone, very fine-grained, much silt, gray, dolomitic	20	415
Sandstone, very fine-grained, much silt, gray, dolomitic	5	420
Shale, gray, dolomitic	15	435
Sandstone, medium to fine-grained, white	50	485
Sandstone, medium to fine-grained, light gray, some dolomitic layers	80	565
Sandstone, fine to medium-grained, light gray, dolomitic	5	570
Sandstone, medium to fine, white, some dolomitic layers (Mt. Simon)	35	605
Sandstone, fine to medium-grained, white	10	615
Sandstone, fine to medium -grained, light grgy, dolomitic	30	645
Sandstone, fine to very fine-grained, white, dolomitic	15	660
Sandstone, medium to fine-grained, white	5	665
Sandstone, medium to fine-grained, light gray, pink, dolomitic	5	670
Sandstone, very fine to fine-grained, white	5	765
Sandstone, medium to fi e-grained, white	25	700
Sandstone, fine to medium-grained, light gray	60	760
Sandstone, medium to fine-grained, white	5	765

Sandstone, fine to medium-grained, light gray	5	770
Sandstone, medium to fine-grained, light gray	5	775
Sandstone, medium to fi e-grained, some fine-grained, white	15	790
Sandstone, medium to coarse-grained, light gray	5	795
Sandstone, fine to coarse-grained, light gray; shale, red	10	805
Sandstone, fine to coarse-grained, light gray	10	815
Sandstone, coarse to fine-grained, pink-gray	10	825
Sandstone, very fine to medium-grained, light pink-gray	5	830
Sandstone, coarse to medium-grained, light gray	5	835
Sandstone, fine to medium-grained, light gray	5	840
Sandstone, medium to fine-gra'ned, light gray	20	860
Sandstone, fine to medium-grained, white	5	865
Sandstone, fine to coarse-grained, pink and grya	5	870
Sandstone, fine to coarse-grained, gray	10	880
Sandstone, medium to fine-grained, light gray	10	890
Sandstone, fien to coarse-grained, light gray	5	895
Sandstone, fine to medi m-grained, light gray	15	910
Sandstone, medium to fine-grained, light gray	5	915
Sandstone, fine-grained, light gray	10	925
Sandstone, very fine to coarse-grained, light gray	10	935
Sandstone, medium to coarse-grained, light gray	15	950
Sandstone, fine to medium-grained, much silt, light gray	15	965
Sandstone, medium to fine-grained, light gray	10	975
Sandstone, very fine to coarse-grai ed, silty, light gray	10	985
Sandstone, medium to fine-grained, light gray	12	997
Total Dresbach 727 feet		
Granite, pink (pre-Cambrian)	—	—

Partial lòg of well No. 3, Wisconsin State Prison, Waupun, Wis.

Sandstone, coarse to fine-grained, light gray, dolomitic (Franconia)		480
Sandstone, medium to fine-grained, white (Galesville)	55	535
Sandstone, fine to medium-grained, light gray	20	555
Sandstone, medium to fi e-grained, white	25	580
Sandstone, fine to medium-grained, light gray, dolomitic (Eau Claire)	35	615
Sandstone, fine-grained, light gray, dolomitic	15	630
Sandstone, fine to medi m-grained, light gray	15	645
Sandstone, medium to coarse-grained, light gray	25	670
Sandstone, fine to medium-grai ed, light gray	20	690
Sandstone, fine-grained, light gray	20	710
Sandstone, medium to fine-grained, light gray (Mt. Simon)	10	720
Sandstone, fine to medium-grained, light gray	5	725
Siltstone, light gray, dolomitic	15	740
Sandstone, fine-grained, much silt, light gray	5	745
Sandstone, medium to fine-grained, light gray	47	792

Total Dresbach 322 feet

Quartzite, purple; shale, green-gray (pre-Cambrian)

Partial log of Wisconsin Oil and Refining Co., Jensema No. 1 well, Gibbsville, Wis.

Sandstone, medium to coarse-grained, light gray, dolomitic, glauconitic (Franconai)		1385
Sandstone, medium-course to fine-grai ed, white (Galesville)	60	1445
Sandstone, medium to fine-grained, light gray	10	1455
Sandstone, fine to medium-grained, light gray	20	1475
Sandstone, medium to fine-grianed, light gray	10	1485
Sandstone, medium to fine-grained, white	10	1495
Sandstone, madium-coarse to fine-grained, white	10	1505

Sandstone, medium to fine-grained, light gray	10	1515
Sandstone, medium to fine-grained, light gray, red, dolomitic (Eau Claire)	10	1525
Sandstone, fine to medium-grained, light gray	10	1535
Sandstone, medium to fine-grained, white	20	1555
Sandstone, medium to fine-grained, light gray, red, dolomitic	20	1575
Sandstone, fine to medium-grained, white to light gray	50	1625
Sandstone, fine to medium-grained, light gray	10	1635
Sandstone, fine-grained, light gray	20	1655
Sandstone, fine to medi m-grained, light gray	10	1665
Sandstone, fine to medium-grained, light pink	30	1695
Sandstone, very fine to medium-grained, light pink	10	1705
Sandstone, medium to fine-grained, light gray (Mt. Simon)	80	1785
Sandstone, medium to fine-grained, light pink	10	1795

Total Dresbach 410 feet

Granite (pre-Cambrim)

Partial log of Liebmann Packing Co. well, Green Bay, Wis.

Sandstone, medium to coarse, light gray (Franconia)		830
Sandstone, medium to fine-grained, white (Galesville)	25	855
Sandstone, finr to medium-grained, light gray	20	875
Sandstone, medium to fine-grained, white	35	910
Sandstone, fine to medium-grained, white	15	925
Sandstone, medium to fine-grained, white	5	930
Sandstone, fine to medium-grained, white	25	955
Sandstone, medium to fine-grained, white	30	985
Sandstone, medium to fine-grained, light pink (Eau Claire?)	25	1010
Sandstone, medium to fine-grained, pink	15	1025
Sandstone, fine to medium-grained, pink-gray	10	1035

Sandstone, medium to fine-grained, white	15	1050
Sandstone, fine to medium-grained, pink-gray	5	1055

Total Dresbach 225 feet

Granite, pink (pre-Cambrain)

Pre-Cambrian

Introduction. Rocks of pre-Cambrian age form an irregular floor beneath the younger Paleozoic formations of Wisconsin. These rocks are crystalline: granite, gneiss, schist, quartzite, etc. (see figure 10) This surface is commonly spoken of as a "peneplain" and its regularity has been much overemphasized by many writers. As a matter of fact it is quite irregular in detail with local relief of over 1000 feet.

Character. The rocks of the "basement", as it is often called, comprise besides those listed above, some slate, other metamorphized sediments, possibly including iron formation and some red sandstone and shale in far northwestern Wisconsin. No well has ever been proved to have reached pre- Cambrian rocks southeast of a line roughly from Menomonee Falls to Platteville Most water wells stop as soon as pre-Cambrian is reached. A few oil tests have been carried deep into pre-Cambrian especially those at Avoca (granite Gneiss), Gibbsville (granite) and Porterfield (grainite). One of the city wells in Hartford was carried 878 feet into quartzite. The principle areas of quartzite are around (a) Hartford and (b) Fond du Lac. Some of the ancient quartzite hills appear to be terraced and truncated by flat areas which the writer suggests are the product of Paleozoic marine shore erosion. (Thwaites, 1935, p. 401-402; Thwaites, 1931, and 1940) Aside from northwestern and southern Wisconsin there is no definite evidence of a pre-Cambrian or pre upper Cambrian sandstone which is either conformable or unconformable below the recognized lighter-colored marine sandstones. In Illinois deep wells show a gradation in colors and a low feldspar content of the sands which facts discourage the explanation. (Weller, map, 1945) Some Illinois geologists applied the name "Fond du Lac" to the lower sandstones which are absent in Wisconsin. This name was once proposed by Winchell for rocks near Fond du Lac, Minnesota (Wilmarth, 1938, p. 747) (Trowbridge and Atwater, 1934, pp. 26-31) The rocks found in deep wells in Illinois are unlike those of the original locality and there seems no advantage in reviving this term. Some well drillers have proposed to "drill through the granite" and find what lies below. The great width of granite areas laid bear by erosion in northern Wisconsin demonstrates the futility of any such effort for thickness may well be as great. The Gibbsville well penetrated close to half a mile of granite without any important change. Any other expensive tests would undoubtedly disclose nothing of value, simply more hard rock, possibly slightly different but nevertheless non-water-bearing and apparently devoid of valuable minerals. Should iron ore be discovered, as it was near Baraboo, in the concealed pre-Cambrian it is well to realize that mining below so much water-bearing rock is likely to be very expensive.

Disintegration of pre-Cambrian surface. The fact that the surface of much of the concealed pre-Cambrian is deeply disintegrated was discussed with references by the writer (Thwaites, 1931, pp. 745-748) Little new can be added except that incomplete samples from the well at Casco Junction, Kewaunee County, show disintegrated granite, 1660 feet below the present surface. The difficulty of explaining why the marine waters which deposited the Cambrian sandstones did not remove all older regolith is still a major argument against the conclusion that this is a pre-Cambrian soil profile. It is possible that it is due to subsurface weathering along the contact of the crystalline rocks which contain compounds of the alkalies and the waters of the Cambrian which contain dominantly the salts of the alkaline earths, Calcuim and Magnesium. The problem demands further chemical research. A similar condition is described by Sharp in the Grand Canyon of Arizona who ascribes the weathered material to surface pre-Cambrian weathering. (Sharp, 1940)

Deposits of Unknown Age

Introduction. Besides the well-known bed rock formations which underlie almost all of Wisconsin there are some other sediments have been met with in wells. No well is known to have encountered the Windrow gravels (Thwaites and Twenhoefel, 1921) and its occurence in small patches on high bluffs is unfavorable for discovery in water wells. Two wells at Baldwin found sandstone and shale of unknown age.

Character. The sandstone which overlies the Prairie du Chien dolomite at Baldwin is eithologically unlike the St. Peter sandstone and shale in the remainder of the state. No fossils could be found so that the only means of age determination lies in the heavy minerals. A sample from 105 to 110 feet depth in Well No. 2 shows: garnet 53%, leucoxene 16%, magnetite-ilmenite 16%, horneblende 8%, tourmaline 5%, zircon 5% with minor amounts of staurolite, rutile, zircon, kyanite, and epidote. This assemblage is unlike any previously known St. Peter. A sample from Well No. 1 between 89 and 90 feet depth shows: leuconxence 42%, magnetite-ilmenite 16%, hornblende 12%, garnet 8%, tourmaline 7%, zircon 6%, rutile 2%, chlorite 2%, staurolite, 2% with minor amounts of epidote and titanite. This collection is possible for St. Peter. Neither assemblage is like that of known Cretaceous deposits farther west in Minnesota (George Andrews, personal communication.) The deposit is probably filling of an erosion channel in the Prairie du Chien dolomite. The heavy minerals in these samples are unlike those of the sandy deposits contai ing lenses of kaolin once mined near Hersey a few miles to the east. (Buckley, 1901, pp. 234-230) DEtails of the Baldwin wells are given in the following logs.

Partial log of Well No. 1, Dairyland Power Cooperative Diesel Plant, Baldwin, Wis.

	Thickness, feet	Depth, feet
Drift		47
Silt, sandy, light gray	8	55
Shale, silty, yellow-gray	25	80
Sandstone, medium to fine-grained, yellow-gray	9	89
Shale, silty, sandy, dark yellow-gray, dolomitic	1	90
No sample	5	95
Shale, brown, white, yellow-gray	10	105
Sandstone, medium to fine-grained, brown, dolomitic	9	114
Shale, silty, yellow-gray, dolomitic	21	135
Chert, white; dolomite, light gray; sand (Prairie du Chien)	21	

Partial log of Well No. 2, same location

Drift		45
Shale, silty, gray, some yellow-gray (no sample 60-65)	40	85
Shale, silty, gray, dolomitic; sandstone, very fine grained, light gray, dolomitic	15	100
Shale, silty, brown-gray, dolomitic, some quartz pebbles, (no sample 120-125)	55	155
Chert, white; dolomite, light gray (Priairie du Chien)		

Heavy minerals. The writer has had neither time nor apparatus to examine the heavy minerals of the Paleozoic formations and the following notes are based on work of others (Graham, 1933, Tyler, 1936, Wilgus, 1933, Ockerman, 1930, Pentland, 1931) Dresbach formation: Mt. Simon member; dominant zircon and tourmaline, garnet rare. Eau Claire member: garnet and zircon common. Galesville member: zircon major, tourmaline minor, also ilmenite leucoxene high. Franconia formation: garnet dominant, tourmaline important, zircon low except in Baraboo region and in the Ironton member. Trempealeau formation: garnet makes up about 80%, remainder is zircon, tourmaline, leuconxene, and rutile. St. Lawrence member; zircon may reach 25%. Jordan member (or formation) almost no garnet. Madison member (or formation): 50 to 80% zircon, with tourmaline higher than leucoxene and anatase. Garnet is generally below 1% in the Madison with rutile and tourmaline higher than in older formations. Prairie du Chien basal sandstones: 60 to 90% garnet. St. Peter: zircon, tourmaline and leucoxene make up 97% of the heavy minerals; the last two occur mainly in central Wisconsin; the remaining 3% consists of anatase, ceylonite, apatite, rutile, staurolite, and garnet.

Structure

General statement. The maps of Figures 11 and 12 show the elevation of the tops of the St. Peter sandstone in eastern Wisconsin and of the Galesville member of the Dresbach formation throughout the state. They differ slighlty from former maps (Kansas Geological Society, 1935)

Large faults are not common in Wisconsin. One is exposed in a quarry north of Waukesha. The evidence of a fualt between the two wells at Algoma is presented in figure 2. This fault may be related to one which was long ago observed south of New Londoh but the direction of displacement is opposite. The western fault was not shown, however, on the maps with the report on Brown County (Drescher, 1953), although observations on outcrops and well logs by the writer indicate that it extents at least as far east as Greenleaf. Downthrow is to the north. Field work and subsurface studies clearly show that faults which were formerly mapped at Sturgeon Bay and Two Rivers do not exist. The conclusion of faulting at Two Rivers depended upon a drillers log of an old test well which does not agree with several new logs. There is a monoclinal displacement, dipping to the southeast, which trends southwest from Sturgeon Bay. It is clearly shown in outcrops but has not been proved to be a fault.

Many, if not most, of the minor irregularities in structure are explanable by settling over the irregular surface ot the pre-Cambrian basement. Figure 13 shows this condition at Fond du Lac where a large amount of test drilling has been done. The marked anticline in th southwestern part of that city is clearly a result of the buried ridge of quartzite. The minor rolls and depressions of the strata in the city of Oshkosh (figure 14) bould be due to the same cause but not enough wells reach the pre-Cambrian to be certain. The highly disturbed area around Glover Bluff in northwestern Marquette County has been described by Ekern and Thwaites (1930). Its origin is unknown but there is no evidence of an intrusion of igneous rock as has been postulated for some similar structures.

Usage of geologic names. (table on p. 73)

General statement. The application of geologic names to the Paleozoic formations in and around Wisconsin has been most confused. Many geologists have varied in what units they deem "formations" and which they classify only as "members" as well as the identity of formation. The following table is an attempt to reconcile some of these views and is based on recent state maps and reports on underground waters. The names are those distinguishable in well logs. Twenhofel, Raasch and Thwaites presented (1935) a detailed table for the Cambrian formations. Since publication it has been found that two major errors are present in that: first the Minnesota usage at that time was to confine the name Franconia to strata near the base of that formation as recognized in Wisconsin, and second, some Minnesota reports applied the name "Hinckley" to sandstones found in deep wells which are now classed as part of the Mt. Simon member of the Dresbach formation. (Trowbridge and Atwater, 1934, pp. 31-35)

Drilling difficulties, center drift

Introduction. The following summary includes some of the drilling difficulties which have come to the attention of the Survey. The rate of penetration of the several formations depends on the type of drilling machine, the skill of the driller

Table 7

Comparison of usage of formation names in Wisconsin and adjacent states.*

	Wisconsin, 1883	Wisconsin, map, 1912	Wisconsin, Ulrich, 1924	Wisconsin, this report	Minnesota, Startler, 1939 Thier, 1944	Iowa, Norton, 1935	Illinois, map, 1945	Michigan, map, 1936
DEV	Hamilton	Milwaukee	Milwaukee	Milwaukee Thiensville Lake Church	Cedar Valley	Lime Creek Cedar Valley Wapsinicon Wapsipinicon	Cedar Valley Wapsipinicon	Traverse Dundee Detroit River
SILURIAN	Lower Helderburg	Waubakee	Waubekee	Waubekee	absent	absent	absent	absent
	Niagara	Niagara	Guelph Racine Waukesha Byron Mayville	Niagara	absent	Gower Hopkinton Wauconia	Port Byron Racine Waukesha Joliet Kankakee Edgewood	Niagara
ORDOVICIAN	Cincinnati-Hudson River	Cincinnati	Richmond	Richmond (Maquoketa)	Maquoketa	Maquoketa	Maquoketa	Richmond
	Galena	Galena Platteville	Galena Decorah Platteville	Galena (Decorah)*** Platteville	Galena Platteville	Galena Decorah Platteville	Galena Decorah Platteville	Trenton Black River
	St. Peter	St. Peter	St. Peter	St. Peter	St. Peter	Glenwood St. Peter	St. Peter	St. Peter
	Lower Magnesian	Lower Magnesian	Shakopee Oneota	Prairie du Chien	Shakopee Root Valley Oneota Blue Earth Kasota	Shakopee New Richmond Oneota	Shakopee New Richmond Oneota	Prairie du Chien Hermansville
CAMBRIAN	Madison	Madison	Madison** Mendota** Devils Lake**					
	Mendota	Mendota	Jordan Trempealeau	Trempealeau Jordan	Jordan St. Lawrence	Trempealeau	Jordan Trempealeau	
	Potsdam	Potsdam	Mazomanie Franconia Dresbach Eau Claire Mt. Simon	Franconia Dresbach****	Franconia Galesville Eau Claire Mt. Simon	Franconia Dresbach	Franconia Galesville Eau Claire Mt. Simon Fond du Lac?	Munising
PRE-CAMBRIAN	Pre-Cambrian	pre-Cambrian	pre-Cambrian	pre-Cambrian	Hinckley Red Clastics igneous, meta.	pre-Cambrian	pre-Cambrian	pre-Cambrian

* members not shown - see text
** later shown to be duplications
*** not shown on well logs
****members shown on well logs where distinguished

and the tool dresser, the depth of hole, the diameter of hole and the depth of water in the hole. A general summary is impossible although much data from daily reports has been collected.

Drift. In the drift the major difficulties are boulders, sand, and in some instances dense clay. Boulders are found mainly in till. They can be broken by blasting and forced to the side although in so doing a crooked pipe may result from driving past the remnants. Pipe can bend at a noticable angle when driven hard. Dry sand may be rendered stable by adding mud to the hole so thatit is possible to drill ahead of the casing which is later driven down in an open hole. Wet sand, especially if it contains much water, is more difficult. In one well an air jet was used to blow the sand out of the hole. A jet of water should prove better where a source of water is available because it takes less pressure and lifts sand more readily. The relative amount of mud in the wate which is brought up with the bailer is a guide as to where to set a screen in ground or sand. Difficulty in drilling clay is sometimes reported in clay which may aggregate into clay balls, some of them very hard. Addition of sand to the hole may remedy this difficulty.

Limestone and dolomite. In drilling limestone and dolomite difficulties include crooked hole and flat hold. Abrupt bends are very bad for turbine and plunger pumps both of which are driven from the surface. It is largely obviated with modern submersible pumps where the electric motor is placed below the pump so that there are no moving parts above the level of the pump. Crooked hole is to a large extent due to inclined rock layers or crevices which are common in the Niagara and Prairie du Chien dolomites. There is at present no means of forcasing where they may be encountered. Too small a drill stem in a big hole allows the bit to strike at an angle. Flat hole, or rather an eleipitical hole, results from the drill striking in the same place every stroke because of a crack or joint in near the middle of the drill hole. Both crooked and flat holes may be corrected by shooting with light shots or by filling with iron junk or glacial cobbles, and then redrilling. These proceedures result in contamination of smples for some distance below. The check for crooked hole which is specified in most contracts is to lower a length of timber where size is slightly smaller than the hole. It this will go in and out without sticking the hole is accepted. Much more reliable is a survey of the well by methods now common in the oil fields so that its exact departure from vertical is recorded. Observation of declection of the drilling cable means nothing after it toughes one side of the hole. "Star bits" with two cutting edges at right angles have also been used in formations which are much jointed. Trouble with crooked or flat hole is sometimes encountered in sandstone.

Shale. Shale may cause trouble in more than ne way. Certain shales, for instanse the Glenwood at the base of the Platteville dolomite locally cause the dolomite cuttings and sand to stick to the tools and the walls of the hole so that the tools cannot be withdrawn. Hard spots in soft shale might easily deflect t e drill. Many shales like those of the basal

St. Peter cave badly and must be lined. A thin shale may make a big hole where the drill will not strike in the same plane below every time thus slowing drilling. Thin shale beds are often missed in sampling.

Sandstone. With the old cable tool rigs where the drill had to be rested on the bottom of the hole before hoisting much trouble was encounteded when the water level in the hole was declining. Since the water level in the lower formations has been lowered by heavy pumping this condition is common at the top of the St. Peter sandstone. Falling water level causes the sand cuttings to pack around the drill so that they are very difficult to loosen. Being in the state known as "tight packing" a small hole must be drilled alongside to allow them to expand befor the tools can be recovered. Many sandstone cuttings will not stay in suspension and settle to the bottom of the hole making progress very slow and crushing the grains. Clay or bentonite is added to promote suspension and hence speed up the work. This cly may contaminate samples.

Crystalline rocks. Although there is in most places no reason to drill into crystalline rock for water in some parts of the state where the sedimentary rocks are absent this is the only source of wate for farm wells. Progress is at best slow but varies greatly. At places where the rock is not true granite but is schist or gneiss drilling is comparatively easy. Cracks may cause much trouble.

Geophysical logging. In the oil fields where wells are drilled with the rotary method in which sample collection is at best inferior to that with cable tools various geophysical methods are used to supplement sample information. The methods employed embrace: (a) measurment of electrical resistance of the walls of the hole, (b) determination of faint electrical currents in the ground (self-potentisl, (c) radioactivity logs, (d) measurments of diameter of hole by electrical calipers, (e) temperature measurments and (f) inclination of hole from vertical. Very few electrical logs made in Wisconsin in water wells have been reported to the Wurvey. Electrical resistance probably tells more of the nature of the rocks than do any of the others. Dolomite and limestone show high resistance whereas shales are low; sandstone is highest where purest. Uniform resistance indicates uniform lithology and variable resistance indicates diversity of lithology. Self-potential measurments used in the oil fields to determine porosity are unworkable in wells in a city on account of the stray electircal currents of man-made origin. Logs of radioactivity show a peak in shale; none have been reported in Wisconsin, Caliper surveys are limited in the diameter of hole which can be shown because of the construction of the instrument. They indicate soft and caving formations where there is a larger hole than in firm rock. Temperature measurments do not show much variation with depth once the water is stirred up in a large diameter well Attempts to find where the water is entering a well by pouring warm water down the hole and finding at what depth it excapes are unreliable. It the rate of pouring is low all the water may flow into the top aquifer. The present consensus of opinion is that geophysical logs of water wells are very valuable if there is no good sample-controlled geological log. They check where casing is present by the very low electrical resistance of pipe and give some indications of where clean sandstone is present. They may aid in locating caving spots and hence the source of sand which is being pumped as well as in choosing shot points. It seems unlikely that geophysical logs can ever replace sample logs.

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