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THE
BARABOO IRON-BEARING DISTRICT
OF WISCONSIN

BY

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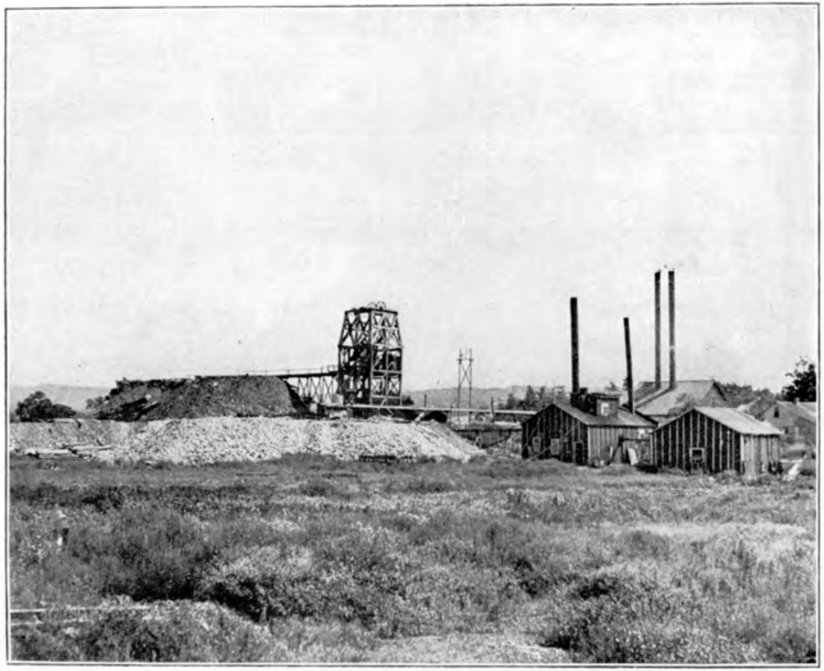

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PREFACE.

The discovery of large deposits of iron ore in iron-bearing formation of pre-Cambrian age in the region of the Baraboo quartzite ranges has come as an agreeable surprise to mining men and geologists. The finding of these valuable deposits in the district is especially noteworthy when it is understood that the region is a well-settled, agricultural district, and that the data which led to the recent successful exploratory work consisted not of a single surface outcrop but was composed entirely of underground exploration by churn and diamond drilling through sandstone and drift.

The iron ore and iron-bearing rock having once been located in the district, it became a matter of the first importance to discover the association of this iron-bearing formation with the outcropping pre-Cambrian quartzite of the prominent Baraboo ranges to which the ore-bearing strata had apparently some definite relation. The object of the present geological report, therefore, besides describing and locating the various formations of the district and giving other useful information, has been to present an account of the pre-Cambrian rock structure of and stratigraphic succession in the district, in order that those engaged in exploration might be able to judge, with a better understanding, the probable location and distribution of the iron-bearing strata and iron ore in the district.

The fact that throughout the district the iron-bearing strata nowhere appears at the surface but lies everywhere buried beneath sandstone and drift, varying from a few feet up to over 600 feet in thickness, and that for this reason the exploration is more expensive than that of other pre-Cambrian iron districts, makes it all the more imperative that as full information as possible concerning the geology of the district should be available and utilized by those engaged in mining in this new and comparatively unexplored area.

All information concerning the buried iron formation and associated rock has been obtained by examination of the mines and drill records of the mining and exploration companies operating in the district. For much valuable information and many courtesies the writer is especially indebted to Messrs. C. T. Roberts and E. A. Pike, of the Illinois Iron Mining Company, to Mr. W. G. La Rue, and to Messrs. E. J. Longyear and J. E. Hodge.

The writer is also indebted to Dr. E. A. Birge, Director of the Survey, for many kindnesses and courtesies shown in the preparation of this report, and to President C. R. Van Hise for suggestions and kindly criticisms.

THE BARABOO IRON-BEARING DISTRICT OF WISCONSIN.

CHAPTER I.

INTRODUCTION AND GENERAL GEOLOGIC FEATURES.

INTRODUCTION.

The following report describes the Baraboo district of southern Wisconsin, a district which has lately come into prominence on account of the discovery of iron ore. Field work was begun in the district May 4, 1903, and the larger part of three months was devoted to the mapping of outcrops of quartzite and a study of the geologic structure of the district. In the field the writer was assisted by Mr. W. D. Smith.

The topography of the district shown on the accompanying map had previously been sketched by Messrs. W. H. Griffin, V. H. Manning, R. C. McKinney, and Robert Muldrow, of the topographic corps of the United States Geological Survey, the several 15′ quadrangles represented in the district having been surveyed at intervals between 1892 and 1900.

GEOGRAPHY AND TOPOGRAPHY.

The Baraboo district lies near the center of the southern half of Wisconsin, in Sauk and Columbia counties, along the parallel 43° 30′ north latitude, and between the meridians 89° 30′ and 90° west longitude. The length of the district east and west is approximately 28 miles, and the width varies from two miles at the east end to 10 and 12 miles in the middle and at the west end. The area of the district, as described in this report, and as outlined by the distribution of pre-Cambrian rocks is approximately 225 square miles. The Baraboo quartzite ranges extending east and west occupy much the largest portion of the district. The principal ranges, known as the North and South ranges, unite at the eastern end of the district to form a bold point, rising abruptly from the low-lying land of the great bend of the Wisconsin River south of Portage. Tracing these ranges to the westward, they are found to diverge towards the western end of the district, where they are joined by a short range, here referred to as the West Range, extending north and south. The ranges of quartzite thus constitute a cordon of bluffs enclosing a depressed interior. To the north, south, and east of this circuit of quartzite bluffs the country is comparatively low, the main topographic features being the broad bottom lands of the drift-filled valleys. From the surrounding country, therefore, the quartzite ranges stand out as bold features of the landscape and can be seen for many miles around. West of the West Range the country is more broken and hilly, for here the more resistant Lower Magnesian limestone is the prevailing formation of the land surface.

The South Range forms the main topographic feature of the district and constitutes approximately one-half of the area. It has a width of from one to four miles, being broad and flat at the west end and narrow and ridged at the east end. The highest point of the South Range, 1,620 feet above the sea level, is about four miles east of Devils Lake, in sec. 15, T. 11, R. 7 E. Farther west, in the town of Freedom, the broad table-land of the summit of the South Range rises in many places over 1,400 feet above sea level. The South Range is broken down in only one place, the pre-glacial river gorge in which lies Devils Lake. While the general trend of the South Range is east-northeast, there are many irregularities in the border along both the north and the south sides. The north slope of the range, facing the interior valley, is generally gentle; while the south slope, facing outward, is generally quite abrupt.

The North Range is much less pronounced than the South Range, being broken down by erosion at several places, notably in the gorges at the Upper and Lower Narrows of the Baraboo River, and in much wider stretches north and northwest of Baraboo in the vicinity of sections 21 and 22, T. 12 N., R. 6 E. Where not broken down by erosion it is generally about a mile in width. Its highest points are 1,300 feet above sea level in the vicinity of the Lower Narrows of the Baraboo River, and at the juncture with the South Range at the east end of the district.

The West Range trends north and south across the west end of the district and is about seven miles long. Its width is approximately two miles, and its broad slopes are covered with excellent farms. Its highest elevation is over 1,400 feet, in the NE. ¼ of sec. 14, T. 11 N., R. 4 E.

The valley between the quartzite ranges has an elevation of 800 to 900 feet, and is drained by the Baraboo River and its tributaries. The Baraboo River enters the valley near the northwest corner of the district through a narrow gorge in the North Range at Ablemans, known as the Upper Narrows, and, after flowing eastward for 15 miles, passes out at a much broader gorge in the same range, known as the Lower Narrows. Seeley Creek, Skillet Creek, and Rowley Creek are the main branches of the Baraboo in the valley between the quartzite ranges. Seeley Creek heads in the southwest part of the district, at the junction of the West and South ranges, and flows northeast to join the Baraboo. Skillet Creek heads in the central portion of the South Range and flows north to the Baraboo. Rowley Creek drains the eastern part of the area between the North and South ranges and flows westward, joining the Baraboo near the Lower Narrows. Narrows Creek, which drains the west side of the West Range, flows through a narrow gorge of the North Range two miles west of Ablemans, joining the Baraboo at Ablemans.

The streams flowing southward from the South Range into the Wisconsin River, beginning at the west, are the north branch of Honey Creek, east branch of Honey Creek, Otter Creek, and Prentice Creek.

Devils Lake is the only lake within the district. This is a picturesque body of water, well known as a summer resort, located in a notch of the South Range. This notch or gorge is generally believed by geologists to be the valley of some preglacial river, probably corresponding to the Wisconsin.

The industry of the district is mainly agricultural, rich farm lands occurring over the slopes of the quartzite ranges and in the valley between the ranges. The soil upon the bluffs is mainly a clayey soil, while that on the bottoms is clay and loam. Large portions of the South Range, where quartzite lies at and near the surface, are still covered with hardwood forest, in which many deer find shelter.

The principal town is Baraboo, with a population of 5,751. North Freedom and Ablemans are villages in the western part of the district. The Chicago & Northwestern Railway is the only railroad line crossing the district, though the Chicago, Milwaukee & St. Paul Railway and the Wisconsin Central Railway at Portage are within a few miles of the east end.

GENERAL GEOLOGY.

The rock formations and their succession, beginning with the youngest, are shown in the following table:

Pleistocene	Glacial drift.
Unconformity.	
Paleozoic Sedimentary	Trenton limestone.
	St. Peter sandstone.
	Lower Magnesian limestone.
	Potsdam sandstone.
Unconformity.	
Pre-Cambrian Sedimentary (Baraboo Series)	Freedom formation (dolomite and iron-bearing rock).
	Seeley slate (gray clay slate).
	Baraboo quartzite (quartzite of the quartzite ranges).
Unconformity.	
Pre-Cambrian Igneous	Rhyolite.
	Granite.
	Diorite.

The principal rock formations appearing at the surface are the Baraboo quartzite, the Potsdam sandstone, and the glacial drift. The formations not occurring at the surface and found only by exploration are the Seeley slate and the Freedom iron-bearing formation.

The rock constituting the prominent ranges, briefly described above, is the hard, vitreous Baraboo quartzite. The Seeley slate and the Freedom iron-bearing limestone formation are found in the valley between the quartzite ranges beneath the sandstone. The Potsdam sandstone formation occurs beneath the drift in the valley between the quartzite ranges, and also occurs in abundance along the base of the quartzite bluffs. Above the Potsdam, reaching to the summits of the bluffs, occur the later Paleozoic formations mentioned in the table. The glacial drift occurs mainly in the valley bottoms throughout the district and upon the sides and summits of the bluffs in the eastern part. Besides these abundant formations, small areas of rhyolite, granite, and diorite occur along the outer border of the district.

CHAPTER II.

HISTORY AND LITERATURE OF THE DISTRICT.

The quartzite ranges derive their name from the Baraboo River, this river being named for Jean Barribault, an early French trapper. So far as known, the first map[1] to show a sketch of the Baraboo bluffs was published in 1836. The land survey of this region by the United States Government was made in 1840–44.

The bold character of the Baraboo quartzite ranges and the dissimilarity between their rocks and those of the surrounding sandstone and limestone region attracted the attention of explorers and geologists at a comparatively early date. Probably the first geologist to visit the district was Dr. James Gates Percival, in 1856.[2] He regarded the quartzite ranges as a metamorphosed phase of the Potsdam sandstone. Dr. James Hill, paleontologist, in 1862 correctly referred the quartzite to the Archean. In 1864 Alexander Winchell,[3] finding[4] Potsdam fossils in the sandstone lying against the quartzite bluffs, and overlooking the fact of the unconformable relations of the two formations, called the quartzite Lower Potsdam. There was a slight controversy, therefore, among the earlier writers concerning the age of the Baraboo quartzite ranges, which, however, was readily

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[1] Map of the Territory of Michigan and Wisconsin, by John Farmer.

[2] See papers cited on pp. 8–10.

[3] Am. Journ. Sci., 2d ser., vol. 37, p. 226.

[4] The fossils had been sent to Professor Winchell. He himself never visited the locality.

settled a few years later, in 1872, by the work of Irving. The Huronian age of the quartzite was fully established by the work of Irving during the progress of the former state geological survey in 1873–4.

While the presence of iron ore in the Baraboo district was not definitely known until very recently, Prof. T. C. Chamberlin[1] in 1882 recognized the possibility of its occurrence in the area of the quartzite ranges, as shown in the following statement:

"In the Baraboo region of Sauk County, large bunches of brilliant specular iron in veins of white quartz are often met with, but no indication of the existence of ore in quantity in the Huronian of this region has been observed. It is a matter of great interest that while we have in the Penokee and Menominee Huronian the same kinds and succession of rocks as in the iron district of Marquette, in the Baraboo country, and to the northeast from there, we find a great development of the porphyry so characteristic of the Huronian iron district of Missouri. It is wholly within the possibilities that iron ores may yet be discovered in the Baraboo Huronian."

DISCOVERY OF IRON ORE IN THE DISTRICT.

Iron ore was first discovered in the Baraboo district by W. G. La Rue, in April, 1900. Previous to this, however, exploration for iron ore had been started as early as the autumn of 1887 by the Douglas Iron Mining Company. This organization, a stock company, held an option on the Douglas farm, and the first exploration, known as the Douglas mine, was made in the near vicinity of the present Illinois mine. Exploration at this place was begun on account of the iron formation,—iron-bearing slates and chert, having been struck in the well at the Douglas farm house. So far as known, this is the only place in the whole district where either the iron formation or the clay slates are so near the surface as to be struck in digging or drilling the farm wells.

On account of the showing in the Douglas well of ferruginous

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[1] Geol. of Wis., vol. 1, p. 624.

chert and slate similar to that occurring in the iron-bearing districts of the Lake Superior region, the Douglas Iron Mining Company, as above stated, was organized in 1887 and exploratory work begun. This company operated quite continuously for about two years, under the charge of Chas. P. Pease, and about $40,000 was expended in sinking a shaft near the present Illinois mine and in sinking several other shafts in the near vicinity in the sandstone formation. The principal shaft, that near the Illinois mine shaft, was sunk 40 feet to the clay slate formation, drifting 77 feet to the west and then crosscutting 60 feet to the north, thus keeping wholly within the iron formation. The best material obtained from this exploration averaged about 35 per cent in iron. The property in 1889 was leased by the Douglas Mining Company to the Chicago & Northwestern Railway Company, which mined the iron-formation rock for mineral paint. The first lease was for five years, and this was later renewed for five years longer. On the lapsing of the rights of the Chicago & Northwestern Railway Company, the control of the property was secured by W. G. La Rue, Robert B. Whiteside, and Herman Grotophorst. The exploration of this company was mostly by diamond drill work under charge of Mr. La Rue, whose persistent faith was rewarded by striking good ore about 100 feet west of the Illinois mine shaft, as already stated, in April, 1900.

PREVIOUS LITERATURE.

Below is presented as complete a list as possible of the principal papers dealing with the geology of the district.

1856.

PERCIVAL, J. G., On Southern Wisconsin, including the iron, lead and zinc districts, with an account of the metamorphic and primitive rocks: Ann. Rept. Wis. Geol. Survey, 1856, p. 111.

1858.

DANIELS, EDWARD, The iron ores of Wisconsin: Ann. Rept. Wis. Geol. Survey, 1857, p. 62.

1862.

Hall, James, Physical geography and general geology: Rept. of the Geol. Survey of the State of Wisconsin, vol. 1, p. 11.

1872.

Irving, R. D., On the age of the quartzite, schists and conglomerates of Sauk County, Wisconsin: Am. Journ. Sci., 3d ser., vol. 3, pp. 93–99.

Eaton, James H., Report on the geology of the region about Devils Lake: Wis. Acad. Sci., vol. 1, pp. 124–128.

1873.

Eaton, James H., On the relations of the sandstone conglomerates and limestone of Sauk County, Wisconsin, to each other and to the Azoic quartzites: Am. Journ. Sci., 3d ser., vol. 5, pp. 444–447. Same article in Wis. Acad. Sci., vol. 2, pp. 123–127.

Chamberlin, T. C., Some evidences bearing upon the methods of upheaval of the quartzites of Sauk and Columbia counties: Wis. Acad. Sci., vol. 2, pp. 129–132. On fluctuations in level of the quartzites of Sauk and Columbia counties: Wis. Acad. Sci., vol. 2, pp. 133–138.

1877.

Irving, R. D., The Baraboo quartzite ranges: Geol. of Wis., vol. 2, pp. 504–519. Sauk and Columbia counties, op. cit., pp. 579–597, with atlas, Plate XIV.

1886.

Irving, R. D., The classification of the early Cambrian and pre-Cambrian formations: Seventh Ann. Rept. U. S. Geol. Survey, pp. 403–408.

1892.

Van Hise, C. R., Correlation papers, Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, pp. 186–187.

1893.

Van Hise, C. R., Some dynamic phenomena shown by the Baraboo quartzite ranges of Central Wisconsin: Journ. of Geol., vol. 1, pp. 347–355.

1895.

WEIDMAN, S., On the quartz keratophyre and associated rocks of the North Range of the Baraboo Bluffs: Bull. Univ. of Wis., Sci. ser., vol. 1, No. 2, pp. 35–56.

SALISBURY, R. D., Pre-glacial gravels on the quartzite range near Baraboo, Wisconsin: Journ. of Geol., vol. 3, pp. 655–667.

1897.

SALISBURY, R. D., and ATWOOD, W. W., Drift phenomena in the vicinity of Devils Lake and Baraboo, Wisconsin: Journ. of Geol., vol. 5, pp. 131–147.

1900.

SALISBURY, R. D., and ATWOOD, W. W., The geography of the region about Devils Lake and the Dalles of the Wisconsin: Bull. Wis. Geol. and Nat. Hist. Survey No. 5.

SUMMARY OF PREVIOUS LITERATURE.

The early papers of Percival, Daniells, and Hall, above cited, refer very briefly to the Baraboo district. Hall was the first to correctly place the quartzite in the Huronian system. Irving, however, in his earliest papers on the quartzite range, as already stated, was the first to definitely prove the unconformable relationship of the quartzite to the overlying Potsdam sandstone, and hence its position in the Huronian series as stated by Hall.

Irving,[1] in his report on Central Wisconsin, in vol. 2 of the former Geological Survey, was the first to present a systematic account of the quartzite ranges. He made a general survey of the whole district, visited most of the outcrops, and described the general geology clearly, giving accurate descriptions of the character of the quartzite and the general structural features of the quartzite ranges. His report was accompanied by an excellent map[2] of the district, which has been of great value in the

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[1] Irving, R. D., The Baraboo quartzite ranges: Wis. Geol. Survey, vol. 2, pp. 504–519. This report is unfortunately out of print, but may be obtained from dealers in second-hand books.

[2] Atlas of the Geol. Survey of Wisconsin, Pl. XIV.

prosecution of the present work. The conclusions arrived at by Irving, as well as those of other geologists, concerning the structure of the district, are not in accord with those of the present writer, as fully discussed in the following pages of this report. The report[1] upon the geography of the district by R. D. Salisbury and W. W. Atwood is an admirable treatment of the geographic features of the region and the distribution of the glacial drift.

Six of the sheets of the topographic atlas[2] of the United States Geological Survey include portions of this district. These are the Denzer, Baraboo, Poynette, Portage, Briggsville, and Dells sheets. The Denzer and Baraboo sheets cover most of the district.

Since this report was begun an article on the Baraboo iron range, by Oscar Rohn,[3] has appeared, and also a brief account of the geology of the Baraboo district,[4] prepared by the author of this report.

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[1] Bull. Wis. Geol. and Nat. Hist. Survey No. 5. This bulletin may be obtained from the Director of the Wisconsin Geological and Natural History Survey, Madison, Wis., on the payment of 30 cents postage.

[2] These topographic maps may be obtained from the Director of the U. S. Geological Survey, Washington, D. C. The price is 5 cents each, payable by money order.

[3] Eng. and Min. Journ., vol. 76, pp. 615–617.

[4] Bull. U. S. Geol. Survey No. 225, pp. 218–220.

CHAPTER III.

THE PRE-CAMBRIAN IGNEOUS ROCKS.

DISTRIBUTION.

The igneous rocks of the Baraboo district are found on the north side of the North Range and the south side of the South Range, and hence are distributed about the outer border of the district. The areas of igneous rock are quite widely separated from one another and vary widely in extent, some of them consisting of a single small or large outcrop, and others of several separated outcrops near one another (see map, Pl. I).

The largest area, and the only one along the North Range, is located along the north side of the North Range in the vicinity of the Lower Narrows. Much the largest portion of this area is confined to the west side of the Lower Narrows. A much smaller area, though the next in size, is located on the south side of the South Range, near the eastern end, in the vicinity of Alloa, in sec. 3, T. 11 N., R. 8 E. The next outcrop, going west along the south side of the South Range, is located about 15 miles from the Alloa outcrop, on the middle branch of Otter Creek, about one-half mile north of Myer's mill in the SE. 1/4 of sec. 32 and SW. 1/4 of sec. 33, T. 11 N., R. 6 E.

About three miles farther southwest, near the center of the SE. 1/4 of sec. 11, T. 10 N., R. 5 E., is a small, single outcrop; and a mile and one-half farther west, in the vicinity of Denzer, in the northern part of sec. 10 and SE. 1/4 of sec. 9 are two outcrops, constituting the most westerly known area.

The location of the igneous rocks at the Lower Narrows at

Alloa and Denzer was known before the present work began. The outcrops at Myer's mill on Otter Creek, and on the Markert farm in the SE. ¼ of sec. 11, were discovered during the prosecution of the present survey. It is likely that a careful search will reveal other outcrops of igneous rock along the outer borders of the quartzite ranges.

KINDS OF ROCKS.

The igneous rocks bordering the quartzite ranges consist of three distinct kinds of rock, viz: rhyolite, granite, and diorite. The rhyolite is by far the most abundant igneous rock of the district. The granite and diorite form outcrops covering only a few acres.

RHYOLITE.

There are three widely separated areas of rhyolite, viz: at the Lower Narrows, at Alloa, and on the Markert farm. Because the areas are widely separated from one another, it seems most convenient to describe each one separately.

The Lower Narrows Area.

Location and Extent. By far the largest area of igneous rock in the district is the area of rhyolite located east and west of the Lower Narrows of the Baraboo River. From the map it is seen that the rhyolite extends along the north face of the North Range for a distance of over three and one-half miles. Its most eastern outcrops are in the northeast corner of the SE. ¼ of sec. 23, and its most western are found in the NW. ¼ of sec. 20. The broadest portion lies in the N. ½ of sec. 21 and the adjacent part of sec. 16, where the exposures are distributed over the width of more than half a mile. A small area, entirely surrounded by the quartzite, lies in the vicinity of the east quarter post of sec. 20.

General Character of the Rhyolite. The rhyolite is a very hard, pinkish rock, which is usually unweathered and breaks under a stroke of the hammer with a sharp conchoidal fracture. It consists of numerous crystals of pinkish feldspar and translucent quartz, which are imbedded in a very fine matrix, or groundmass. In places, as along the wagon road in the NE. 1/4 of sec. 21, the rhyolite is very much fractured. These fractures cut the rock in all directions, so that it weathers out in small fragments bounded on all sides by plane surfaces. In other places the rhyolite is not much fractured, and when this is the case the ledges are rounded and massive. Reticulating veins of quartz from a fraction of an inch to three or four inches in thickness are quite numerous throughout the rhyolite.

The rhyolite, as already stated, is of igneous origin, and hence shows no evidence of having been deposited by water, such as bedding and stratification, which is everywhere exhibited by the sedimentary quartzite adjoining it. The rhyolite belongs to that class of igneous rocks which is of volcanic origin, in contradistinction to the deep-seated or plutonic igneous rocks represented by the granites and diorites of the district. Volcanic or extrusive rocks are delivered upon or beneath the surface by volcanic action, while yet in a molten condition, and spread out in streams or layers. On account of their sudden cooling, many volcanic rocks are either wholly glassy or only partially crystallized. Undoubtedly the rhyolite in this vicinity was originally only a partially crystallized rock when brought to the surface. A rough examination of the hand specimens is sufficient to show that the rock consists of two parts: one part the fine groundmass, or background, and the other the scattered crystals of pinkish feldspar and translucent quartz distributed through it. The groundmass was originally the glassy or uncrystallized portion of the rock, and the included crystals of feldspar and quartz the crystallized portion. In many places the outcrops of the area reveal fine streaks and wavy lines in the groundmass, which represent lines of flowage of the rhyolite magma as it spread out over the surface during the process of its extrusion.

At several places within the rhyolite formation are zones of rhyolite schist, consisting mainly of sericite and fine quartz. This schist is grayish and has a typical schistose or slate-like structure, and for this reason it has sometimes been called a slate. It is, however, a phase of the rhyolite formation. It occurs as a zone 150 to 200 feet wide along the contact of the rhyolite with the main body of quartzite, and also farther north in the immediate vicinity of the outcrops of conglomerate in the NE. 1/4 of NW. 1/4 of sec. 21. These gray sericitic schists generally, if not always, occur near the contact with the overlying pre-Cambrian quartzite or conglomerate and may in places contain some sedimentary rock, but they are mainly merely weathered and mashed phases of rhyolite.

Microscopic Character. Thin sections of the rhyolite, examined under the microscope, show the feldspar to be the principal porphyritic mineral in the groundmass. Very often the crystals are seen to be broken and bent, undoubtedly caused by the motion of the magma after the feldspar had crystallized. Sometimes they are merely cracked or broken, but often the broken parts are separated from each other, allowing a thin stream of viscous groundmass to flow between the dismembered parts. The feldspar crystals are more or less altered to sericite. The porphyritic crystals of quartz in the groundmass are not so abundant as those of feldspar. Many of the quartz crystals, like the feldspar, show the effect of a moving viscous magma by being broken and moved apart. Besides the quartz and feldspar, ilmenite and small flakes of biotite and zircon are present. The fine groundmass of the rhyolite in which the crystals of quartz and feldspar are distributed is now wholly crystalline, though it is believed to have been originally of a glassy or semi-vitreous nature. The groundmass shows three well-known structures common to volcanic rocks, viz: the fluxion or flowage structure, the poikilitic structure, and the spherulitic structure. The fluxion structure is the most common and is present in all the thin sections examined. It consists of sinuous lines of flow, developed by a slowly-moving magma, which curve and wind about the included crystals and fragments in the rock.

The thin sections of the sericitic schist associated with the massive rhyolite show the schist to be mashed phases of the massive rhyolite rather than sedimentary rock.

Chemical Composition. The composition of the rhyolite, as shown by two previously published[1] analyses, is as follows:

SiO_2	71.24	73.00
Al_2O_3	12.20	15.61
Fe_2O_3	1.71	.....
FeO	5.44	1.95
MnO	.97	.....
CaO	.98	.79
MgO	.13	.....
K_2O	1.86	.88
Na_2O	4.29	4.95
SO_3	.....	.76
H_2O	.81	1.06
	99.63	99.00

The Alloa Outcrops.

Location and Extent. A short distance north and northeast of Alloa are several small outcrops of rhyolite located immediately northeast of the United Presbyterian Church in the NE. ¼ of the NE. ¼ of sec. 3, T. 11 N., R. 8 E., and also nearly half a mile north of the latter place, along the south side of the quartzite range, in the southern half of sec. 34, T. 12 N., R. 8 E.

The outcrop near the church forms an ellipsoidal mound, trending northeast. Numerous small ledges and large loose blocks occur in the near vicinity of the mound along the small stream. Several other outcrops were noted by the writer during a brief examination of the vicinity. Each of the outcrops of the vicinity cover but fractions of an acre, but from their distribution it is safe to predict that a considerable area of similar rock very probably occurs in this locality beneath the Potsdam sandstone and the glacial formations.

General Character of the Rock. The character of the rhyolite of the Alloa outcrops is very similar in most respects to the rhyolite of the vicinity of the Lower Narrows. In general it ap-

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[1] Weidman, S., Quartz keratophyre and associated rocks of the North Range of the Baraboo Bluffs: Bull. Univ. of Wis., vol. 1, No. 2, p. 47.

pears to have a grayish tint, instead of pinkish like that of the above locality. As in the rock of the above locality, the porphyritic constituents of feldspar and quartz are generally very small. Associated with the normal phase of the rhyolite is an abundance of conglomerate. As this conglomerate belongs with the sedimentary quartzite, its description is necessarily deferred to the following chapter. Judging, however, from the character of the rhyolite fragments occurring in the conglomerate, it may be stated that the rhyolite formation of the vicinity consists of quite variable phases of rock, the most abundant of which is a banded rhyolite.

Microscopic Character. The microscopic character of the rhyolite in the vicinity of Alloa is similar in all respects to that at the Lower Narrows. The phenocrysts of feldspar in the groundmass appear to be more abundant than those of quartz. Some of the crystals of feldspar show replacement by calcite.

The Markert Farm Outcrops.

Location and Extent. These outcrops of rhyolite occur about a mile and a half northeast of Denzer, on the Markert farm in the SE. 1/4 of sec. 11, T. 10 N., R. 5 E.

Numerous loose blocks occur at this place along the road at the bridge and farther northeast along the stream. The largest outcrop is a small, nearly flat ledge, forming the northwest bank of the stream, about 150 yards above the bridge. It is not unlikely that a thorough search would reveal other outcrops of rhyolite in this vicinity.

General Character. The rhyolite of these outcrops varies from a very fine-grained rock, having very few phenocrysts of feldspar, to a coarser rock, having abundant porphyritic crystals of feldspar. Quartz phenocrysts are present but not abundant.

Microscopic Character. The fine-grained phase of the rhyolite consists of uniformly fine-grained feldspar and quartz, having a compact, granular texture. The coarser phase consists of a fine-grained groundmass, in which are imbedded crystals of feldspar and a few of amphibole, the latter considerably altered to chlorite. The rhyolite of these outcrops resembles very closely the rhyolite at the Lower Narrows and at Alloa.

A photomicrograph of this rhyolite, fairly representative of this kind of rock for the whole district, is shown in figure 1, Plate XIX.

DIORITE.

So far as known, only a single area of diorite occurs in the district, and this is near Denzer and not far from the last described outcrop of rhyolite.

Denzer Outcrops of Diorite.

Location and Extent. Two outcrops of diorite occur near Denzer, one being near the center of the SE. 1/4 of sec. 9, T. 10 N., R. 5 E., on the Mellenthein farm, and the other about a mile northeast of the latter place and about one and one-quarter miles north of Denzer, in sec. 10.

The diorite on the Mellenthein farm forms a low knob 30 or 40 feet above its surroundings, showing several well-exposed ledges of the massive diorite. The diorite along the road north of Denzer appears in numerous large blocks; and since hard, crystalline rock is reported to have been struck in the wells at the farm houses a few rods distant, it is probable that diorite in place occurs not far below the surface in the vicinity. There is an abundance of glacial drift in this locality, very apparently belonging to a very early drift sheet, but the boulders of this drift are in marked contrast to the huge angular blocks of diorite occurring along the stream in this locality. Large blocks and boulders of the diorite are scattered along the adjacent hillsides also, but these latter are believed to have been moved from the parent ledge by glacial movement, as they occur with various other kinds of boulders.

Character of the Rock. The character of the diorite in both the above localities is the same. The prevailing rock is massive and medium grained, has a reddish color, and consists of feldspar, hornblende and quartz. The popular name for this rock is granite, but it should be termed a diorite because it contains a much larger percentage of hornblende and a much smaller percentage of quartz than granite. Like granite, however, the diorite is a plutonic, or deep-seated igneous rock, and thus its mode of origin is in marked contrast to the origin of the rhyolite, which, as already stated, is of volcanic or extrusive origin. The normal type of the diorite is a medium-grained rock. In places the ledges show a gradation into fine-grained diorite. In places, also, there are thin seams or ramifications of a very fine-grained, dark-colored rhyolite-like rock, which may be veins connected with the rhyolite formation. Sufficient data, however, is not at hand to prove the intrusive relation of the rhyolite to the diorite.

Microscopic Character. Under the miscroscope, the diorite is seen to consist mainly of finely-striated, plagioclase feldspar, forming from 70 to 85 per cent. of the rock, and showing in weathered specimens considerable alterations to sericite and chlorite. The mineral next in abundance to plagioclase is the hornblende, which constitutes from 10 to 20 per cent of the rock. The hornblende is apparently the common, green variety, considerably altered to chlorite. The quartz is much less abundant than the hornblende, and occurs in small crystals filling the interspaces between the feldspar and hornblende. Mica, apatite, and iron oxide are minor constituents. A photomicrograph of the diorite is shown in figure 2, Plate XX.

GRANITE.

But one small area of granite is known to occur in the district.

Myer's Mill Outcrop of Granite.

Location and Extent. This small area of granite is located on the south side of the South Range, on the main branch of Otter Creek, a short distance north of Myer's mill. The ledges of granite extend on both sides of the section lines, as indicated on the map, in the SE. 1/4 of sec. 32 and SW. 1/4 of sec. 33 of T. 11 N., R. 6 E. The granite exposures in this vicinity constitute an area of 10 or 20 acres, and form several low hills along the creek.

General Character. The granite is a medium to fine grained variety, varying in color from grayish to reddish, and consists of feldspar, quartz and a small amount of dark mineral. The granite forming the knob on the southwest side of the creek is much fractured and jointed, and as a result it weathers into angular pieces. The granite on the east side of the creek, at the base of the quartzite bluff, is somewhat schistose and is considerably weathered. At first sight it was thought this weathered, schistose phase might be arkose, but the microscopic examination shows it to be a much weathered and mashed phase of the granite formation. This schistose phase of the granite forms a zone between the massive granite on one side and the massive quartzite formation on the other, similar to the zone of weathered rhyolite schist occurring between the massive rhyolite and the quartzite at the Lower Narrows.

Microscopic Character. In thin sections the granite is seen to consist of plagioclase feldspar, quartz, and a small amount of mica and hornblende. The feldspar forms from 50 to 75 per cent of the rock and is altered to sericite, chlorite, and zoisite. The quartz occurs in crystals about the size of those of the feldspar and constitutes from 20 to 45 per cent of the rock. The mica and hornblende occur in small crystals and generally form from one to five per cent of the rock. Apatite, in long, needle-like crystals, is a minor constituent. A photomicrograph of the granite is shown in figure 1, Plate XX.

THE RELATION OF THE IGNEOUS ROCKS TO THE BARABOO QUARTZITE FORMATION.

The various igneous rocks above described are nowhere known to be in contact with one another, and hence their relative ages cannot be determined. It is possible, however, that by a more detailed study and the discovery of more outcrops the structural relation of these formations of igneous rock can be ascertained.

A matter of much more interest and importance, however, is the relation of the igneous rocks to the quartzite formation. Concerning this point it may be here briefly stated that the diorite, rhyolite, and granite form the floor upon which the overlying sedimentary rock, the Baraboo quartzite, was deposited. Hence between the igneous rocks and the quartzite there is a structural unconformity. The proof of the unconformity between the quartzite and the igneous rocks is the occurrence of conglomerate forming the base of the quartzite formation, which is made up of fragments of the igneous rock. The evidence for placing the igneous rock in a much older series, forming the basement upon which the quartzite was later deposited, is necessarily best brought out in the discussion of the character of this conglomerate and the structural relations of the quartzite formation, in the following chapter.

CHAPTER IV.

THE PRE-CAMBRIAN SEDIMENTARY SERIES (BARABOO SERIES).

The sedimentary rocks of pre-Cambrian age comprise, from the base upward, (1) the Baraboo quartzite formation, consisting mainly of quartzite but containing also a small amount of conglomerate at its base, (2) the Seeley slate formation, consisting of a quite uniform gray clay slate, and (3) the Freedom formation, consisting of two members,—a lower, of iron ore, ferruginous slates, ferruginous dolomite, and ferruginous chert, and an upper, of dolomite.

No outcrops of the Freedom formation and the Seeley slate formation are known to occur in the district, and hence all information concerning these formations is necessarily based on recent exploratory work, and mainly consists of a study of these formations exposed in the Illinois mine and samples of drill cores from many drill holes southwest of North Freedom. Outcrops of the Baraboo quartzite are sufficiently abundant to furnish data upon which the structure of the district has been worked out. The boundary lines shown on the map between the quartzite formation and the overlying slate are mainly conjectural, as only in one or two drill holes was the exact location of the contact determined. While mainly conjectural, however, it is believed the border of the quartzite formation is approximately located as indicated.

At the present writing, February, 1904, exploratory work has been mainly confined to the west end of the district, and hence it is only in that vicinity that the slate and iron formations have been demonstrated to occur. It is believed, however, as stated in a following chapter, that exploration at the east end of the district, in the interior valley between the quartzite ranges, will reveal the presence of these formations south and east of Baraboo.

SECTION I.

THE BARABOO QUARTZITE.

DISTRIBUTION.

The Baraboo quartzite, as previously stated, is by far the most abundant pre-Cambrian rock formation of the Baraboo district. The quartzite forms the main body of the quartzite ranges already briefly described under the topographic features of the district. The distribution is best seen by a glance at the general map (Pl. I). The South Range varies in width from 10 or 11 miles in the southwestern part of the district to one mile at the eastern end. The North Range has a fairly uniform width of about a mile. The West Range has a width varying from one to three or four miles. Between the ranges are a number of isolated areas of quartzite, as shown on the general map.

KINDS OF ROCK.

The Baraboo quartzite formation consists of two kinds of rock, the ordinary quartzite of the ranges and the conglomerate found at its base.

QUARTZITE.

The great bulk of the Baraboo formation is hard, brittle, vitreous quartzite. The quartzite is a sedimentary or water-deposited rock, whose original form was sandstone which through processes of metamorphism has been changed to hard, crystalline quartzite. The quartzite consists of rounded grains of quartz of medium size, mainly cemented together by secondary interstitial quartz. The color of the quartzite is generally pink, varying through gray and pink to purplish red and sometimes brick red. In a few places only is the quartzite white.

Bedding is generally well marked by large, parallel joint planes, as indicated in the photographs (Plates III—V). Ripple marks and also thin seams of fine conglomerate along these joint planes are abundant. In determining the position of the beds of the quartzite, viz, the dip and strike, only the pronounced approximately parallel bedding joints are considered. Between the parallel bedding joints are minor stratification lines, indicating cross bedding, which often depart as much as 60 to 80 degrees from parallelism with the principal and true bedding plane. Cross bedding, sometimes referred to as false bedding, is due to the varying conditions under which the sand grains of the quartzite were accumulated, the irregular stratification denoting the changing condition of wave action and shore currents along the shallow bottom of the sea in which the formation was deposited. Lines of lamination, which curve and bend about in an intricate manner and which are very obviously due to secondary causes, must also be discriminated from the true bedding of the quartzite. The quartzite breaks up on weathering in large, approximately rectangular blocks, especially in the low-dipping beds of the South Range, as illustrated in the talus slopes about Devils Lake.

A common feature of the quartzite is the occurrence of layers of quartz schist lying between the massive beds of quartzite. These layers of quartz schist vary in thickness from a few inches to several feet and are usually found wherever the quartzite is exposed to any extent. The schistosity or lamination of these quartz schist layers dips in the same general direction as the bedding of the quartzite, but always at a much higher angle. This is illustrated along the railroad at Devils Lake, where the quartzite dips to the north at angles varying from 10 to 15 degrees and the schistosity of the quartz schist dips in the same direction at an average angle of about 40 degrees.

The quartz schist, as shown by the microscope,[1] originally

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[1] Van Hise, C. R., Some dynamic phenomena shown by the Baraboo quartzite ranges: Journ. of Geol., vol. 1, pp. 347–355.

contained more clayey material than the quartzite beds; hence they were weaker beds than the quartzite, and for this reason were subjected to shear and differential movement during the process of tilting and uplifting of the quartzite ranges.

The quartzite in places, notably in the Upper Narrows at Ablemans, consists of a mass of angular and rounded fragments of pink quartzite firmly cemented by white quartz. This phase of the quartzite is a friction conglomerate, or Reibungs breccia, and like the quartz schist was developed during the fracturing and crushing of the quartzite beds when the tilting of the quartzite ranges took place. In several places in the district, far above the base of the quartzite, occur considerable beds of fine conglomerate, consisting mainly of pebbles of white quartz rock and of fine-grained, pink and red cherty rock and ferruginous slate. This conglomerate is the prevailing rock forming the low ridge in the northern part of the NE. ¼ of sec. 32, T. 12 N., R. 7 E. Similar fine conglomerate also occurs in the railroad cut in the SW. ¼ of sec. 34, T. 12 N., R. 6 E., and upon the top of the south quartzite range along the road in the NW. corner of sec. 25, T. 11 N., R. 5 E. The possibility of this uniformly fine conglomerate being unconformable to the quartzite was considered; but the microscopic examination shows it to contain no pebbles or fragments of the Baraboo quartzite, nor other evidence of its being unconformable to the prevailing quartzite. This conglomerate is again referred to under the description of the conglomerate of this formation.

Microscopic Character. Under the microscope the quartzite is seen to be made up of well-rounded and sub-angular grains of quartz, firmly cemented by interstitial quartz, and variable but small amounts of iron oxide, chlorite, and sericite. The cementation and consolidation of the Baraboo quartzite has been explained[1] as due to the enlargement of the original quartz grains and to the deposition of independent interstitial quartz. The

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[1] Irving, R. D., and Van Hise, C. R., Enlargements of quartz fragments and genesis of quartzites: Bull. U. S. Geol. Survey No. 8, pp. 33–34.

prevailing pinkish color of the quartzite is mainly due to the iron oxide associated with the interstitial quartz.

The Baraboo quartzite, as shown by the microscope, as well as by its general character in the field, is throughout a pure quartz rock, containing little or no feldspar or other minerals. As shown by the photomicrograph of the quartzite (fig. 1, Pl. XXI), the secondary interstitial material probably forms 30 to 40 per cent of the rock.

CONGLOMERATE.

The conglomerate, occurring at the base of the quartzite, may conveniently be described as basal, and that occurring at higher horizons within the quartzite formation as intra-formational.

Basal Conglomerate. The conglomerate at the base of the quartzite formation is not abundant, but on account of its character and location, it is very important since it shows conclusively the unconformable position of the sedimentary series above the igneous rocks of the district.

In the vicinity of the area of rhyolite, on the north side of the North Range at the Lower Narrows, several occurrences of conglomerate were noted. A considerable exposure is located on the north side of the road near the centre of the NE. 1/4 of the NW. 1/4 of sec. 21, T. 12 N., R. 7 E. In a former paper by the writer[1] this outcrop was referred to as volcanic breccia, which indeed it resembles very closely, since all of the fragments which compose it are phases of rhyolitic flows. However, a closer examination shows the outcrop to contain layers and thin seams made up of stratified water-deposited material, such as rounded pebbles of the rhyolite and schist, and small grains of quartz. The coarse phase of the conglomerate consists of a variety of rounded and angular fragments and pebbles from two to four inches in diameter. This outcrop of conglomerate is immediately adjacent to the rhyolite, and the character of the pebbles and fragments is such as to indicate that it is undoubtedly mainly

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[1] Bull. Univ. of Wis., vol. 1, No. 2, pp. 44–46.

made up of detritus from the adjacent rhyolite. On the summit and on the southwest side of the North Range, in a field near the center of sec. 20, T. 12 N., R. 7 E., are numerous large blocks of conglomerate made up of various phases of rhyolite and of fine quartz rock. These blocks are immediately west, and thus in the line of glacial movement, of a small area of rhyolite surrounded on all sides by the quartzite formation, and thus very probably have not been moved far by glacial movement from conglomerate in place.

In the area of the Alloa outcrops of rhyolite on the south side of the South Range, in the NE. ¼ of sec. 3, T. 11 N., R. 8 E., and the SE. ¼ of the adjoining section 32 to the north, are several large exposures of the conglomerate, which are immediately associated with outcrops of the rhyolite. In fact, a large part of the area mapped as rhyolite consists of conglomerate, largely made up of rounded and angular fragments of the adjacent rhyolite formation. The ridge immediately northeast of the United Presbyterian Church is very largely conglomerate, and several ledges at the base of the quartzite bluff to the north consist of similar conglomerate. The pebbles and fragments making up the conglomerate at Alloa are mainly banded rhyolite, and, so far as observed, do not show the large variety of rock exhibited in the conglomerate at the Lower Narrows. The conglomerate at Alloa does not appear to be so much mashed and metamorphosed as the conglomerate at the Lower Narrows. The pebbles and fragments vary from a fraction of an inch in diameter to four and five inches. Thin seams and beds of slate and arkose are interstratified with the coarse conglomerate and prove conclusively its sedimentary nature.

In the vicinity of the granite at Myer's mill in the SW. ¼ of sec. 32, T. 11 N., R. 6 E., numerous loose blocks of conglomerate were noted along the contact of the quartzite and the granite. The conglomerate at this place is made up of pebbles of white vein quartz, black slate, and pink cherty rocks, varying from a fraction of an inch up to three and four inches in diameter. No pebbles of granite were found in the conglomerate, though they probably occur. The conglomerate at this place does not appear to be abundant, the weathered schist, which may in part be of sedimentary origin, forming outcrops between the massive quartzite and the granite.

No conglomerate was noted in the vicinity of the diorite outcrops near Denzer, but adjacent to the outcrop of rhyolite on the Markert farm, in the SE. 1/4 of sec. 11, T. 10 N., R. 5 E., a number of loose blocks of conglomerate were found which consisted mainly of pebbles of phases of rhyolite.

Microscopic Character. The microscopic examination of the conglomerate occurring in the vicinity of the rhyolite outcrops shows the conglomerate to be made up of rounded and angular pebbles of phases of the rhyolite, vein quartz, black slate, greenstone, and ferruginous chert rocks. The matrix of the conglomerate consists clearly of water-worn, fragmental material, such as rounded quartz grains and stratified layers of fine-grained sediment. Thin sections of the thin layers of shale and slate interbedded with the conglomerate show the former to be stratified, water-deposited material. Much of the conglomerate of the Alloa outcrop near the church, consisting of closely-packed, rounded and angular fragments of rhyolite and having but a small amount of matrix and thus resembling closely a brecciated rhyolite, has a matrix of rounded grains of quartz and fine sediment. A photomicrograph of the conglomerate at Alloa is shown in figure 2, Plate XIX. A thin section of the conglomerate adjacent to the granite outcrops shows the conglomerate to consist of pebbles of vein quartz, ferruginous chert, and black slate in a matrix of quartzite.

Intra-formational Conglomerate. Besides the conglomerate at the base of the quartzite formation along the outer borders of the quartzite bluffs, conglomerate occurs in several places between the quartzite ranges. This conglomerate has already been referred to in the description of the quartzite, the three important occurrences being the ridge on the north side of the NE. 1/4 of sec. 32, T. 12 N., R. 7 E., the railroad cut in the SW. 1/4 of sec. 34, T. 12 N., R. 6 E., and near the summit of the South Range, at the farm house in the NW. corner of sec. 25, T. 11 N., R. 5 E.

The conglomerate in these various localities is of very similar character and is made up of pebbles of white quartz, reddish chert, and grayish and black schist or slate. The most conspicuous pebbles are of a rather coarse-grained, white and pink quartz. The conglomerate quite generally contains only small pebbles, which usually do not exceed one inch in diameter and none were noted larger than two or three inches in diameter.

The conglomerate forming the ridge in the northern part of the NE. 1/4 of sec. 32, T. 12 N., R. 7 E., shows a dip of about 55° to the south and very evidently has a thickness of 200 or 300 feet.

The conglomerate in the railroad cut also has a dip to the south and shows a thickness of 150 to 200 feet. The conglomerate in the NW. corner of sec. 25, T. 11 N., R. 5 E., shows a thickness of about 100 feet. At the latter place the conglomerate is associated with the normal quartzite and is clearly interbedded with the latter.

Microscopic Character. Thin sections of the intra-formational conglomerate show the pebbles to consist of quartz rock, both fine and coarse grained, made up of close-fitting crystals of quartz without interspaces of any sort. These quartz pebbles have the character and texture of vein quartz or of quartzite like the Rib Hill quartzite and the Powers Bluff quartzite of north central Wisconsin. The possibility was considered, as already stated, of this conglomerate containing pebbles of the Baraboo quartzite formation and hence indicating a structural unconformity in the sedimentary series, but the microscopic examination showed no pebbles of the Baraboo quartzite formation occurring in the conglomerate. Besides the pebbles of quartz rock, there is present a good proportion of pebbles of chert, containing considerable iron oxide and also a few pebbles of slate. The matrix of the conglomerate resembles in all respects the ordinary normal Baraboo quartzite.

STRUCTURE OF THE QUARTZITE.

The structure of the thick Baraboo quartzite formation practically furnishes the structural framework of the district as a whole. Upon the structural features of the quartzite, therefore, are largely based the writer's opinions regarding the probable location and distribution of the slate and iron-bearing rocks, which everywhere lie buried beneath the sandstone formation. Since the structure of the quartzite is the key to the structure of the district, and since this structure has never been fully described nor understood, and since the writer's conclusions here presented are not in accord with the views previously held, this subject is treated in the following pages with considerable detail.

The description of the structure will begin with the northwest part of the district, at the junction of the West and North ranges, and the West Range, South Range, and North Range will be taken up in consecutive order. Frequent reference will necessarily be made to the map of the district (Pl. I).

Beginning at the northwest corner of the district, about two miles west of Ablemans, where the Narrows Creek flows through a gap in the quartzite range, the quartzite is seen, as elsewhere in the North Range, to have a nearly vertical dip. About half way through this gorge, known as the narrows of the Narrows Creek, there is a large mass of much brecciated quartzite, north of which mass the quartzite has a variable though nearly vertical dip, in some places the dip being S. at an angle of 80, and in other places N. from 70° to 75°. On the inner side of the range, however, south of the breccia, the quartzite dips from 60°–70° to as low as 45° SE. The strike of the quartzite here is from N. 40° E. to N. 70° E. One-half mile southwest of the narrows of Narrows Creek, in the SW. ¼ of the NE. ¼ of sec. 36, T. 12 N., R. 4 E., the quartzite dips 57° SE. and strikes N. 55° E. In the gulch near the road in the SE. ¼ of the NW. ¼ of sec. 36 the quartzite has a distinct dip SE. at angles of 75° to 80°, and a strike N. 40° to 45° E. In this locality, therefore, there is a distinct bend in the quartzite formation, the latter trending from about 50°–60° E. of N. at the narrows of Narrows Creek to N. 40°–45° E. a mile farther southwest. The prevailing dip in this locality is either nearly vertical or SE.

In the E. ½ of the SE. ¼ of sec. 2, T. 11 N., R. 4 E., and adjoining the SW. ¼ of the SW. ¼ of sec. 1, are several low outcrops of quartzite showing distinct bedding, with strike N. 5° E. at the most northern exposures to N. 75° W. one-half mile farther southeast, thus indiating a bending of the formation through a quarter of a circle in this distance of one-half mile. The dip is low, from 25° to 35° E. at the northern end of the quarter circle, and 25° to 30° N. at the southeastern end.

In the NE. ¼ of the NE. ¼ of sec. 12, T. 11 N., R. 4 E., at the farm house of J. Borders, the quartzite lies a short distance below the surface. A mile and one-quarter north of the latter place, on the farm of W. Tibbetts, the quartzite ledges occur at the surface, and between these places, in the area of the Rumpf, Weidman, and C. Scharnke farms, is a slight depression of the land surface in which wells have penetrated into the Potsdam sandstone at several places to a depth of 200 feet without striking the quartzite, thus showing a considerable depression of the buried quartzite.

Southeast of the brick Methodist Church in the NW. ¼ of the SE. ¼ of sec. 12, T. 11 N., R. 4 E., several outcrops were noted by W. D. Smith to have a dip of 50° to 60° E. and a strike N. 10° to 60° E. In the E. ½ of the NE. ¼ of sec. 14 and the SE. ¼ of the SE. ¼ of sec. 11, the quartzite rises to a prominent elevation, the outcrops showing conspicuous bedding with strike N. to N. 35° E. and dip of 20° to 35° E. and SE. In the SE. ¼ of the SE. ¼ of sec. 14, immediately north of the stone Lutheran Church, the strike is 10° to 20° E. of N. and dip 20° to 30° SE. In the SE. ¼ of the NW. ¼ of sec. 13 the quartzite strikes 40° to 50° E. and N. and dips 70° SE.

South of the stone Lutheran Church, in the SE. ¼ of the NE. ¼ of sec. 23, the quartzite has a dip in the opposite direction 25° NW., and a strike N. 45° E. A number of outcrops immediately north of the center of sec. 24 have a nearly vertical dip, and a strike N. 40° E. A half-mile northeast of the latter place, in the SE. corner of sec. 13, the quartzite dips 30° to 40° N. and strikes E-W.

In the NW. ¼ of the NW. ¼ of sec. 25 the dip is 45° to 50° NW., and the strike is N. 50° E. No other outcrops of quartzite were noted south of the last named localities in sections 25, 26, 35, and 36 of T. 11 N., R. 4 E., nor in sections 1, 2, and 12 of T. 10 N., R. 5 E., with the exception of the ledge forming a 30 foot waterfall in a small stream in the SE. ¼ of the SW. ¼ of sec. 35, where the dip is approximately vertical and the strike is 10° to 20° W. of N. Throughout the above named area, however, the quartzite was struck in numerous wells, and hence the area is underlain with quartzite.

From the above account of the dip and strike of the quartzite in the western part of the district, it is seen that there is considerable folding of the formation. While the West Range has a prevailing dip E. and S., several folds occur which reverse the dip to the NW., like the dip in the South Range,—a fact which can be more satisfactorily considered when the folding of the quartzite formation in its entirety is discussed.

The South Range, as already stated, has a width varying from five miles in the southwestern part of the district to one mile at the eastern end. Throughout, the South Range has a prevailing north dip, generally NW., at angles usually varying from 15° to 35°. The strike is generally N. 70° E., varying from N. 45° E. to N. 80° E. A good illustration of the northward dip of the quartzite of the South Range is shown by the quartzite in the gorge at Devils Lake (see Pl. III) and farther south at the Devils Nose. Throughout this gap in the South Range at Devils Lake a continuous north dip prevails, at angles varying from 15° at the lake to 40° on the south face of the range at the Devils Nose.

While the South Range has a prevailing northward dip, there are a few notable exceptions where the dip is in the opposite direction, which are of special interest. In the NW. ¼ of sec. 25 and the SW. ¼ of sec. 24, T. 11 N., R. 5 E., the quartzite is well exposed and has a decided dip SE., at angles varying from

THE EAST BLUFF OF DEVILS LAKE.

Shows the north dip of quartzite, and talus above and below the level where the beds are shown. (After Salisbury and Atwood in Bull. Wis. Geol. and Nat. Hist. Survey No. 5.)

30° to 70°. This locality is at the head of the Pine Creek valley, and on the opposite side of the valley, in the NE. ¼ of sec. 25, the dip is in the opposite direction, viz: N. W., at angles varying from 25° to 35°. It is very probable, therefore, that the valley of Pine Creek lies in a synclinal fold throughout its course in the quartzite.

In only one other place in the South Range was a SE. dip noted, viz: in the SE. ¼ of sec. 16, T. 11 N., R. 7 E., where the quartzite is slightly inclined southward at a low angle of about 5°.

As the South Range is followed east into the town of Caledonia, Columbia County, it narrows to a width of a mile or less, and the beds have an appreciably steeper dip, as shown in the NE. ¼ of sec. 34 and NW. ¼ of sec. 35 and the S. ½ of sec. 26 of T. 12 N., R. 8 E., where numerous outcrops reveal a dip varying from 50° to 75° NW. The narrower the range, therefore, the steeper is the inclination of the bedding, a fact well illustrated throughout the North Range, presently to be described.

Along the south border of the South Range southward-dipping quartzite was especially searched for, but none was found. In the immediate vicinity of the outcrops of igneous rocks at Alloa, Myer's mill, the Markert farm, and near Denzer, the quartzite without exception dips to the north and away from the outcrops of the igneous rocks, and thus indicates that the latter formation overlies the igneous series.

Throughout the South Range, the strike, with few exceptions, as above stated, is approximately N. 70° E. The few exceptions observable occur on the south side of the railroad in the NW. ¼ of sec. 5, T. 11 N., R. 6 E., where the strike is N. 65° to 70° W., and about two miles south in the NW. ¼ of the NW. ¼ of sec. 17. This vicinity is within the widest portion of the South Range and is also immediately north of the synclinal fold in the Pine Creek valley, and hence undoubtedly represents the northeast end of the anticlinal fold complementary to the above synclinal of the Pine Creek valley.

At the east end of the district the North and South ranges meet at an angle approximating 60° to 80°. The dip of the quartzite in the South Range, as above stated, is NW., whereas the dip in the North Range immediately adjoining is SW. The strike of the beds changes from N. 30°–40° E. in the S. ½ of sec. 26 to N. 30°–40° W. in the NE. ¼ of sec. 27. Hence, as indicated by the strike, the quartzite formation is here clearly bent into a >-shaped form, the > opening outward toward the interior of the Baraboo valley. A short distance west, in the SW. ¼ of the SW. ¼ of sec. 22 and in the SW. ¼ of sec. 21, the strike is approximately N. 80° E.

Throughout the North Range the strike is about parallel to the strike in the South Range. There is a marked difference, however, in the dip of the beds in the two formations. Throughout the North Range the dip is steep, nowhere being less than 45° and generally between 70° and 90°. East of the Lower Narrows of the Baraboo River the dip is shown at numerous places to be either to the south or near verticality. For two miles west of the Lower Narrows there is without doubt a steep monoclinal dip to the south. However, in secs. 20 and 29 and in the northern part of sec. 32 of T. 12 N., R. 7 E., there is evidently considerable duplication of the beds by close folding. The distribution of the rhyolite in secs. 20 and 21, as the rhyolite has already been shown to be basal to the quartzite, indicates a synclinal fold of the quartzite at this place lying between the two rhyolite areas. The quartzite between these areas of igneous rock was observed at numerous places to have a vertical dip. Also southwest of the small area of rhyolite, in the S. ½ of sec. 20, the quartzite has an approximate vertical dip.

In the N. ½ of the SE. ¼ of sec. 29 the quartzite dips decidedly to the north at angles varying from 60° to 85°, while south of this, half a mile, where the low ridge of fine conglomerate occurs, the formation dips S. and SE. at angles varying from 35° to 40°. In this vicinity, therefore, there is very clearly folding of the formation. An eroded anticlinal fold once arched over the small rhyolite area in the vicinity of the east quarter post of sec. 20, and immediately north, between the

GENTLE FOLDS IN THE NORTH-DIPPING QUARTZITE OF THE SOUTH RANGE.
In the SE. ¼ of sec. 15, T. 11 N., R. 5 E. Photograph by Messrs. Longyear and Hodge.

rhyolite areas, is an intervening synclinal fold. Immediately south is another synclinal fold accompanied by an anticlinal fold, with apex extending E-W. across the southern part of sec. 29.

Immediately west of the above described area for several miles no outcrops of quartzite are known to occur. The absence of quartzite outcrops in this vicinity north of Baraboo may be in part due to the unusually thick covering of terminal moraine, or to greater erosion of the quartzite before the deposition of the Potsdam sandstone formation, or to a combination of these causes.

Outcrops of quartzite at the bend of the road near the center of the SE. ¼ of sec. 27, T. 12 N., R. 6 E., have a dip of 75° to 85° N. and strike N. 80° W. In the northern part of the NE. ¼ of sec. 33, where the quartzite is being quarried for macadam, the dip is nearly vertical and the strike nearly E-W. On the north side of this ridge, in the southern part of the SE. ¼ of sec. 28, the quartzite has a dip approximating 45° to the north. About a mile southeast of this the formation is exposed in a cut of the railroad, the rock being of fine conglomerate, having a distinct dip of 45° to the SE. and strike N. 65° to 75° E. There appears, therefore, to be an anticlinal fold in this vicinity similar to that just described five miles farther east in secs. 29 and 32 of T. 12 N., R. 7 E. A common feature of both these anticlinals is the thick beds of fine conglomerate on the south limb of the fold.

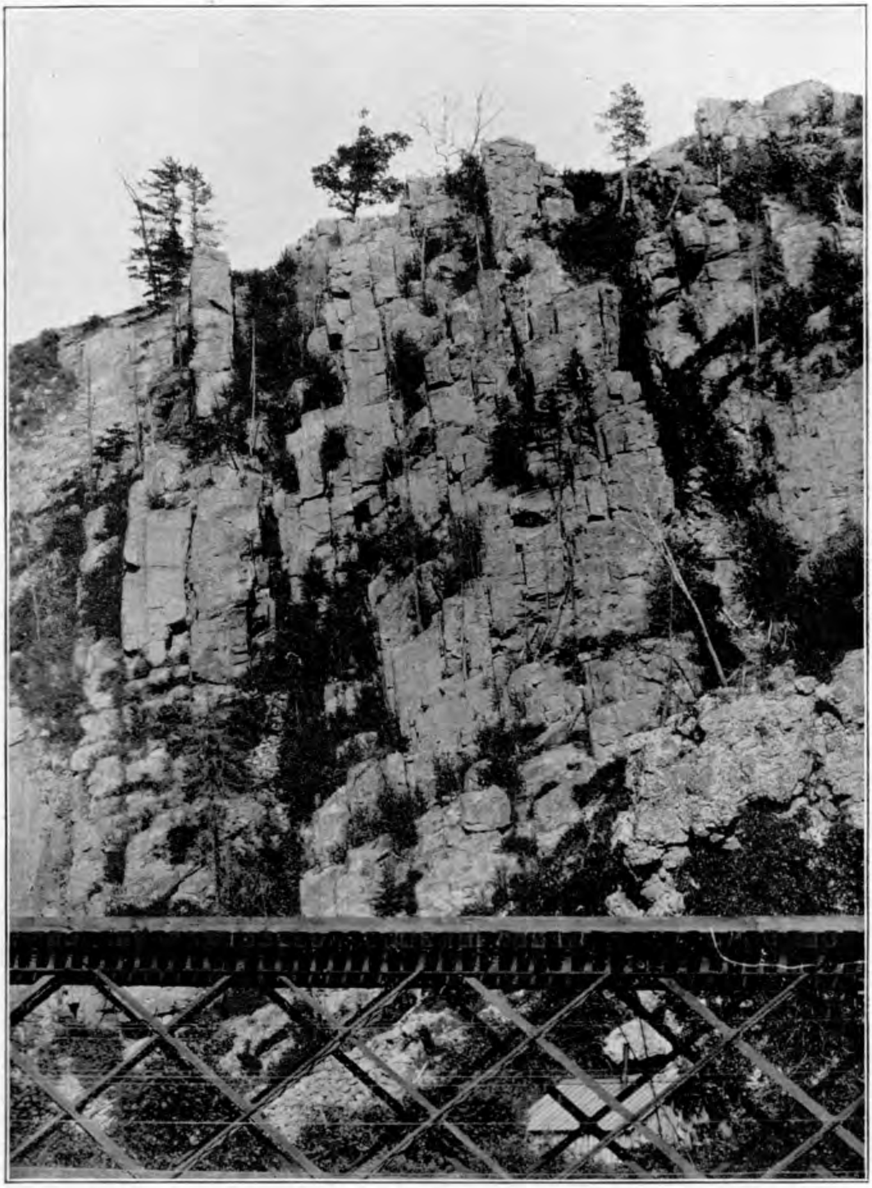
In the central part of the SW. ¼ of the NW. ¼ of sec. 28, T. 12 N., R. 6 E., are two outcrops of quartzite dipping to the west at angles varying from 55° to 60°, the outcrop to the southeast having a strike N. 30° E., and the one to the northwest N. 10° W. A short distance northwest of these outcrops, on the section line near the NW. corner of the same forty, is a very small outcropping, the bedding of which is somewhat obscure but apparently striking N. 70° to 75° W. North of this locality about half a mile is the prominent ridge of the North Range, in which numerous outcrops show the quartzite dipping nearly vertically, sometimes to the north and sometimes to the south.

In sec. 28, therefore, as indicated by the north strike of the quartzite beds, there appears to be a bending of the formation into a cross fold that joins the above described anticlinal fold with the monoclinal fold of the North Range. This point will be referred to again in summarizing the structural features.

West and southwest of the above locality for several miles is a flat-bottomed area, containing, so far as known, no outcrops of quartzite. Three miles north of North Freedom in the NE. ¼ of the SW. ¼ of sec. 23, T. 12 N., R. 5 E., the quartzite dips to the SE. at angles varying from 50° to 70° and strikes N. 70° E.

At the gap in the North Range at Ablemans, known as the Upper Narrows, the quartzite has a nearly vertical dip (see Pl. V), but, in general, it dips somewhat to the south, at angles varying from 70° to 90°, and strikes N. 70° E. In the Upper Narrows is a conspicuous mass of brecciated quartzite, which is very much more extensive in the east face of the gorge than it is in the west face.

Between Ablemans and North Freedom are several ridges of quartzite of especial structural interest. One of these is cut across at its northern end by the Baraboo River, and by the Chicago & Northwestern railroad about a mile SE. of Ablemans. In the railroad cut the quartzite has generally a low dip SE., at angles varying from 15° to 30°, and a strike approximately N-S. A short distance northwest of the railroad bridge, along the side of the ridge, the quartzite has a dip of 20° to 30° NE. and a strike N. 60° W. Going along this ridge, south of the Baraboo River, the dip is seen to be from 25° to 30° SE., the strike varying from N-S. at the railroad bridge to N. 55° to 65° E. immediately west of the bridge and also throughout the ridge farther southwest. At the southwest end of the ridge, on the Zart farm, the quartzite has an obscure bedding, apparently dipping NW. at an angle of 25°, while a short distance east, in the NE. ¼ of the SW. ¼ of sec. 4, the formation dips SE. at 20°. This ridge, therefore, trending NE. from the SW. ¼ of sec. 4 to the SW. ¼ of sec. 34, as indicated by the dip of the beds at the SE. end of the ridge, is very evidently a portion of an anticlinal



THE EAST BLUFF OF THE UPPER NARROWS OF THE BARABOO AT ABLEMANS.

Shows the south dip of the beds of quartzite. In the lower right-hand corner, above the bridge, appears some of the brecciated quartzite mentioned on p. 36. (After Salisbury and Atwood in Bull. Wis. Geol. and Nat. Hist. Survey No. 5.)

fold, the northwest limb of which has been mostly removed by erosion, as no northwest-dipping beds could be found on the northwest side of the ridge. Out in the flat-lying bottom land southwest of this ridge quartzite has been struck in exploration work, and it seems probable that this anticlinal extends beneath the sandstone and drift to the West Range.

The probability that the above described ridge is a portion of an anticlinal fold is strengthened by evidence of the complete anticlinal fold in the adjoining ridge immediately to the southeast in the vicinity of the school house and the Thom farm. A few hundred paces west and northwest and also southwest of the latter place, as indicated upon the map (Pl. I), the quartzite dips NW. 60° and strikes N. 60° E. On the east side of this ridge, at the school house in the SE. corner of sec. 4, and also NE. and SW. of the school house, the quartzite dips in the opposite direction, to the SE., at angles varying from 40° to 75° and generally trending N. 45° to 60° E. Thus there can be no doubt that in the vicinity of the SE. corner of sec. 4 this ridge represents an arched fold of the quartzite, the apex of the arch trending about N. 45° E.

The outcrops of quartzite in the eastern part of the village of North Freedom and also in the southwestern part of the village are suggestive of another fold in the quartzite, but at these places the bedding position cannot be definitely determined, though the quartzite in the outcrop in the eastern part of the village appears to be dipping steeply to the SE. and trending NE. Later exploration on the Hackett farm, showing the occurrence of the Freedom dolomite with steep dip about one fourth of a mile west of the quartzite outcrop in the southwestern part of North Freedom, would seem to indicate that the quartzite at this place stands nearly vertical.

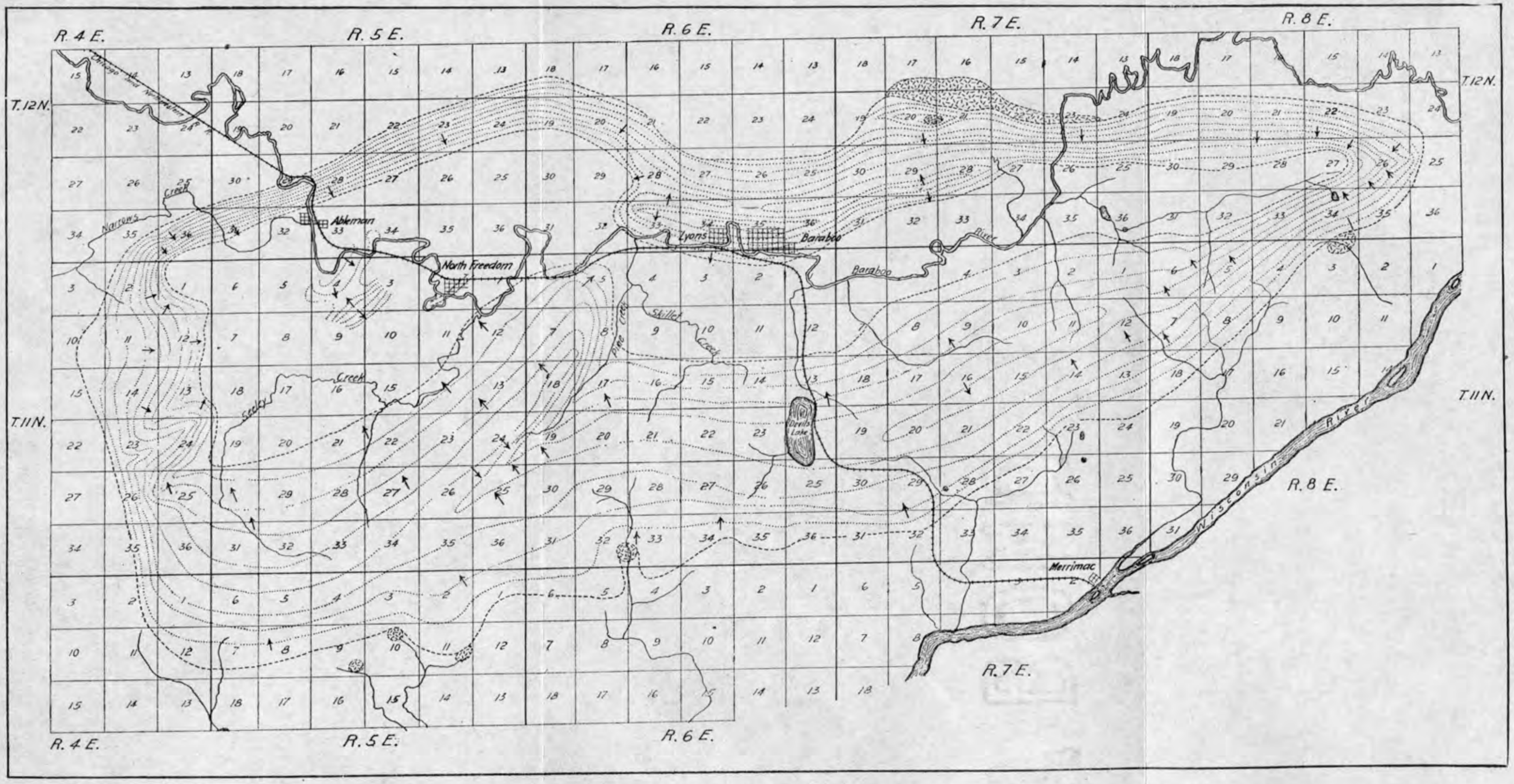
SUMMARY OF THE STRUCTURE OF THE QUARTZITE FORMATION.

The dips and strikes of the quartzite in the various parts of the district, as above described, and also many other determinations of local structure noted in the field but not specifically mentioned in the preceding discussion are graphically placed before the reader in hte accompanying sketch map (Pl. VI). This map shows at a glance the structure of the quartzite formation, the distribution of the older igneous series along the outer borders of the quartzite, and the location of the younger formations of slate and iron formation between the quartzite ranges, not yet described in detail.

Summarizing what has already been described in detail concerning the position of the quartzite beds in different parts of the district, the following structural features may be briefly pointed out.

The quartzite of the West Range has a prevailing dip to the eastward,—either east, northeast or southeast, and therefore, towards the interior of the basin between the quartzite ranges. There seems to be but a single thickness of the quartzite formation between the gorge of the Narrows Creek and the vicinity of the NE. 1/4 of sec. 23, T. 11 N., R. 4 E., the broadening of the range in secs. 11, 12, 13, and 14 being very evidently due to the low dip of the quartzite in this locality. The bending of the formation to the west, to form a half circle in sec. 1, would seem to indicate more or less arching of the beds in secs. 11 and 12. No westward dips complementary to the eastward dips were found in the West Range, though especially searched for.

The area of secs. 23, 24, 25, and 26, of T. 11 N., R. 4 E., is at the juncture of the West and South ranges, and here the formation is arched and bent as indicated in the sketch. The scarcity of outcrops in this section of the district leaves definite information concerning the amount of folding unsettled, but the vertical dips of the quartzite shown by the outcrops in the center of sec. 24 and the E-W. trend of the beds exposed in the SE. corner of sec. 13 suggest much close folding and bending in this vicinity. The vertical dip of the quartzite forming the falls of the small stream in the SE. 1/4 of the SW. 1/4 of sec. 35 also suggests close folding. The amount of adjustment by folding, fracturing, or faulting required for this turn at right angles of the quartzite formation at the junction of the South and the West range is undoubtedly very considerable in comparison



MAP DESIGNED TO SHOW THE STRUCTURE OF THE BARABOO QUARTZITE.

The space between any two of the dotted lines represents an estimated thickness of 500 feet of quartzite. The direction of the dotted lines indicates the strike of the quartzite beds and that of the arrow heads the dip. The barred areas on the north and south sides of the quartzite represent outcrops of igneous rock, upon which the quartzite rests.

with the generally low monoclinal dips and slight folding generally prevailing elsewhere throughout the West and South ranges.

The strata of the broad South Range, with very few exceptions, dip at a low angle, generally varying from 10° to 35° to the north-northwest, and have a strike N. 70° E. The most important and interesting exception to the NW. dip and NE. strike is occasioned by the synclinal fold in the Pine Creek valley. The high ridge of quartzite between Pine Creek on the southeast and the Seeley Creek and Baraboo River on the northwest, as already pointed out, is an anticlinal fold. The arching of the formation here not only explains the unusual width of the South Range in this vicinity, but is also especially significant when considered with the folding and bending of the quartzite in the North Range directly opposite, across the narrow portion of the Baraboo valley.

The other exception to the prevailing northwest dip is in the SE. ¼ of sec. 16, T. 11 N., R. 7 E., where the strata dip at a low angle, about 5° to the SE. In many places in the South Range the quartzite lies nearly flat, generally dipping slightly to the north, but the above low south dips suggest the possibility of the occurrence of other shallow synclinal folds. The east end of the South Range is comparatively narrow, but with this narrowing of the range there is a corresponding steeper dip of the strata.

The persistent north dip of the strata along the south face of the South Range is especially significant when considered in connection with the distribution of the areas of rhyolite, granite, and diorite along this side of the range, and with the basal character of the conglomerate at the bottom of the quartzite formation. The north dip of the quartzite, the basal conglomerate, and the distribution of the igneous rocks along the south margin of the range are entirely in harmony with each other and prove conclusively the overlying position of the quartzite of the South Range with respect to the adjacent igneous series.

At the east end of the district, where the South and North ranges join to form the pointed end of the canoe-shaped distribution of the quartzite, the formation is sharply bent into a <

shaped form with the strata converging to form the end of the trough of the canoe as indicated on the map. Going from the east end of the North Range towards the Lower Narrows, the strata are seen to be standing with nearly vertical dip, and trending N. 70° to 80° E., approximately parallel to the strike of the strata in the South Range. The north face of the North Range, immediately east of the Lower Narrows and for three miles to the west, is flanked with a considerable thickness of rhyolite, adjacent to which the strata have a nearly vertical dip, sometimes N. as low as 75° and sometimes S. 75°. The occurrence of conglomerate along the contact of the rhyolite and quartzite in this vicinity, basal to the quartzite and resting upon and containing fragments of the rhyolite, when considered in connection with what has already been shown concerning the structural relation of the quartzite adjacent to similar rhyolite along the South Range, obviously proves the similar relation existing here.

The quartzite strata in sections 20 and 29 and in the northern part of sec. 32, T. 12 N., R. 7 E., are very evidently folded into two anticlines with an intervening syncline. Farther west for several miles the quartzite is buried beneath drift and sandstone, but appears again at the surface a short distance west of Baraboo, in secs. 21, 28, 33 and 34, T. 12 N., R. 6 E., where a similar arching of the strata is present. The close folding in the last named locality is directly opposite the anticlinal fold west of Pine Creek in the South Range, and probably signifies an arching of the district as a whole in this vicinity, and thus very obviously is the cause of bringing the two ranges together here and narrowing the interior basin. Farther west, as far as the Upper Narrows at Ablemans, and also beyond, as far as the junction of the North and West ranges, the North Range is narrow and appears to show but a single thickness of the formation, the strata dipping vertically but more often to the south than to the north, as illustrated in the view of the quartzite of the Narrows at Ablemans (Pl. V).

Between the North and South ranges, west of North Freedom, the quartzite is arched into two anticlinal folds, illustrations undoubtedly of puckerings of the formation in the interior of the basin. Similar puckerings of the formation very probably exist elsewhere between the main quartzite ranges, but are obscured by the blanket of drift and sandstone covering the valley bottom.

The quartzite of the West Range is thus seen to have a prevailing dip eastward, of the South Range northward, and of the North Range southward. The dip of the strata is, therefore, with few exceptions, towards the interior valley, and the three ranges taken together form a synclinal basin with a varying amount of arching of the strata within the outer borders of the ranges, the synclinal resting unconformably upon igneous rock.

PREVIOUS THEORIES CONCERNING THE STRUCTURE OF THE QUARTZITE RANGES.

It has already been stated that the present study has shown the structure of the quartzite and its relations to the associated rock formations to be essentially different from the views of the structure held by geologists who have written upon the quartzites of the Baraboo district. Since the structure of the quartzite is essentially the structure of the district as a whole and the knowledge of it has an important bearing upon the exploration for iron ore in the district, and since the former theories of the structure have often been referred to in literature and adopted in part if not in full by many, it seems advisable to discuss these theories, though briefly.

One of the hypotheses, the earliest, concerning the structure of the quartzite ranges is shown in the following sketch by Irving,[1] a similar sketch having previously accompanied a paper by Chamberlin.[2]

Chamberlin and Irving, however, held only tentatively the view illustrated in this sketch, that the South and North ranges together formed the north half of an anticlinal fold, the apex

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[1] Geol. of Wis., vol. 2, p. 506.

[2] Wis. Acad. of Science, vol. 2, p. 134.

of the anticlinals being south of the South Range. The observations upon which this hypothesis was based and the explanation as given by Irving are as follows:[1]

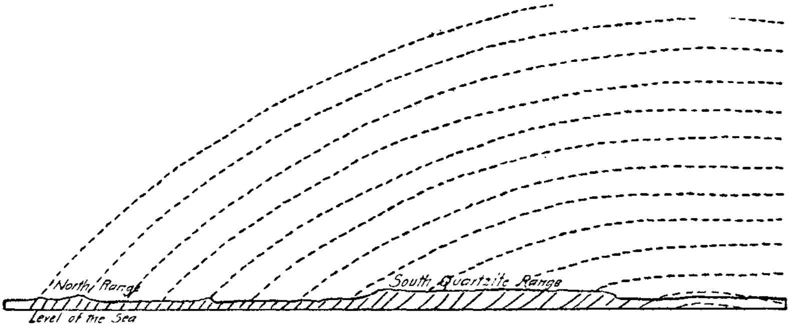

FIG. 1.—Ideal sketch to show structure and amount of erosion of the Baraboo Ranges. Scale natural, 12,000 feet to the inch. (After Irving.)
The error in this sketch is due to the erroneous assumption that quartzite lies immediately south of the South Range, and that the North and South Ranges together form the north half of the same anticline. (The author.)

"The quartzites and associated rocks are quite distinctly bedded, though the bedding is not unfrequently obscured by cross-jointing, which is often to be observed on a grand scale. The dip, wherever observed, is towards the north, through the whole extent of both ranges, but varies much in amount. In the southern range it is usually quite low, as low sometimes as 15° in the middle and broadest portions. In the northern range the dips are always much higher, running from 55° to 90°. The rocks of the two ranges appear, however, to be parts of a continuous series, the quartz porphyry beds of the northern range constituting the uppermost layers.

"For the relative positions of the different ranges and their relations to the surrounding horizontal strata, see Atlas Plate XIV, and the sections of Plate XXI of this volume.[2] If the view, just indicated, that there are no folds concealed beneath the sandstone in the intervening valley, is the correct one, the thickness of the entire series must be very great, and the amount

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[1] Geol. of Wis., vol. 2, pp. 506–507.

[2] Geol. of Wis., vol. 2.

of erosion that has taken place correspondingly great. Figure 23[1] indicates the present structure and relative positions of the ridges, and, by the dotted lines above, the possible original structure, and the extent of the erosion that has taken place. The figure is drawn to a natural scale, the line of section being the same as that of figure 11 of Plate XX. The heavy black line represents the overlying Potsdam sandstone. It is not impossible that the valley between the ranges owed its existence, to some extent, in the first place to soft rocks intercalated between the harder quartzites. The hypothesis of figure 23 is not altogether satisfactory. The entire disappearance of the other side of the great arch, as well as the peculiar ways in which the ranges come together at their extremities are difficult to explain by it. It may be said in this connection that the dip observations toward the west are not so satisfactory or numerous as they might be."

This hypothesis was unsatisfactory to Irving for several reasons, as he himself fully appreciated. After what has been presented by the writer concerning the dips and strikes of the quartzite and the relations of the quartzite to the associated igneous rocks, it will at once be seen that the observations upon which Irving based his hypothesis (see figure 1) were incomplete concerning dips and strikes of the quartzite strata throughout the district, and his idea erroneous concerning the structural relations of the quartz porphyry to the quartzite. It is probable that Irving based his cross section on observations of the dip made only at Devils Lake and the Lower and the Upper Narrows. It is obvious that if a cross section extending across the east and west ends of the district had been constructed a quite different appearing section would have been the result. It was Irving's belief that the quartz porphyry, called rhyolite in this report, along the north face of the North Range was later in origin than the quartzite. It may be stated in this connection that Irving was not aware of the occurrence of similar igneous rocks along the south face of the South Range. In previous

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[1] **Fig. 1 of this report. See opposite page.**

pages the writer has described the conglomerate at the base of the quartzite formation as made up of pebbles and fragments of the rhyolite. The character of this conglomerate, taken in connection with the position of the quartzite bedding immediately adjacent to the rhyolite, shows clearly that the rhyolite forms the basement upon which the quartzite was later deposited.

The other hypothesis suggested to explain the structure of the quartzite has been presented by R. D. Salisbury and W. W. Atwood in a cross section[1] of the Baraboo district. This hypothesis was based on the errneous belief that the North and South ranges are each complete anticlinal folds instead of each being a half of an anticlinal fold, as shown by the writer. The observations of dip, as platted in the above mentioned cross section, are essentially correct. The error in this cross section lies in the suggestion of the continuation of the quartzite beds dipping north on the north side of the North Range and south on the south side of the South Range, where igneous rock, consisting of rhyolite, granite, and diorite, is now known to occur and to underlie the quartzite. This hypothesis was very probably based on the erroneous belief that the rhyolite associated with the quartzite was of intrusive character and overlaid the quartzite.

For the better comparison of the hypothesis of the writer with the two erroneous hypotheses above described, the following sketch (see Pl. VII) is presented, which illustrates the principal structural feature of the district, the explanation of which has been given in detail in previous pages and stated briefly in the closing paragraph of the discussion concerning the structure of the quartzite (see p. 41).

THICKNESS.

The structural features of the quartzite being understood, an estimate of the probable thickness of the formation can be calculated. For purposes of comparison, the estimated thickness in various parts of the district is given.

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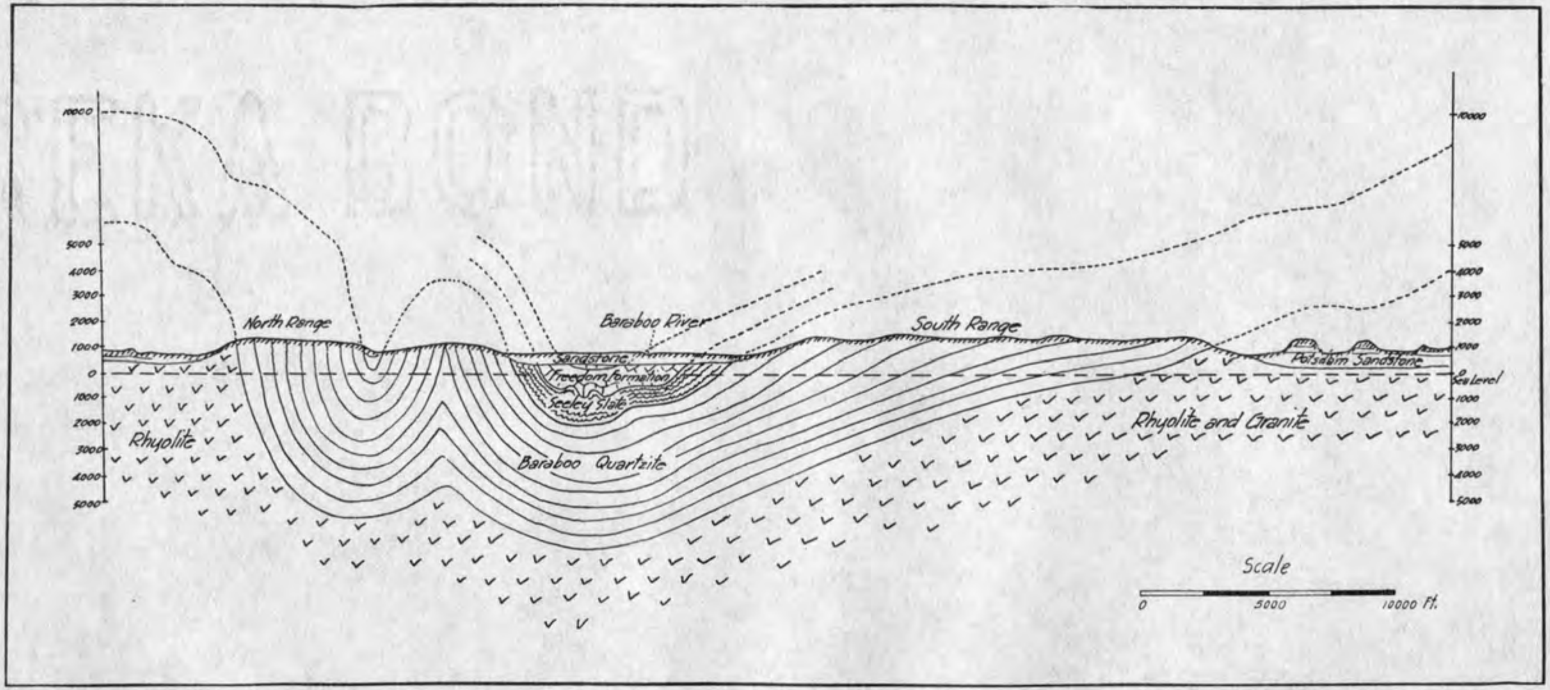
[1] Bull. Wis. Geol. and Nat. Hist. Survey No. 5, p. 16, fig. 4.

[2] Op. cit., p. 18.



GENERALIZED CROSS SECTION EXTENDING NORTH AND SOUTH ACROSS THE BARABOO DISTRICT.

The horizontal and vertical scales are the same. The Baraboo quartzite rests unconformably upon the basement of igneous rock, consisting of rhyolite, granite, and diorite. The continuous lines represent the synclinal folds of the quartzite, slate, and Freedom formation, upon which rests unconformably the overlying Potsdam sandstone. The dotted lines indicate the probable position of the quartzite, slate, and Freedom formation above the present surface before they were eroded.

The width of the South Range at Devils Lake is about three and one-half miles, with a dip varying from 5° to 25°. Along the lake shore the dip is 5° to 20°, while on the south face of the range, south of the lake, the beds stand at a higher angle, varying in places from 20° to 40°. Throughout the width of the range at the lake, however, the most common dip seems to be between 5° and 20°, and hence an average of 15° will probably be not far from correct. On the basis of a width of three and one-half miles and dip of 15°, the calculated thickness is 4786 feet.

At the east end of the district, where the North and South ranges join, the width of outcrop in both ranges is approximately the same and is about one mile, with dip generally varying between 50° and 70°. If a width of 5000 feet and dip of 60° be taken as representing the probable conditions, the thickness would be 4330 feet.

At the Lower Narrows the width of the range is slightly less than a mile, probably 5000 feet, with nearly vertical dip, which would indicate a probable thickness of 5000 feet. At the Upper Narrows at Ablemans the width of the range is about 4000 feet with dip varying from 75° to 90°, and hence indicating a thickness of 4000 feet. At the gorge of Narrows Creek a similar thickness of about 4000 feet is indicated.

In the broad portion of the west end of the South Range, south of the Illinois mine, the width of the range across the strike of the formation is about four and one-half miles. In this section of the range there is probably some broad open folding and, therefore, nearly flat-lying strata in places. It seems very probable that there is a continuation of the Pine Creek syncline existing in this vicinity. The observed dips across this section of the range varied from 10° to 30° northwest, which would seem to indicate a much greater thickness than the above estimates. However, if folding occurs here, as seems probable, a thickness of 4000 to 5000 feet is amply sufficient to explain the surface width of this part of the range.

It is very probable, of course, that the thickness of the formation varies in different parts of the district on account of the difference in original thickness of sedimentation. Unequal original sedimentation would likley occur in a fragmental deposit like this quartzite, especially when deposited unconformably upon an underlying floor of igneous rock like that prevailing in this district.

If faulting does not occur, it seems probable from the above and other similar estimates that the thickness of the quartzite formation is somewhere between 4000 and 5000 feet. Faulting undoubtedly occurs to a small extent, though no evidence of large faults has yet been discovered. While this thickness may seem unusually large, all evidence seems to point to the above estimate as a fair approximation to the thickness on the above assumption of little or no faulting.

RELATIONS TO OTHER FORMATIONS.

The stratagraphic position of the quartzite formation has already been stated. The structure of the quartzite and the character of the conglomerate at its base are such as to prove conclusively the superjacent position of the quartzite with respect to the igneous rocks of the district. The formation immediately overlying the quartzite is the Seeley slate, described in the following pages.

SECTION II.

THE SEELEY SLATE.

DISTRIBUTION.

The Seeley slate formation, locally called the "gray slate", is not known to form surface exposures in the district, and hence all information concerning the distribution, character, etc., of this formation has been obtained through the work of exploration for iron ore. The local name "gray slate" is appropriate, but in geological literature it is much more convenient to use specific names for formations, and hence the name Seeley slate is adopted because of the occurrence of this slate near the Seeley Creek. The slate is at present known to be distributed along the north side of the south quartzite range, in the vicinity southwest of North Freedom, for a distance of six or seven miles. It has been found, as shown on the map (Pl. I), to extend across portions of secs. 1, 2, 3, 10, 11, 14, 15, 16, 17, 18, 19, 20 and 21 of T. 11 N., R. 6 E. The area indicated as slate on the map is necessarily that portion of it lying immediately beneath the Potsdam sandstone. It is, of course, shown by exploration to extend beneath the overlying Freedom iron-bearing formation. The boundary lines of the slate formation between the slate and underlying quartzite and between the slate and overlying iron-bearing formation are necessarily only an approximation. It is very probable that if the boundary could be definitely located, it would be found to form a very undulating line, much more undulating between the slate and overlying softer iron formation than between the slate and the underlying more rigid quartzite. The boundary of economic importance, of course, is the one delimiting the iron formation; hence it is only occasionally that contacts between the slate and the quartz ite are definitely located.

Character of Rock. The normal Seeley slate is a gray rock, generally, showing stratification by alternating bands varying slightly in texture and color. The slate, as shown in the Illinois mine and in the large number of drill cores from various parts of the explored district, is strikingly uniform in all respects. It is not unlikely, however, that phases of this slate formation may later be found in other parts of the district quite unlike that known at the present time. The slate occurring in the Illinois mine and noted in drill cores is uniformly fine grained and sufficiently soft to be readily whittled with a knife. At the mine some of the slate shows abundant fine lines of stratification, while some of it shows very little banding. It generally possesses good cleavage, usually cutting diagonally across the bedding. Some of the slate at the mine can be split into very thin leaves, the cleavage approaching in character that of commercial slate.

Microscopic Character. Thin sections of the slate examined under the microscope are seen to consist of an abundance of a nearly colorless to grayish mineral and a green mineral, both occurring in very minute scaly particles, and numerous small grains of quartz. From 60 to 80 per cent of the slate appears to be made up of this mixture of gray and green mineral. The colorless gray mineral has a double refraction approximating that of feldspar, and is believed to be andalusite developed out of an alumina-rich variety of kaolin by dehydration. Some kaolinite is also probably present. The green mineral occurs in considerably larger flakes than the colorless to grayish mineral, and has a very low double refraction, corresponding to chlorite. The quartz generally occurs in very minute grains and its quantity is difficult to estimate, but it probably forms from 25 to 35 per cent of the rock. Numerous small crystals and grains of magnetite or hematite are quite uniformly distributed throughout some of the sections of the slate, probably constituting two or three per cent of the rock. Small crystals of brown mica, tourmaline, and apatite are also present. The occurrence of tourmaline and apatite is of interest, since it indicates the presence of the elements boron, fluorine, phosphorus and chlorine in small quantities. A photomicrograph of the slate is shown in figure 2, Plate XXI.

Chemical Analysis. The following analysis of the slate, from two specimens[1] collected from the Illinois mine, is by Dr. Victor Lenher,[2] of the University of Wisconsin:

Silica, SiO_2	62.03
Alumina, Al_2O_3	29.34
Ferric oxide, Fe_2O_3	trace
Ferrous oxide, FeO	5.09
Manganese oxide, MnO	none
Magnesia, MgO	0.29
Lime, CaO	0.16
Sodium oxide, Na_2O	trace
Potassium oxide, K_2O	trace
Water, at 110°, H_2O	0.01
Water, at red heat, H_2O	2.24
Titanium oxide, TiO_2	none

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[1] Specimens 6966 and 6967.

[2] The original analyses in this report, unless otherwise indicated, were made by Dr. Lenher.

Phosphoric oxide, P_2O_5	0.08
Chromium oxide, Cr_2O_3	none
Carbon dioxide, CO_2	none
Carbonaceous matter, C	none
Sulphur, S	0.10
	99.40

The composition of this slate is an interesting one. The analysis shows the rock to consist almost entirely of silica, alumina, ferrous oxide and a small amount of water of constitution. The microscopic examination, as already stated, shows the rock to consist almost entirely of a grayish mineral, probably andalusite, chlorite, and quartz, and probably a small amount of kaolin. The protoxide of iron and most of the small amounts of lime and magnesia are probably combined with alumina and silica and part of the water to form a chlorite corresponding to the iron-bearing variety, daphnite. The remainder of the alumina is combined with silica, after deducting about 20 to 30 per cent for quartz, to form a variety of aluminosilicate, probably andalusite. The comparatively high percentage of alumina shown by the analysis seems to indicate that the slate originally contained a large amount of kaolin, which might very easily through processes of deep-seated metamorphism lose its water of constitution and form one of the pure aluminosilicates, such as andalusite. There can be little doubt that the original clay mineral must have contained a much larger amount of water than the present corresponding mineral of the slate, and it has been shown by experimentation[1] that by ignition at low redness kaolin loses its water of constitution and aluminosilicate is formed. By hydration under surface conditions andalusite usually alters to kaolin.

STRUCTURE.

The slate, as already stated, shows faint lines of stratification across which well-developed diagonal cleavage extends. At the

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[1] Clarke, F. W., The constitution of the silicates: Bull. U. S. Geol. Survey No. 125, p. 32.

Illinois mine, where the contact of the slate with the overlying iron formation is exposed in the several levels, the dip of the slate is 47° NW., the strike being approximately N. 80° E. The dip of the cleavage is steeper than that of the bedding and is generally about 65° to 75° NW. The slate seen in the cross section of the mine is considerably crumpled, and the above dip of 47° is only the average for the formation at this place.

There can be little doubt that the bedding of the slate essentially conforms to the bedding of the quartzite and has, therefore, been subjected to all the folding of the latter. The position of the slate, as far as known at present, is indicated in the several cross sections of Plate XII.

THICKNESS.

The thickness of the slate can only be estimated. A thickness of at least 100 feet is shown in the second level of the Illinois mine. A drill hole at the Illinois mine, inclined 60° SE., is known to have penetrated 460 feet of the gray slate without striking any other formation, thus indicating a known thickness of at least 400 feet. The horizontal distance between the contact of iron formation with the slate and contact of slate with the quartzite would seem to indicate a thickness of somewhere between 500 and 1000 feet. The probable thickness of the formation is, therefore, placed at 500 to 1000 feet.

RELATIONS TO OTHER FORMATIONS.

The junction of the Seeley slate with the underlying Baraboo quartzite has been penetrated at several placs by drilling, and there was no indication of an unconformity between the two formations, such as the occurrence of conglomerate. The parallel distribution of the slate formation along the south quartzite range, as shown by exploration in the western part of the district, also indicates its conformable position upon the quartzite formation. The contact of the Seeley slate with the Freedom iron-bearing formation, as shown in the Illinois mine and by numerous drill cores, also clearly indicates a gradual transition between these two formations. All evidence, therefore, points to the conformable relations of the Seeley slate to the underlying quartzite and the overlying iron-bearing formation.

SECTION III.

THE FREEDOM FORMATION (IRON-BEARING).

DISTRIBUTION.

The distribution of the Freedom iron-bearing formation (see map, Pl. I), like that of the Seeley slate, has been outlined entirely from information gained by underground exploration. It is, therefore, only southwest of North Freedom that sufficient information has been obtained to delimit the iron-bearing rocks. In this vicinity where diamond drilling has been done, covering perhaps an area of eight or ten square miles, from fifty to seventy-five diamond drill holes have been put down through portions of this formation to the underlying Seeley slate. This formation, as shown on the map, is known in the partially explored district to cover an area of five or six square miles in sections 2, 3, 9, 10, 11, 15, 16, 17 and 20 of the town of Freedom, T. 11 N., R. 5 E. The probable distribution of the iron-bearing formation in the unexplored parts of the district is discussed in another chapter of this report.

KINDS OF ROCK.

The Freedom formation consists of a variety of rock, including slate, chert, dolomite, and iron ore and all gradational phases between these kinds of rock. The formation consists almost entirely of the minerals quartz, dolomite, hematite, and varieties of the clay-producing minerals, such as chlorite and kaolin or an alumino-silicate corresponding to dehydrated kaolin, such as andalusite. Mixtures of all possible proportions of these minerals are present in the rocks composing the formation, the resultant rocks being ferruginous slate, ferruginous chert, ferruginous dolomite, cherty dolomite, cherty slate, dolomitic slate, dolomite, and iron ore.

The dolomite is by far the most abundant rock of the formation and forms its upper member, while the various kinds of ferruginous rock form the lower member. It is possible that future work based on later exploration may furnish data upon which to divide the formation into two formations. It is much more convenient at present, however, to consider the dolomite and the iron-bearing rocks as one formation on account of the interstratification of ferruginous dolomite in the lower member and because of the overlying position of the pure dolomite with respect to the iron-bearing rocks.

FERRUGINOUS KAOLINIC SLATE.

The rocks of this type occur in thin beds between the Seeley slate and the ore deposit in the Illinois mine, and also closely overlying the iron ore deposit. It is also struck in numerous drill holes of the district. This phase is usually black and fine grained, having a greasy feel like ordinary soapstone. Some of the phases are so soft as to be readily cut with the finger nail; other phases are very hard, showing a gradation into siliceous or cherty slate. In places this phase of slate contains iron pyrite in abundance. A phase of this slate[1] from the Illinois mine, as seen under the microscope, consists mainly of a colorless mineral with low birefringence and low index of refraction, probably kaolinite grains and also aggregations of grains of hematite. There is also usually present a small amount of carbonate and numerous very minute specks and dots of a yellowish and brownish mineral, probably limonite.

An analysis of the black slate was made, resulting as follows:

Silica, SiO_2	33.29
Alumina, Al_2O_3	28.57
Ferric oxide, Fe_2O_3	27.51
Ferrous oxide, FeO	2.54
Manganese monoxide, MnO	0.21
Magnesia, MgO	none
Lime, CaO	0.17
Carbon dioxide, CO_2	1.25
Water, at 110°, H_2O	0.76

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[1] Specimen 6884.

PLATE VIII.

PLATE VIII.

FERRUGINOUS CHERT AND FERRUGINOUS SLATE.

Fig. 1.—Photograph of polished specimen of a phase of ferruginous chert. Natural size. Specimen 6888. From Illinois mine. This phase consists of very thin layers of fine cherty quartz, alternating with layers of hematite, chlorite, and kaolin (see fig. 2, Pl. XXIII, and analysis, p. 56). The rock is folded, and in the upper right-hand corner of the specimen, on the convex sides of the folds, are numerous tension fractures filled with vein quartz.

Fig. 2.—Photograph of polished specimen of ferruginous slate. Natural size. Specimen 7017. From Illinois mine. This phase of the iron-bearing formation consists of layers of nearly pure hematite, generally varying from thin leaves to layers one-half inch in thickness, interstratified with layers of kaolinic slate containing much hematite. The photograph shows a layer of hematite near the middle of the specimen and a much thinner seam of hematite near the middle of the lower half of the specimen.

Fig. 1. FERRUGINOUS CHERT.

Fig. 2. FERRUGINOUS SLATE.

Water, at red heat, H_2O	5.19
Phosphoric oxide, P_2O_5	0.008
Titanium oxide, TiO_2	none
Sulphur, S	0.04
Carbonaceous matter, C	none
	99.538

The composition of this ferruginous slate resembles in many respects the aluminous slate of the Seeley formation, the principal difference being the higher content of iron present in this phase. The analysis shows the principal constituents to be silicia, alumina, ferric oxide, ferrous oxide, water of constitution, and carbon dioxide. The ferric oxide, Fe_2O_3, is mainly in the form of hematite, the ferrous oxide mainly in the form of siderite, and since no free silica (quartz) was noted in the slide, the silicia, alumina, and water of crystallization are very probably largely represented by the colorless mineral, evidently a partially dehydrated member of the kaolin group. A finely ground portion of this slate was washed with hydrochloric acid containing stannous chloride, which resulted in the entire removal of the iron, leaving a white, greasy, plastic mass having the physical properties of kaolin. The principal constituents of the rock are mainly, therefore, partially dehydrated kaolin, hematite, and siderite, in the following proportions:

Partially dehydrated kaolin	67.05
Hematite	27.51
Siderite	3.29

FERRUGINOUS CHERT.

An abundant rock occurring in the iron formation, and likewise abundant in iron-bearing formations of the Lake Superior region, is banded, ferruginous chert. Good examples of this type of rock are to be seen in the crosscuts of the Illinois mine, lying between the ore body and the Seeley slate formation. It was also noted in many drill cores. This phase of the formation is closely associated with banded rock containing much calcite, siderite, and kaolin.

The ferruginous chert consists of layers of red and grayish chert, alternating with layers of nearly pure hematite, and with layers of chert mixed with hematite. These alternating layers generally vary from one-fourth of an inch to an inch in thickness, and each layer also varies in thickness as it is followed along the strike and dip.

The ferruginous chert is very fine grained, the quartz of the cherty layers occurring in very minute granules. A photomicrograph of a portion of a cherty layer is shown in figure 1, Plate XXII. The iron oxide layers are not sharply separated from the cherty layers, the hematite and fine quartz being mixed in varying proportions along the junction of the two layers. In some of the phases of this rock the iron oxide is occasionally concentrated in spheroidal forms, and is probably of concretionary origin. Besides the hematite and cherty quartz, there is often present a small amount of a green and colorless mineral occurring in the form of scales and needles, evidently members of the chlorite or kaolin group. These cherts show considerable folding, puckering, and also brecciation. The vein material is very largely quartz, and to a minor extent calcite or dolomite.

An analysis of a phase of the ferruginous chert by Dr. Lenher (specimen 6888) is shown in the following table:

Silica, SiO_2	52.00
Alumina, Al_2O_3	2.62
Ferric oxide, Fe_2O_3	40.11
Ferrous oxide, FeO	2.78
Manganese monoxide, MnO	none
Lime, CaO	0.10
Magnesia, MgO	none
Carbon dioxide, CO_2	0.52
Water, at 110°, H_2O	0.21
Water, at red heat, H_2O	1.88
Carbonaceous matter, C	0.05
Phosphoric oxide, P_2O_5	0.13
Sulphur, S	0.01
Titanium oxide, TiO_2	none
Chromium oxide, Cr_2O_3	none
	100.41

The rock analyzed is the one from which the photomicrograph (fig. 2, Pl. XXII) was taken. This rock, in thin section, is seen to consist of quartz, hematite, a small amount of carbonate, and colorless and grayish mineral in minute specks and scales.

Considering the whole of the Fe_2O_3 as hematite, the CO_2 as combined with CaO and FeO to form calcareous siderite, the remaining FeO, the Al_2O_3 and H_2O combined with SiO_2 to form chlorite, and the remaining SiO_2 as quartz, as seems to be shown by the thin section, the following approximate proportions of minerals are indicated.

Hematite	40.11
Calcareous siderite	1.34
Chlorite	9.38
Quartz	49.00

DOLOMITIC SLATE.

An apparently important phase of the formation is a slaty rock, rich in carbonate. This rock was noted in considerable abundance among the drill cores from various explorations in the district and in the crosscuts of the Illinois mine. The rock is grayish to slate colored, is readily cut with the knife, and effervesces rapidly on the application of cold hydrochloric acid. The drill cores of this phase quite generally show slaty cleavage, and usually indistinct lines of bedding.

Under the microscope this rock is seen to consist of carbonate, generally dolomite, small grains of quartz, flakes of chlorite and kaolin, and specks and small grains of iron oxide. These minerals do not generally have a uniform distribution, but certain ones predominate in irregular layers and patches. The proportions of each of the predominating minerals, such as the quartz, calcite, chlorite, and kaolin, are very difficult to determine. Not only is the real amount of fine quartz and calcite, as seen in thin section, deceptive in appearance, but the amount of each rapidly varies within narrow limits in the beds.

A phase[1] of this calcareous slate was analyzed and shown to have the following composition:

Silica, SiO_2	42.53
Alumina, Al_2O_3	11.48
Ferric oxide, Fe_2O_3	6.43
Ferrous oxide, FeO	2.31
Manganese monoxide, MnO	0.03
Lime, CaO	13.61
Magnesia, MgO	7.09
Carbon dioxide, CO_2	15.82
Water, at 110°, H_2O	0.09
Water, at red heat, H_2O	0.38
Carbonaceous matter, C	none
Phosphoric oxide, P_2O_5	0.01
Sulphur, S	0.04
Titanium oxide, TiO_2	none
Chromium oxide, Cr_2O_3	none
	99.82

The thin section appears to indicate that the phase analyzed contains about 25 per cent of quartz, and that all the Fe_2O_3 occurs as hematite. As indicated by the thin section and the analyses, the approximate amounts of principal minerals appear to be about as follows:

Quartz, SiO_2	25.00
Hematite, Fe_2O_3	6.43
Dolomite—$CaCO_3$, 24.30; $MgCO_3$, 9. 79	34.09
Chlorite and other clay mineral	33.65

CHERTY DOLOMITE.

An abundant phase (see Pl. XI) of the formation, well illustrated in the workings of the Illinois mine, is a banded fine-grained carbonate rock, which effervesces readily on the application of hydrochloric acid. The banded appearance of this rock is quite similar to some phases of the banded, ferruginous cherts. This is a softer rock than the banded, ferruginous cherts, however, and can readily be cut with the knife. The

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[1] Specimen 6894.

PLATE IX.

PLATE IX.

BANDED FERRUGINOUS CHERT AND BANDED FERRUGINOUS DOLOMITE.

Fig. 1.—Photograph of polished specimen of banded ferruginous chert. Natural size. Specimen 6887. From Illinois mine. Common phase of the banded ferruginous red chert closely associated with the iron ore of this district and common in the other pre-Cambrian iron-bearing districts. The uppermost layer is hematite, the next is red chert or jasper, the next is hematite, and the next, the lower half of the specimen, is jasper. The light-colored specks are crystals of carbonate, probably calcite. Small veins of quartz penetrate the rock.

Fig. 2.—Photograph of polished specimen of banded ferruginous dolomite. Natural size. Specimen 7069. From Illinois mine. Common phase of the dolomite containing layers of hematite. The upper, grayish portion of the specimen is mainly dolomite containing very thin laminae of hematite; the lower half contains two layers of hematite with an intervening laminated band of ferruginous dolomite. The alternating layers of hematite and dolomite are irregular in thickness. Veins of quartz and of quartz and calcite cut across the stratification.

Fig. 1. BANDED FERRUGINOUS CHERT.

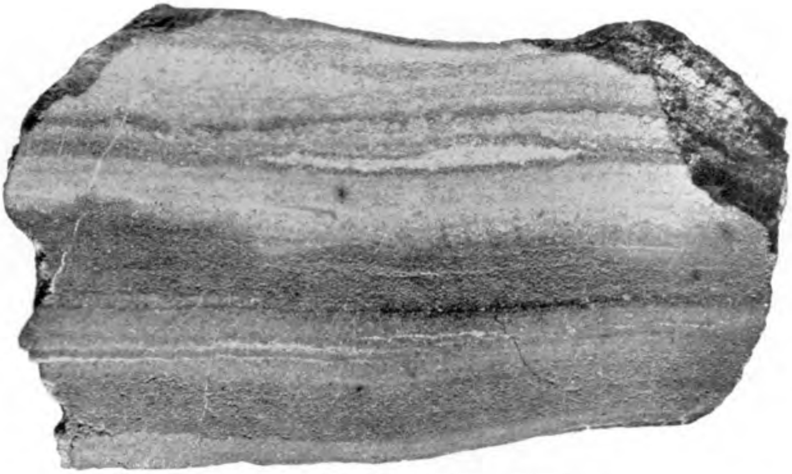

Fig. 2. BANDED FERRUGINOUS DOLOMITE.

bands generally vary from minute leaves to layers nearly an inch in thickness, the alternating layers varying from grayish and greenish brown to slate color. A thickness of five to ten feet of this phase of rock occurs in the Illinois mine, between the Seeley slate formation and the iron ore deposit. This impure dolomite is associated with nearly pure dolomite and also with banded ferruginous cherts and slates, and grades into them. Similar rock was observed among the drill cores from the NE. corner of the SE. ¼ of the NE. ¼ of sec. 10, T. 11 N., R. 5 E., at depth of 374 to 387 feet, above which lie ferruginous and calcareous slates, and below which are strata of cherty dolomite, ferruginous chert, and ferruginous slate. Thin sections of this phase show a prevailing carbonate mineral, associated with various amounts of fine quartz, flakes of kaolin or chlorite, or both, and grains of hematite.

A thin section of a phase[1] of this rock, the chemical composition of which is shown in the following analysis, consists of a large proportion of finely granular carbonate, an abundance of minute laths of kaolin, chlorite, or a member of the clintonite group, and considerable fine quartz. The carbonate forms the principal portion of the section, mingled with which the other constituents have an irregular distribution in layers and patches. The kaolin or chlorite is especially noticeable in patches, as well as in small amounts irregularly distributed with the carbonate. The thin section shows two small veins, consisting mainly of quartz associated with a small amount of carbonate.

An analysis of a common phase of this rock (specimen 7006) occurring abundantly in the crosscuts of the Illinois mine, about half way between the Seeley slate and the ore deposit, is as follows:

Silica, SiO_2	23.04
Alumina, Al_2O_3	2.50
Ferric oxide, Fe_2O_3	trace
Ferrous oxide, FeO	8.57
Manganese oxide, MnO	1.44

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[1] Specimen 7006.

Lime, CaO	20.78
Magnesia, MgO	11.50
Carbon dioxide, CO_2	30.81
Titanium oxide, TiO_2	none
Sulphur, S	none
Phosphoric oxide, P_2O_5	trace
Alkalies, Na_2O, K_2O	trace
Water, at 110°, H_2O	0.13
Water, at red heat, H_2O	0.97
	99.74

The proportion of minerals in this particular phase, as indicated by thin section and analysis, is difficult to determine. The carbonate necessarily contains some iron or manganese, or both, as there is more than enough CO_2 to satisfy the valence of the CaO and MgO. It is very probable that the hydrous alumino-silicates, as well as the carbonate, contain all of the bases, and therefore the proportion may be estimated as follows:

Manganic ferro-dolomite	about 66.00
Hydrous alumino-silicates, containing calcium, magnesium, iron, and manganese	about 20.00
Quartz, partly secondary in veins	about 14.00

A somewhat similar phase of cherty dolomite occurs to a small extent near the Seeley slate formation in the second crosscut of the Illinois mine. The same strata may occur in the first level, but were not noted. This phase, in the hand specimen,[1] appears to consist almost entirely of red carbonate, through which are scattered pockets and irregularly shaped areas of white cherty quartz. A thin section of this rock shows about equal proportions of carbonate, quite uniformly colored red and of similar aspect throughout, and cherty quartz, comparatively free from the coloring matter of red iron oxide. A vein of gray-colored carbonate, probably calcite or dolomite, cuts through the rock, as seen in thin section. This carbonate rock was analyzed because it was thought the red carbonate might be nearly pure siderite. The portion from which analysis was made was a

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[1] Specimen 6994.

fragment about an inch in diameter, from which the section described above was cut. The partial analysis, made by Dr. Lenher, is as follows:

Silica, SiO_2	44.34
Alumina, Al_2O_3	1.92
Ferric oxide, Fe_2O_3	2.05
Ferrous oxide, FeO	6.20
Manganese monoxide, MnO	0.79
Lime, CaO	15.07
Magnesia, MgO	6.04
Carbon dioxide, CO_2	22.55
Water, at 110°, H_2O	0.06
	99.02

This partial analysis is an interesting one, for it indicates that the red carbonate is not siderite but a ferro-dolomite, bearing some manganese. It has already been pointed out that the carbonate present in the rock, with the exception of the carbonate of the secondary vein, is red and of uniform character throughout. Calculating the amount of CO_2 necessary to satisfy the valency of all the CaO, MnO, and FeO, it will be seen that there is lacking only 0.15 per cent of CO_2 theoretically required to satisfy all of the above bases. Since it is impossible to know which of these bases is united in small amount with SiO_2, and since the difference in amount of determined and required CO_2 is so small, it may be assumed that all the above bases are united with CO_2 to form the carbonate. The percentage of each carbonate present in the rock would then be as follows:

$CaCO_3$	26.906
$MgCO_3$	12.64
$MnCO_3$	1.235
$FeCO_3$	9.98
Total carbonate	50.76

As already stated, these bases are very probably present in isomorphous combination to form a single carbonate, forming a manganic ferro-dolomite. (A probable exception to this is the small amount of carbonate in the vein material.)

The mineral constituents of the rock may be estimated as follows:

Manganic ferro-dolomite		50.76
Quartz	about	42.00
Chlorite, or other clay mineral		5.00
Hematite		2.00

After this partial analysis had been made of the small fragment from which the thin section was cut, a complete analysis of the whole specimen, representing a mass about three inches in diameter, was made, with the following result:

Silica, SiO_2	18.17
Alumina, Al_2O_3	4.73
Ferric oxide, Fe_2O_3	8.37
Ferrous oxide, FeO	7.04
Manganese monoxide, MnO	0.63
Lime, CaO	19.00
Magnesia, MgO	12.55
Carbon dioxide, CO_2	29.21
Water, at 110°, H_2O	0.21
Water, at 250°, H_2O	0.18
Alkalies, K_2O, Na_2O	trace
Sulphur, S	trace
Phosphoric oxide, P_2O_5	trace
	100.09

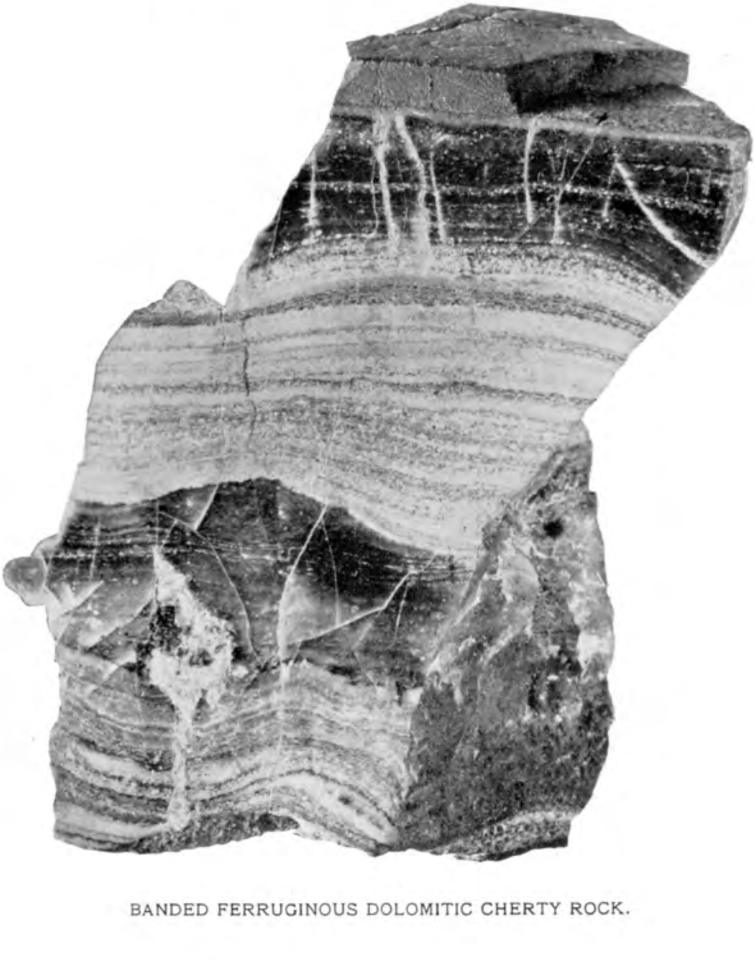
The marked difference in the amount of some of the principal constituents of the small fragment, as compared with the larger mass in SiO_2, Al_2O_3, and Fe_2O_3 indicates how rapidly these rocks, though throughout very fine grained, vary in composition. After calculating the amount of CO_2 necessary to satisfy the valency of the CaO and MgO, there still remains some CO_2 to combine with the FeO or MnO, or both. It is reasonable to presume, since 4.73 per cent of Al_2O_3 is present, that some of the MgO and CaO is in combination with alumina to form silicates, and therefore a still larger amount of CO_2 is in combina-

PLATE X.

PLATE X.

BANDED FERRUGINOUS DOLOMITIC CHERTY ROCK.

Photograph of polished specimen of banded ferruginous dolomitic cherty rock. Natural size. Specimen 7025. From Illinois mine. This phase of the iron-bearing formation consists of alternating layers of chert, dolomite or ferro-dolomite, and hematite. This single specimen exemplifies the relations of quartz, hematite and carbonate shown in the two specimens of Plate IX. Beginning at the top, the uppermost layer is hematite, the next layer below is chert, the next of laminated gray rock is dolomite, the next is chert grading down into alternating thin laminae of chert, dolomite, and hematite at the bottom. Numerous veins, consisting largely of quartz and to a small extent of calcite or dolomite, permeate the rock and extend through all the layers.



BANDED FERRUGINOUS DOLOMITIC CHERTY ROCK.

tion with the FeO than would be the case if all the CaO and MgO formed carbonate. It seems reasonable to presume, therefore, that the carbonate present in the larger mass is a ferrodolomite, bearing some manganese, though bearing less iron and manganese in proportion to the lime and magnesia than the carbonate of the small fragment above described. The proportion of minerals in the larger sample is estimated to be about as follows:

Manganic ferro-dolomite	61.50 to 66.45
Hematite	8.00
Chlorite, etc.	14.00
Quartz	13.00

DOLOMITIC MARBLE.

The most abundant rock of the Freedom formation is dolomite. The dolomite is generally grayish in color, but often assumes tints of brown and yellow, as the content of iron oxide becomes appreciable. A bed about a foot thick of rather pure dolomite occurs about half way between the Seeley slate and the iron ore deposit in the second level of the Illinois mine. This bed contains numerous veins of quartz and some nodules or concretions of iron oxide, somewhat less than half an inch in diameter, some of the nodules having a radial or rosette structure. This pure dolomite is in contact with and grades into a finely stratified dolomitic slate, which effervesces readily on the application of hydrochloric acid, and is probably a ferro-dolomitic slate. This dolomite and dolomitic slate are in approximately the same horizon as the quartzose dolomite (specimen 7006), above described, from the first level of the mine.

In the numerous drill holes of the partly explored area the dolomite is abundantly met with. Especially is this true in the middle of the valley between the quartzite ranges where the Freedom formation shows its greatest thickness. The alternation of dolomite with cherty dolomite, ferruginous chert, ferruginous slate, and iron ore in the ferruginous horizon of this formation is indicated in the numerous drill records given in following pages (see pp. 79–89).

The pure, or nearly pure, dolomite forming the upper member of the Freedom formation is not usually banded. It is only where quartz, clay-forming minerals, or iron oxide are abundant that the thin stratification lines and banding appear. In thin section the nearly pure dolomite is seen to consist of finely granular and medium to coarse granular, grayish dolomite. The finely granular crystals of dolomite often occur in the form of flattened-out lenses; the coarser granular portions are also in elongated areas; thus giving the rock, in thin section at least, a stratified texture, which is not noticeable in the hand specimens. Usually there is present a small amount of clay mineral in the dolomite. The vein material in the dolomite is mainly quartz, there being usually associated with the vein quartz a small amount of carbonate, presumably calcite. The quartz in veins is coarse or fine, depending on the thickness of the vein; but in all cases the quartz crystals are very irregular in shape, dovetail into one another, as in granite, and have an association quite dissimilar to that of the granular quartz scattered irregularly through the quartzose dolomite, slates, and in the layers and bands of chert. A like dissimilarity also is true of the crystals of carbonate in veins and the carbonate in the dolomite.

One of the drill cores of what was taken to be a representative phase of pure dolomite (specimen 7000) from a drill hole (see record 10, and map, Pl. XIII) at depth of 569 to 580 feet was analyzed, with the following result:

Silica, SiO_2	4.28
Alumina, Al_2O_3	2.92
Ferric oxide, Fe_2O_3	trace
Ferrous oxide, FeO	1.04
Manganese oxide, MnO	none
Lime, CaO	29.93
Magnesia, MgO	17.75
Carbon dioxide, CO_2	43.57
Alkalies, Na_2O, K_2O	none

Sulphur, S	trace
Phosphoric oxide, P_2O_5	trace
Water, at 110°, H_2O	0.08
Water, at red heat, H_2O	0.27
	99.84

A thin section of this rock is shown in figgure 2, Plate XXIII. The analysis indicates the presence of nearly normal dolomite, the molecular proportion of $CaCO_3$ to $MgCO_3$ being slightly greater than for theoretical dolomite. Nearly the whole of the lime, magnesia, and ferrous iron is required to satisfy the valency of the carbon dioxide, leaving only about 0.10 per cent of these bases to be united with the alumina and silica. The proportion of minerals contained in the dolomite is estimated to be about as follows:

Dolomite bearing some iron	92.00
Alumino-silicate mineral	7.50

FERRUGINOUS DOLOMITIC SLATE.

A common phase of the formation is a red ferruginous rock, containing an abundance of carbonate, and hence readily effervescing on the application of hydrochloric acid. This rock is finely stratified and also coarsely banded, the bands varying from a fraction of an inch up to over an inch in thickness. Each layer or stratum consists of a predominance of either carbonate, hematite, clay mineral, or chert. The color of the strata, therefore, varies from the gray of the carbonate to the red of the ferruginous slate. There is no sharp line separating one layer from another, but each stratum grades insensibly into those above and below. Carbonate is present in variable quantities throughout the red slaty layers, and the clay producing minerals and iron oxide occur throughout the strata predominating in carbonate. Usually this phase, like the others, is more or less fractured, the vein material being quartz, or carbonate, or a mixture of quartz and carbonate. One of the specimens of this phase contains a small, drusy cavity lined with quartz crystals, having the general shape of a fracture into which the quartz has been carried and deposited. Under the microscope, these iron-bearing dolomitic slates are seen to consist of dolomite, fine quartz, clay mineral, and hematite. As just stated, these constituents occur in bands of variable composition, in which one or more of these constituents form the predominating mineral. Sometimes also the constituents are intimately mixed in approximately equal proportions.

The carbonate is mainly dolomite, contains a variable amount of iron and manganese, is generally finely granular when mixed with the clay mineral or hematite, and is generally colored reddish by iron or manganese oxide, or both. The dolomite in the bands, where not intermingled with other mineral, quite generally occurs in larger crystals than elsewhere, and has the general character of the dolomitic marble member of this formation.

The hematite occurs in small, irregular grains and in crystal forms, and is finely disseminated with the carbonate, clay minerals or quartz, or occurs in streaks, irregular patches, and bands. The clay minerals, probably mainly chlorite and partially dehydrated kaolin, appear to be the most abundant minerals in the slaty layers, and are generally in the form of minute flakes. Small quartz crystals are always present and are scattered throughout the bands of slate and dolomite, or form chert bands, thus indicating a gradation of this phase to the banded ferruginous chert and banded cherty dolomite.

Typical phases of this rock (specimens 6978 and 6978-a) were analyzed, with the following results:

Specimen 6978.

Silica, SiO_2	16.29
Alumina, Al_2O_3	14.93
Ferric oxide, Fe_2O_3	25.94
Ferrous oxide, FeO	2.78
Manganese monoxide, MnO	2.22
Lime, CaO	11.86
Magnesia, MgO	4.38
Sodium oxide, Na_2O	0.13
Potassium oxide, K_2O	0.38

PLATE XI.

PLATE XI.

DOLOMITE AND CHERTY DOLOMITE.

Fig. 1.—Photograph of polished specimen of dolomite. Natural size. Specimen 7023. Phase of the nearly pure dolomite strata occurring between the ore deposit and the Seeley slate in the Illinois mine. This thin bed of dolomite was bounded on both sides by thin beds of ferruginous dolomitic slate. Numerous veins of quartz penetrate the pure dolomite and also extend through the irregularly shaped dark patches of hematite mixed with dolomite in the border of the dolomite strata.

Fig. 2.—Photograph of polished specimen of cherty dolomite. Natural size. From Illinois mine. This finely laminated phase of dolomite contains about 66 per cent. of manganic ferro-dolomite, the remainder being fine quartz and clay mineral (see p. 62). Veins of quartz and of quartz and calcite penetrate the rock.

Fig. 1. DOLOMITE.

Fig. 2. CHERTY DOLOMITE.

Carbon dioxide and organic matter, CO_2 and C	19.17
Sulphur, S	trace
Phosphoric oxide, P_2O_5	trace
Titanium oxide, TiO_2	none
Water, at 110°, H_2O	0.46
Water, at red heat, H_2O	1.13
	99.67

Specimen 6978–a.

Silica, SiO_2	16.096
Alumina, Al_2O_3	13.747
Ferric oxide, Fe_2O_3	27.530
Ferrous oxide, FeO	0.770
Manganese monoxide, MnO	1.660
Lime, CaO	11.503
Magnesia, MgO	6.780
Carbon dioxide, CO_2	16.670
Water, H_2O	4.130
	98.886

The analysis of 6978 was made by Professor Victor Lenher, and that of 6978–a by Professor W. W. Daniells. The two specimens analyzed were drill cores from depth of 378 to 388 feet in the No. 4 hole on the Lyons farm (see record 4, p. 80). The two samples were separate pieces of core and may represent rock anywhere from one to 10 feet apart in the drill hole.

The minerals apparent in the thin section of 6978 are dolomite, hematite, quartz, chlorite, kaolin, and an unknown mineral. Thin sections of a dolomite band of this rock show the presence of a mineral having the characteristic features of andalusite. The undetermined mineral has a considerably higher index of refraction and much weaker double refraction than the associated carbonate. It has the color of quartz or feldspar, and, unlike the carbonate associated with it, occurs in idiomorphic crystals, with but faint traces of cleavage. Its crystal system is either hexagonal or orthorhombic. This mineral resembles andalusite very closely. A chemical test showed neither fluorine nor boron to be present, and hence the mineral is not topaz or danburite. It appears to be a common constituent of many of the slaty carbonate rocks of the iron-bearing formation.

The two analyses of this phase of rock are very similar, the principal difference being the smaller amount of carbonate in 6978–a than in 6978. The alkalies were not determined in 6978–a, and probably they constitute the main part of the undetermined elements of this analysis.

The proportions of minerals present in 6978 are estimated as follows:

Manganic ferro-dolomite	38.42
Kaolin, sericite, and other clay mineral	33.00
Hematite	25.00
Carbonaceous matter	2.00
Quartz	small amount

The mineral content of 6978–a is estimated as follows:

Manganic ferro-dolomite	36.00
Hematite	27.00
Kaolin, sericite, and other clay minerals	35.00
Quartz	small amount

A common phase of the ferruginous dolomitic slate is represented in specimen 6976, a drill core from the hole from which 6978 was taken. This core occurs at depth of 343 to 368 feet (see record 4, p. 81). The rock is a red ferruginous, finely stratified slate, which readily effervesces on the application of hydrochloric acid. Under the microscope, it is seen to consist of a quite uniformly stratified mixture of finely granular carbonate, hematite, small flakes of chlorite, sericite, and other clay-producing minerals, and finely granular quartz. A vein of carbonate, presumably calcite or dolomite, occurs in the thin section. The analysis of this phase by Professor W. W. Daniells is as follows:

Silica, SiO_2	20.236
Alumina, Al_2O_3	4.313
Ferric oxide, Fe_2O_3	30.645
Ferrous oxide, FeO	0.622

Manganese monoxide, MnO	1.860
Lime, CaO	20.400
Magnesia, MgO	0.710
Potassium oxide, K_2O	3.635
Sodium oxide, Na_2O	0.510
Phosphoric oxide, P_2O_5	0.141
Carbon dioxide, CO_2	16.085
Water, H_2O	1.240
	100.397

The composition of this slate is strikingly different from the other phases of ferruginous, dolomitic slate in having a very small content of magnesia and a relatively large content of potasium oxide. The relative proportions of minerals present are estimated to be about as follows:

Calcite (Probably bearing a small amount of iron, magnesia, and manganese)	36.00
Hematite	30.00
Quartz	10.00
Kaolin, sericite, and other clay-producing minerals	20.00

IRON ORE.

The iron ore, which constitutes a small though economically important portion of the Freedom formation, is described in full in a following chapter on the ore deposits. It may suffice here to state that there are all gradations between the various kinds of rock above described and the iron ore, and that the iron ore contains variable amounts of each of the constituents of the associated rocks.

RELATION TO ASSOCIATED ROCKS.

The formation underlying the Freedom formation is the Seeley slate. The relations of the two formations are those of gradation and conformity. The stratification in the two formations is everywhere parallel, and the changes in the character of the transition beds are gradual, as is usual in sedimentary formations. The transition is well shown in the main crosscuts of the Illinois mine, as well as in the drill borings throughout the explored portion of the district, where the drills have penetrated both formations.

The Seeley slate formation, a comparatively soft, compact, dry rock of grayish-green color, has a strikingly uniform character throughout. Immediately at the beginning of the transition beds this rock becomes harder and more brittle, on account of the increase in quartz and iron oxide and the addition of dolomite. The uniform grayish green of the Seeley slate also gradually changes to the alternating reddish, yellowish, and black tones of the ferruginous and dolomitic slate. The first 100 feet of the ferruginous horizon contains several strata of slate, in all respects like the Seeley slate, though most of the slate of the iron-bearing horizon is very ferruginous, dolomitic, and cherty, with small amounts of carbonaceous material.

The rock found immediately above this formation is the Potsdam sandstone, lying unconformably upon it. Between the folded pre-Cambrian Freedom formation and flat-lying Potsdam sandstone of Upper Cambrian age is probably one of the greatest unconformities known in stratigraphic geology.

MAGNETIC ATTRACTION.

The normal magnetic attraction for south central Wisconsin is about 5° east of north. Magnetic iron ore has an appreciable effect in deflecting the needle from the normal variation, and hence the compass and dip needle are often used in iron-bearing districts where magnetic ore occurs as a valuable means of locating the iron formation. Magnetic readings were therefore made every 100 paces along the north and south section lines between the quartzite ranges where iron formations and iron ore deposits were known to occur, as well as in those portions of the district where the iron formation is not known to occur but may be present. The results of the readings showed no appreciable variation from the normal, either in the vicinity of known iron deposits or elsewhere in the district. Similar results, showing no special magnetic variation in different parts of the district, have been obtained by private parties. The negative results of the magnetic surveys show, therefore, that the iron oxide of the district must be nearly pure hematite, and that magnetite does not occur in appreciable amounts.

STRUCTURE.

The principal structural feature of the Freedom formation is the bedding, which is a prominent characteristic of the ferruginous member, as well as of the more massive dolomitic marble member. The stratification of the ferruginous slate, ferruginous dolomite, chert, and iron ore is generally much finer than that of the dolomitic marble, though the latter also often shows fine bedding laminae. In the ferruginous horizon the bedding layers generally vary from thin leaves to beds a foot or more in thickness.

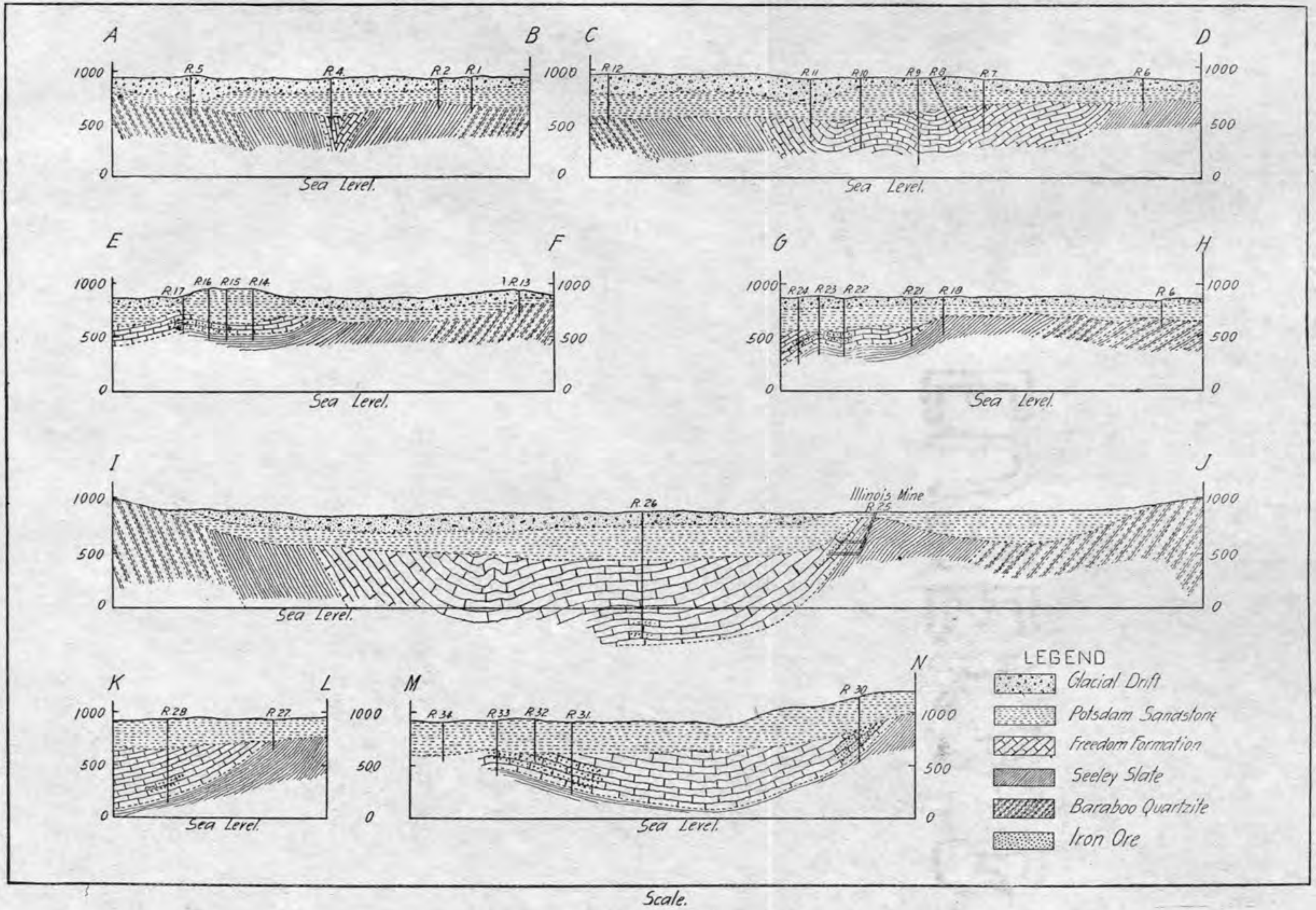
The secondary cleavage of this formation is not at all prominent, the parting planes with few exceptions being along the bedding. In this respect the rocks of this formation differ from those of the Seeley slate formation, where cleavage diagonal to the bedding is usually a prominent feature. While cleavage is but a minor feature of the Freedom formation, deformation by fracturing is without doubt much more abundant in this formation of brittle iron-bearing rock and dolomite than in the soft Seeley slate formation. The fractures, which are now mainly filled with vein material, are generally less than half an inch in diameter, although some are much larger than this, reaching at times a thickness of over a foot. Where these large veins occur numerous other veins lie approximately parallel to them, branching off and penetrating the surrounding rock in an intricate manner. The vein material, with few exceptions, is mainly quartz with a small amount of carbonate. Iron sulphide, iron oxide, and kaolin also occur in small quantities as vein material.

The folding of the Freedom formation, as a matter of course, conforms to the folding of the underlying Seeley slate and Baraboo quartzite formations. The valley between the quartzite ranges which holds the Freedom formation is a broad synclinal trough with minor crumplings, consisting of alternating small anticlinals and synclinals. The location of some of these minor anticlinals and synclinals in the valley bottom is indicated in the cross sections of Plate XII. Along the south side of the valley southwest of North Freedom, the dip of the ore-bearing strata and underlying slate generally varies from 5° or 10° to 45° or 50° to the north. The ore deposit at the Sauk mine is nearly flat lying. The dip in the Illinois mine varies considerably, sometimes being as low as 30° for short distances, the average being about 50°. At the west end of the explored area, on the Judevine farm, the dip is low, there being in this vicinity, as indicated by the section M-N (see Plates XII, XIII), a broad, probably shallow syncline, rising to an anticline immediately north, from which anticline the ore formation was eroded before the deposition of the overlying sandstone. The formation has a steep dip in the vicinity immediately southwest of North Freedom, where there appears to be very general close folding, the drill cores often showing dips varying from 45° to 90°. The broad folding of the formation with accompanying dip is best seen by a study of the cross sections of Plate XII. Considered as a whole, the formation in various parts of the district varies from 0° to 90° in all directions. Minute plications and crumplings of the ferruginous slates and iron ore are well exhibited in the formation at the Illinois mine. It is very likely that on the north side of the valley adjacent to the quartzite ridges west of North Freedom, where the formation generally stands between 45° and 90°, the fine-grained rocks of the ferruginous horizon will be found to be minutely crumpled and buckled together.

The water passages in the ore deposit and associated iron-bearing rock are very largely the fractures in the formation, and to a minor extent the partings along the bedding planes.

THICKNESS.

The entire thickness of the Freedom formation is not at present known, but without doubt it is quite considerable. For

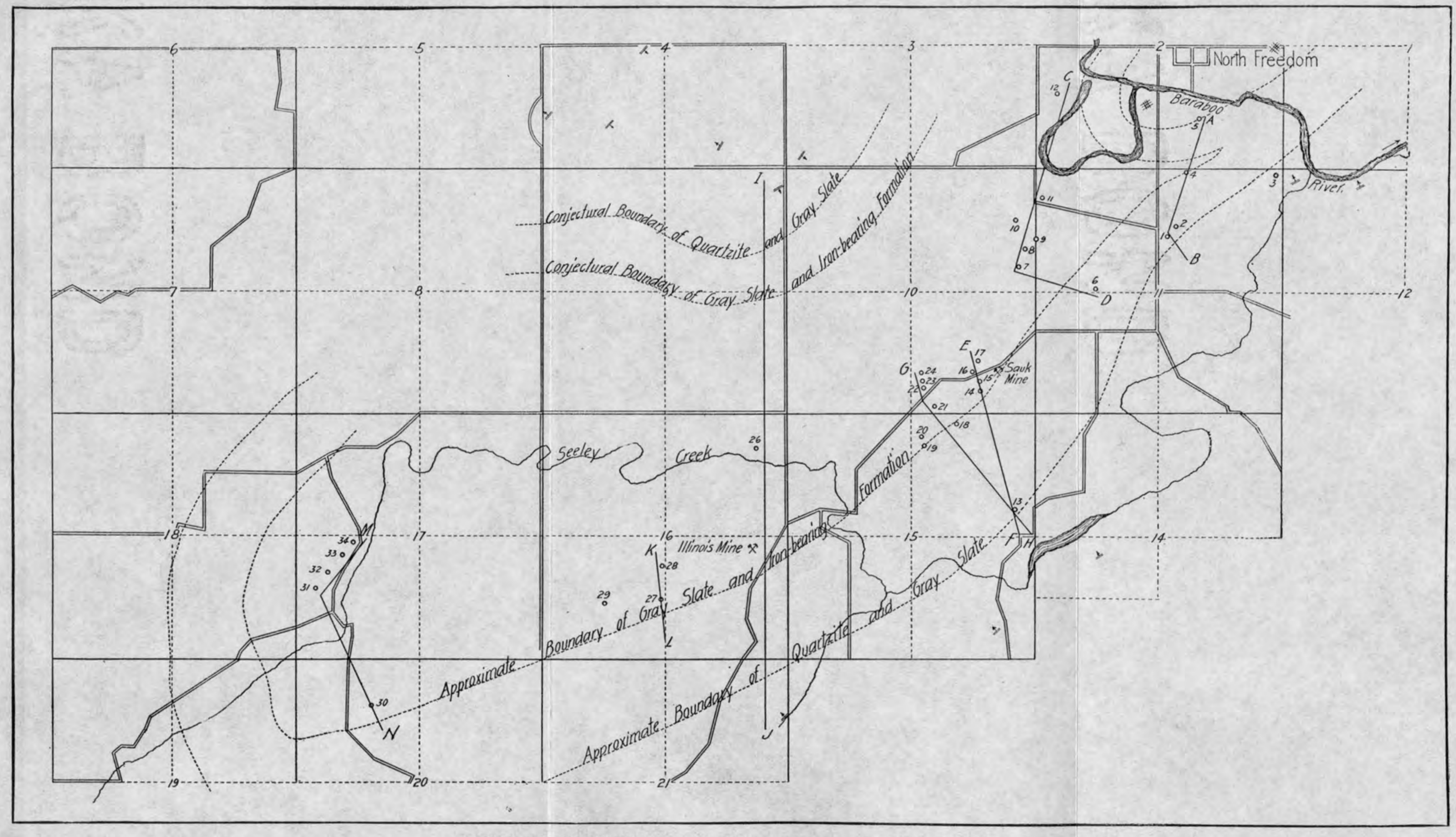


Scale.

1 inch 1500 feet.

CROSS SECTIONS IN THE AREA OF EXPLORATION SOUTHWEST OF NORTH FREEDOM.

The location of the various cross sections is shown on Plate XIII, and the detailed description of drill records 1-34 is given on pp. 79-82.



SKETCH MAP OF THE AREA OF EXPLORATION SOUTHWEST OF NORTH FREEDOM.

Drill records 1 to 34 are described on pp. 72-81, and cross sections A-B to M-N are shown on Plate XII our purpose, it may be best to consider first the known thickness of the ferruginous horizon and then the probable thickness of the overlying dolomite horizon.

About half a mile north of the Illinois mine a drill, after passing through the dolomite, penetrated over 400 feet of highly ferruginous rock, which is reported to bear at least two deposits of iron ore. The known thickness of the iron-bearing horizon at the Illinois mine, at the depth of the second level, is 400 feet. In the southwestern part of the explored district in section 17, on the Judevine farm, two drill holes penetrated over 300 feet of paint rock and iron ore. The entire thickness of the ferruginous horizon is not present at the Illinois mine and the last mentioned locality, owing to the removal of the upper portion by erosion previous to the deposition of the sandstone. It is believed that a safe estimate of the thickness of the ferruginous horizon, as indicated at various places, is at least 450 to 500 feet.

The thickness of the upper horizon of the Freedom formation, consisting mainly of dolomite, approximates 350 feet in the above drill hole, which is about half a mile north of the Illinois mine, the formation at this place probably being at a low dip. At several places southwest of North Freedom a much greater amount of dolomite was penetrated by vertical drilling through steeply inclined strata, and hence at the latter places the thickness across the bedding is not known. A conservative estimate of the thickness of the dolomite horizon would be about 500 feet. As it lies unconformably beneath the sandstone and has suffered an unknown amount of erosion, its original thickness was very likely much more than 500 feet.

STATEMENT OF DRILL RECORDS AND DESCRIPTION OF MINE SECTION.

In the following pages is presented a detailed description of the iron formation shown in the Illinois mine, and also records and descriptions of a number of drill holes in the partially explored area southwest of North Freedom. For information concerning drill records the writer is mainly indebted to the kindness of Messrs. C. T. Roberts and E. A. Pike, of the Illinois Iron Mining Company, and to Mr. W. G. La Rue, of the Sauk County Mining Company. Those records only are given which are believed to be especially instructive. It should be noted that the drill cores of only a portion of the drill holes were placed at the disposal of the writer and examined by him. The descriptions begin at the eastern end of the partially explored area, and, as far as possible, are arranged so as to furnish sections from south to north across the valley in which the formation containing the iron ore deposits occurs. The location of the drill holes is shown in Plate XIII, and generalized cross sections along the indicated lines of Plate XIII in Plate XII.

The following are records along cross section A–B, immediately south of North Freedom:

	Thickness (in feet).	Depth (in feet).
Record 1. (Lyons–Voll farms, hole 1.)		
Clay and sand	90	0 to 90
Sandstone	114	90 to 204
Conglomerate and quartzite	8	204 to 212
Record 2. (Lyons–Voll farms, hole 2.)		
Clay and sand	90	0 to 90
Sandstone	50	90 to 140
Gray slate (Seeley slate)		
Record 3. (Lyons–Voll farms, hole 5.)		
Clay	100	0 to 100
Sand, gravel and boulders	118	100 to 218
Sandstone	38	218 to 256
Gray slate (Seeley slate)	93	256 to 349
Quartzite	19	349 to 368
Record 4. (Lyons–Voll farms, hole 4.)		
Clay and sand	137	0 to 137
Sandstone	164	137 to 301
Sandstone conglomerate containing fragments and pebbles of slate	26	301 to 327
Red ferruginous slate containing carbonate (Dip of formation about 45°)	16	327 to 343

	Thickness (in feet).	Depth (in feet).
Brecciated ferruginous carbonate	25	343 to 368
Red slate containing some carbonate (Dip of formation about 75°)	10	368 to 378
Carbonate slate[1]	10	378 to 388
Gray clayey dolomite and slate	20	388 to 408
Chert, slate and dolomite	60	408 to 468

The dip of the iron formation in this hole apparently varies from 45° to 75°.

Record 5. (Lyons-Voll farms, hole 3.)

Clay and sand	205	0 to 205
Sandstone	40	205 to 245
Potsdam conglomerate and Baraboo quartzite at bottom	15	245 to 260

The following are records of drill holes along cross section C-D. on the Sprowl and Petsky farms. The drill cores, with records, were placed at the disposal of the writer, and a number of samples of the cores were taken and studied microscopically, and analyses were also made of some of the cores.

Record 6. (Sprowl-Petsky farms, hole 1.)

Sand, gravel, etc	208	0 to 208
Potsdam sandstone	83	208 to 291
Red slate	5	291 to 296
Seeley slate	55	296 to 351

Record 7. (Sprowl-Petsky farms, hole 9.)

Clay, sand, and boulders	138	0 to 138
Potsdam sandstone	139	138 to 277
Reddish ferruginous slate	11	277 to 288
Soft ferruginous slate, with some ore	115	288 to 403
Red slate	5	403 to 408
Ferruginous chert and ore	15	408 to 423
Banded chert, and red ferruginous dolomite (Dip of formation 45° to 60°)	17	423 to 440
Banded chert and dolomite (Dip of formation 50° to 90°)	29	440 to 469
Dolomite, ferruginous chert, and some ore (Dip of formation 50° to 90°)	32	469 to 501
Red slate	7	501 to 508
Brecciated ferruginous chert filled with patches of vein quartz	11	518 to 529
Banded slate, much crumpled	9	529 to 538
Banded chert and carbonate, with seams of iron ore (Dip of formation 45° to 90°)	101	538 to 639

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[1] See analysis, p. 73.

The cores at depth of 635 to 639 feet near bottom of the hole are of banded dolomite with streaks of black and red ferruginous material, showing the strata to have a dip of about 45°.

Record 8. (Sprowl–Petsky farms, hole 5.)

This hole is at an angle of 60° SE. The hole in some places is approximately parallel to the bedding.

	Thickness (in feet).	Depth (in feet).
Drift and sandstone	328	0 to 328
Cherty red slate containing some carbonate	8	328 to 336
Soft ferruginous slate	32	336 to 368
Dolomite and ferruginous slate	6	368 to 374
Dolomite containing quartz	13	374 to 387
Chert and black ferruginous slate containing carbonate	10	387 to 397
Ferruginous slate, chert, and dolomite	3	397 to 400
Ferruginous slate and chert, and seams of ore	20	400 to 420
Ferruginous cherty slate and dolomite	33	420 to 453
Dolomite, slate, and seams of ore	2	453 to 455
Ferruginous calcareous slate	12	455 to 467
Ferruginous slate	5	467 to 472
Soft formation, no cores	51	472 to 523
Ferruginous slate	5	523 to 528
Cherty dolomite and ferruginous cherty dolomite	44	528 to 572
Cherty ferruginous slate containing carbonate	11	572 to 583

Record 9. (Sprowl–Petsky farms, hole 8.)

Drift	22	0 to 22
Potsdam sandstone	360	22 to 382
Sandstone and fragments of dolomite	41	382 to 423
Red dolomitic conglomerate	20	423 to 443
Red dolomitic slate and gray dolomite	2	443 to 445
Gray dolomite	180	445 to 625
Slate and dolomite	23	625 to 648
Banded slaty dolomite	215	648 to 863

The dip of the formation in this hole is generally about 45°. All the cores examined are mainly carbonate and strongly effervesce on application of hydrochloric acid.

Record 10. (Sprowl–Petsky farms, hole 6.)

Boulders, clay, and sand	64	0 to 64
Sandstone	505	64 to 569
Dolomite[1] and cherty dolomite	43	569 to 612

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[1] See analysis, p. 68.

	Thickness (in feet).	Depth (in feet).
Record 11. (Sprowl–Petsky farms, hole 7.)		
Gravel and sand	187	0 to 187
Sandstone	158	187 to 345
Sandstone containing pebbles of dolomite	17	345 to 362
Whitish and grayish dolomite	61	362 to 523
Grayish dolomite	110	523 to 633
Record 12. (Hackett farm.)		
Surface	20	0 to 20
Sandstone	454	20 to 474
Conglomerate	24	474 to 498
Dolomite	842	498 to 1,340

The dolomite in this drill hole is the usual massive dolomite of the upper horizon of the Freedom formation, the dip of strata varying from 45° to 90°.

The following are records along cross section E–F, the records of the Iroquois Iron Company having been furnished the writer by Mr. W. G. La Rue:

Record 13. Near the east quarter post of section 15, in a churn drill hole, quartzite was struck immediately beneath the sandstone. A quarter of a mile south of this, along the Seeley Creek, the quartzite has a dip of about 30° NW. and a strike of N. 45° to 50° E.

	Thickness (in feet).	Depth (in feet).
Record 14. (Iroquois Iron Company, hole 7.)		
Sandstone	312	0 to 312
Iron formation (with iron ore)	88	312 to 400
Gray slate (Seeley slate)	16	400 to 416
Record 15. (Iroquois Iron Company, hole 8.)		
Sandstone	282	0 to 282
Iron formation (with iron ore)	101	282 to 383
Gray slate (Seeley slate)	39	383 to 422

	Thickness (in feet).	Depth (in feet).
Record 16. (Iroquois Iron Company, union hole 1.)		
Surface	9	0 to 9
Sandstone	261	9 to 270
Iron formation (with iron ore)	121	270 to 391
Gray slate (Seeley slate)	35	391 to 426
Record 17. (Iroquois Iron Company, hole 14.)		
Surface	40	0 to 40
Sandstone	92	40 to 132
Iron formation (with iron ore)	140	132 to 272
Gray slate (Seeley slate)	20	272 to 292

The elevation of the surface of hole furnishing Record 17 is near the 880 foot contour line (see map, Pl. I), and holes furnishing records 14, 15, and 16 are on the summit of a sandstone ridge, the surface of which is between the 900 and 940 foot contour lines. The iron formation indicated in these records contains considerable bodies of iron ore, the probable extent of which, however, is unknown. The Sauk mine, of the Iroquois Iron Company, is located near the above drill holes on the ridge, and at the present writing, February, 1904, the shaft is in process of construction and still within the sandstone formation.

The following are the records along cross section G-H., the drill holes being located in the NW. 1/4 of the NE. 1/4 of section 15, and the SW. 1/4 of the SE. 1/4 of section 10, on the Wisconsin Iron Mining Company property. These records were furnished the writer by Mr. W. G. La Rue.

Record 18. (Wisconsin Iron Mining Company, hole 3.)		
Surface	16	0 to 16
Sandstone	197	16 to 213
Gray slate (Seeley slate)	40	213 to 253
Record 19. (Wisconsin Iron Mining Company, hole 12.)		
Surface	18	0 to 18
Sandstone	89	18 to 107
Iron formation, bearing ore	93	107 to 200
Gray slate (Seeley slate)	12	200 to 212

	Thickness (in feet).	Depth (in feet).
Record 20. (Wisconsin Iron Mining Company, hole 7.)		
Surface.............Very little surface material	....	....
Sandstone	170	0 to 170
Iron formation, bearing ore	160	170 to 330
Gray slate (Seeley slate)	54	330 to 384
Record 21. (Wisconsin Iron Mining Company, hole 9.)		
Sandstone	271	0 to 271
Iron formation, bearing ore	130	271 to 401
Gray slate (Seeley slate)	18	401 to 419
Record 22. (Wisconsin Iron Mining Company, hole 8.)		
Surface	40	0 to 40
Sandstone	200	40 to 240
Iron formation, bearing ore	200	240 to 440
Gray slate (Seeley slate)	24	440 to 464
Record 23. (Wisconsin Iron Mining Company, hole 10.)		
Surface	80	0 to 80
Sandstone	240	80 to 320
Hanging-wall slate	21	320 to 341
Iron formation, bearing ore	100	341 to 441
Gray slate (Seeley slate)	36	441 to 477
Record 24. (Wisconsin Iron Mining Company, hole 14.)		
Surface	88	0 to 88
Sandstone	211	88 to 299
Hanging-wall slate	62	299 to 361
Iron formation, bearing ore	160	361 to 521
Gray slate (Seeley slate)	24	521 to 545

The following are the records along cross section I–J. About one-half mile SE. of the Illinois mine, along the section line between sections 21 and 22, the Baraboo quartzite crops out on the side of the bluff. The quartzite here has a dip of 25° to 30° NW. and strike N. 45° to 55° E. Between this point and the mine the Potsdam sandstone appears at the surface, overlying the quartzite and gray slate.

At the Illinois mine the shaft is sunk at an angle of 60° to the north, first passing through 30 feet of sandstone, then about 90 feet of ferruginous chert and kaolinic dolomite. At a depth of 130 feet occurs the gray Seeley slate formation, into which the shaft is continued to the depth of about 300 feet, where the first crosscut to the north of the ore deposit is made. In this crosscut 70 feet of the gray slate is penetrated before striking the dolomitic and ferruginous cherts of the iron-bearing formation.

The dip of the gray slate and iron-bearing formation at the mine is approximately 47° NW., and the strike about N. 80° E.

Starting from the shaft in the first level, and approaching the iron ore deposit, the following succession of rock strata is found:

	Width (in feet).	Distance from shaft (in feet).
Record 25. Section along the first crosscut in the Illinois mine.		
Gray slate, typical rock of the Seeley formation.	70	0 to 70
Banded rock, consisting of alternating layers ½ in. to 1 in. in thickness of soft ferruginous clay and grayish carbonate, the latter effervescing rapidly on application of hydrochloric acid. The strata contains vein material of whitish translucent quartz. Between the gray slate and this banded ferruginous slate there is no sharp line of contact, but a gradual transition from one kind of rock to the other.	4	70 to 74
Soft red ferruginous slate....................	2	76 to 78
Hard gray slate, similar to the Seeley slate.....	5	78 to 83
Soft red ferruginous slate....................	5	83 to 88
Red slate and gray slate, the latter much like the Seeley state formation..................	5	88 to 93
Mainly hard red cherty slate..................	5	93 to 98
Reddish cherty slate, cut by narrow veins of quartz..................................	5	98 to 103
Ferruginous chert cut by veins of quartz.......	5	103 to 108
Banded ferruginous chert; large vein of quartz at this place	6	108 to 114
Black soft banded carbonaceous slate; red slate and ferruginous chert	8	114 to 122
Ferruginous slate and chert; black banded carbonaceous slate showing sun cracks on the surface of the crumpled strata (see Pl. XVI)..	6	122 to 128
Banded ferruginous slate and ferruginous chert.	5	128 to 133
Laminated red slate and ferruginous chert, with much dolomitic slate and dolomitic chert.....	15	133 to 148

	Width (in feet).	Distance from shaft (in feet).
Ferruginous chert and ferruginous dolomite, with bands of iron ore	15	148 to 163
Alternating strata of slate, ferruginous chert, iron ore, and dolomitic rock	37	163 to 200
Iron ore of the ore deposit, having a thickness normal to the bedding of about 35 feet, consisting of soft, friable ore, hard blue ore, and banded siliceous ore; lying above the ore body, at the end of the crosscut, is exposed a thin layer of black ferruginous slate (analysis, page 52)	40	200 to 240

In the second level of the mine the character of the rock associated with the ore is found to be similar to that above outlined in the first level. Many samples were collected, showing the alternating layers of chert, dolomite, slate, and thin seams of iron ore, in some instances all being shown in a single hand specimen. A description of the general character of the iron formation grading up into the ore body has already been given and need not be repeated here.

	Thickness (in feet).	Depth (in feet).
Record 26.[1] Near the center of the NE. ¼ of the NE. ¼ of sec. 16.		
Drift	130	0 to 130
Sandstone	330	130 to 460
Dolomite (principally)	340	460 to 800
Banded slate, dolomite, ferruginous chert, and iron ore	400	800 to 1200

In the NE. corner of section 9 the quartzite crops out in a ridge, having a distinct dip of 40° to 75° SE. and a strike of N. 30° to 60° E.

The following are records of drill holes located in the SW. ¼ of section 16, along cross section K–L.

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[1] The drill cores of this hole were not shown the writer.

Record 27. (La Rue property, hole 4.)

	Thickness (in feet).	Depth (in feet).
Gravel and sand	4	0 to 4
Sandstone	204	4 to 208
Red and gray slate (Seeley slate)	33	208 to 241

Record 28. (La Rue property, hole 1.)

	Thickness (in feet).	Depth (in feet).
Surface and sandstone	364	0 to 364
Slate, chert, and cherty dolomite	110	364 to 474
Ferruginous chert and cherty dolomite	47	474 to 521
Ferruginous chert and iron ore	41	521 to 562
Slate and ferruginous chert	39	562 to 601
Banded slate and ferruginous chert	36	601 to 637
Iron ore and slate rich in carbonate	11	637 to 648
Ferruginous chert, red slate, and iron ore	30	648 to 678
Ferruginous slate rich in carbonate	12	678 to 690
Ferruginous cherty carbonate, and ferruginous slate	38	690 to 728
Gray quartzose slate (Seeley slate)	8	728 to 736

The dip of the iron formation in this hole is variable but is generally about 45°.

Record 29. (La Rue property, hole 6.)

	Thickness (in feet).	Depth (in feet).
Gravel, sand, and clay	70	0 to 70
Sandstone	154	70 to 224
Sandstone containing pebbles of ferruginous chert	11	224 to 235
Ferruginous chert and chert	27	235 to 262
Iron ore	32	262 to 294
Red soft ferruginous slate	36	294 to 330
Banded ferruginous slate and iron ore	140	330 to 470
Ferruginous chert and slate	29	470 to 499

The iron formation has generally a steep dip in this hole, varying from 45° to 90°.

The following are records of drill holes on the Goll farm in the E. 1/2 of the NW. 1/4 of sec. 20, and the Judevine farm in the SW. 1/4 of sec. 17, along cross section M-N.

Record 30,[1] Drill hole on Goll farm.

	Thickness (in feet).	Depth (in feet).
Sandstone	350	0 to 350
Hanging-wall slate	89	350 to 439
Iron ore (mainly)	161	439 to 600
Gray slate	....	600 to ...

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[1] Record furnished by W. G. La Rue.

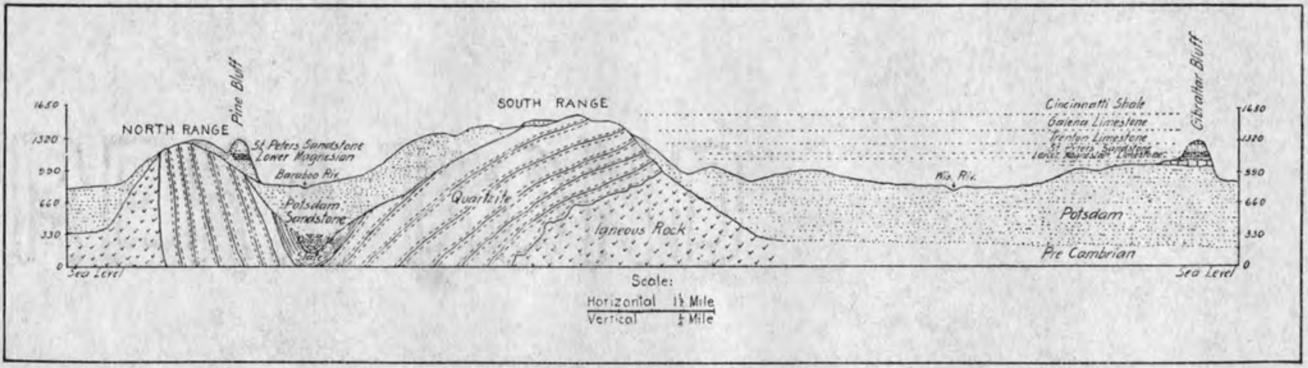
	Width (in feet).	Distance from shaft (in feet).
Record 31. (Judevine farm, hole 1.)		
Sandstone	364	60 to 364
Iron formation	318	364 to 682
Gray slate	...	682 to ...
Record 32. (Judevine farm, hole 2.)		
Sandstone	305	0 to 305
Iron formation	...	305 to ...
Record 33. (Judevine farm, hole 3.)		
Sandstone	291	0 to 291
Iron formation	150	291 to 441
Gray slate	...	441 to ...
Record 34. (Judevine farm, hole 4.)		
Sandstone	328	0 to 328

CHAPTER V.

THE PALEOZOIC SEDIMENTARY ROCKS.

The Paleozoic formations, which throughout the district and elsewhere in Wisconsin and adjoining states lie in approximately horizontal position, consist from the base upward of the following formations: the Potsdam sandstone, the Lower Magnesian limestone, the St. Peter sandstone, the Trenton and the Galena limestone, and probably the Cincinnati shale. The Potsdam sandstone formation occurs on the lower flanks of the quartzite ranges and in the valley bottom, while at higher elevations occur the succeeding formations. The Lower Magnesian limestone formation in this district is mainly conglomerate and sandstone, and in this respect differs from the usual character of the rocks comprising this formation outside the district.

Unconformity of Paleozoic and Pre-Cambrian. The general relations of the Paleozoic formations to the Pre-Cambrian formations are shown in the generalized cross section (Pl. XIV). The unconformable relations of the pre–Cambrian rocks to the Paleozoic have already been referred to. The pre-Cambrian formations were elevated and folded into massive mountain ranges and subsequently greatly eroded, long before the horizontal beds of the Paleozoic were deposited upon them. The unconformity between the Potsdam sandstone and the pre-Cambrian crystallines probably marks one of the greatest gaps, if not the greatest, in the geological column.



CROSS SECTION NORTH AND SOUTH ACROSS THE BARABOO DISTRICT TO GIBRALTAR BLUFF.

The section is drawn to illustrate the general relations of the pre-Cambrian formations to the Paleozoic formations, and also the height to which the quartzite ranges extend above the surrounding Paleozoic formations.

THE POTSDAM FORMATION.

General Character. The Potsdam formation, while consisting mainly of coarse, friable sandstone, also contains beds of conglomerate, shale, and limestone. The sandstone is generally a whitish, medium to coarse grained rock, with pore space generally averaging between 28 and 32 per cent. The Potsdam sandstone throughout Wisconsin is generally quite friable and too weak for building purposes. Numerous exceptions to this condition, however, occur in the Baraboo district, especially where the sandstone lies immediately adjacent to the quartzite. In some of the ridges, also, between the quartzite ranges the rock is sufficiently strong and coherent to form good building stone.

Quite generally there is a considerable thickness of conglomerate wherever the Potsdam formation comes in contact with the older pre-Cambrian rock. Especially is this true where it is adjacent to the quartzite, in which case the conglomerate usually consists of large boulders, several feet in thickness, as well as of fine material. It is quite evident from the topography of the quartzite bluffs that deep valleys and ravines had been incised into the flanks of the ranges previous to the encroachments of the Paleozoic sea, which were later clogged with coarse debris through the action of ocean waves when the Potsdam sea was present. Hence the sharp ravines that extend back into the quartzite ranges often reveal great thicknesses of conglomerate, which is, without exception, so far as observed, made up only of boulders and pebbles of quartzite, probably mainly derived from ledges in the immediate vicinity. Some notable instances of abundant conglomerate in the ancient pre Cambrian ravines are shown at Parfreys Glen, Pine Hollow, and Foxs Glen. Out in the valley between the quartzite ranges, where mining explorations have progressed, conglomerate varying from 10 to 25 feet in thickness is generally struck at the base of the Potsdam. Superjacent to the dolomite and slate, the conglomerate is not generally so coarse as that observed flanking the quartzite ranges. In the drill hole (record 12,

p. 83) a thickness of 24 feet of conglomerate overlying dolomite was struck at a depth of 474 feet, the pebbles of which were mainly quartzite and generally less than four inches in diameter. At the Illinois mine, overlying the paint rock, as shown in the railroad cut, is a thickness of 10 or 15 feet of conglomerate. Other data concerning the thickness of the conglomerate in the valley are shown in many of the drill records cited on pages 80-89.

At several horizons in the Potsdam formation occur beds of red shale, consisting of a mixture of reddish clay and quartz grains, which vary in thickness from a few feet to 20 or 30 feet. Thin beds of shale were noted in Foxs Glen in sec. 22, T. 12 N., R. 8 E., a locality well up on the sides of the quartzite bluff. In boring through the sandstone southwest of North Freedom, a thickness of 15 or 20 feet of red shale is often struck at a depth of about 240 feet, which forms the upper confining strata of the artesian basin in the Potsdam between the quartzite ranges.

Quite a persistent formation of limestone, known as the Mendota beds, occurs within the upper part of the Potsdam formation, in the southern part of the state, and is especially well developed on the shores of Lake Mendota, from which locality these beds derive their name. These beds are impure, shaly limestone and are known to attain a maximum thickness of 35 feet near Madison. Limestone showing a thickness of about 15 feet, and corresponding in general character and position to the Mendota beds, occurs at Skillet Falls on Skillet Creek, near the center of the NW. 1/4 of sec. 10, T. 11 N., R. 6 E. About one-third of a mile south of this, at the abandoned quarry known as Wood's quarry, at an elevation of about 40 feet above the latter beds, is limestone, very evidently belonging with the Lower Magnesian limestone formation. Between the upper limestone at Wood's quarry and the lower limestone at Skillet's Falls is a thickness of 40 or 50 feet of calcareous sandstone, having the general character and stratigraphic position of the sandstone beds known as the Madison beds, which form the uppermost strata of the Potsdam formation. No limestone of the Mendota horizon, other than that at Skillet Falls, was observed by the writer, although it is very probable that such beds of limestone occur in the district.

Thickness. The greatest thickness of sandstone in the valley between the quartzite ranges, in that portion of the district now being explored, is 569 feet, as shown by a drill hole about two-thirds of a mile southwest of North Freedom in the NE. ¼ of NE. ¼ of sec. 10, T. 11 N., R. 5 E., the elevation of the ground at this place being between the 860 and 880 foot contours. A thickness of about 560 feet is reported in the SW. ¼ of the NW. ¼ of sec. 8 of the same town, the surface at this place being at an elevation of about 900 feet. The records of a number of drill cores in the valley between the quartzite ranges show a thickness of 450 to 550 feet. The actual thickness in the valley, of course, varies from a few feet, as at the Illinois mine to the much greater depths above mentioned.

At Portage, a few miles east of the east end of the quartzite ranges, the city waterworks well penetrates a thickness of 572 feet of sandstone, the elevation of this place being about 860 feet.

In a former paper[1] the writer presented evidence showing that the pre-Cambrian land had been reduced by a long continued erosion to an approximate plain previous to the deposition of the Potsdam sandstone. It should be noted in this connection that it is not meant that all the pre-Cambrian land had been reduced to base level, or to a peneplain, but only the principal part of it. A small part, relatively speaking, consisting of the hardest rocks, remained as islands, or monadnocks, in this ancient plain. One of the most notable portions of the pre-Cambrian land not worn down to a plain was, in fact, the prominent ranges of Baraboo quartzite. A few of the other exceptions that may be mentioned, now entirely surrounded by the Paleozoic rocks, are the ridges of Waterloo quartzite, the

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[1] The pre-Potsdam peneplain of the pre-Cambrian of North Central Wisconsin. Jour. of Geol., vol. 2, pp. 289–313.

granite and rhyolite hills along the Fox River, and the Necedah quartzite.

The general location of the pre-Cambrian surface beneath the sandstone in central Wisconsin may be briefly described as follows: In the large area of pre-Cambrian rock in north central Wisconsin, in the vicinity of Merrill and Wausau, the generally even summits of the pre-Cambrian are the striking feature of the landscape. As one follows southward into the region of the Potsdam sandstone, the summits of the pre-Cambrian land are seen to drop lower and lower, and are finally covered with the Potsdam sandstone at Stevens Point and Grand Rapids, and farther south. South of Grand Rapids, where the pre-Cambrian is buried beneath the Potsdam, the ancient pre-Cambrian land surface continues southward at practically the same rate of descent as that shown for many miles north of Grand Rapids. This continuous downward slope is indicated by artesian wells showing the occurrence of the pre-Cambrian at a depth of 198 feet at Necedah, 385 feet at Kilbourn City, 512 feet at Portage, and 810 feet at Madison. The general elevation above the sea of the pre-Cambrian peneplain at Merrill is, therefore, 1560 feet, at Wausau 1420 feet, and at Grand Rapids 1000 feet. Continuing southward beneath the sandstone, the ancient slope of the pre-Cambrian has an elevation of 515 feet above the sea at Kilbourn, and of 70 feet at Madison. The rate of descent from Merrill to Madison is about 10 feet per mile. If a line be drawn from the buried pre-Cambrian surface at Madison, 70 feet above the sea, to the buried pre-Cambrian surface at Kilbourn, 515 feet above the sea, to the exposed pre-Cambrian surface at Grand Rapids 1000 feet, at Wausau 1420 feet, and at Merrill 1560 feet above the sea, this line will be seen to pass through the Baraboo district at an elevation of about 300 feet above the sea, which is approximately at the elevation at which the pre-Cambrian is struck at Portage and in the deepest borings southwest of North Freedom.

It seems very probable, therefore, that in the Baraboo district the Potsdam formation will probably not be found to extend deeper than 300 feet above sea level, which elevation may be taken to correspond with the general elevation of the pre-Cambrian peneplain in this portion of the state. Above this peneplain projected the Baraboo quartzite ranges, standing as truly mountainous ridges, whose summits generally reached from 1000 to 1300 feet, and in places over 1600 feet, above the ancient plain.

The Lower Magnesian limestone at Wood's quarry is at an elevation of about 1000 feet. A similar elevation holds for the Lower Magnesian at Eiky's quarry near the Lower Narrows of the Baraboo River. South of the east end of the quartzite ranges, on Gibraltar Bluff, about two miles southeast of Merrimac, the contact of the uppermost strata of the Potsdam and the Lower Magnesian is reached at an elevation of about 990 feet, and south of the west end of the quartzite bluffs in the numerous sharp ridges capped with Lower Magnesian limestone, a similar elevation of 980 to 990 feet holds for the Lower Magnesian. Since the Paleozoic formations gradually rise towards the north as the pre-Cambrian of north central Wisconsin is approached, there seems to be little doubt that an elevation of about 1000 feet, as shown at Wood's and Eiky's quarries, for the contact of the Potsdam with the overlying Lower Magnesian should hold for the Baraboo district.

As the base of the Potsdam in the district is very probably at an elevation of 300 feet above the sea and the uppermost strata at 1000 feet, the maximum thickness of the Potsdam formation may be considered to be very close to 700 feet.

LOWER MAGNESIAN FORMATION.

The lower Magnesian formation, as already stated, occurs at an elevation of about 1000 feet at Wood's quarry, in the SW. ¼ of sec. 10, T. 11 N., R. 6 E., and at Eiky's quarry, in sec. 25, T. 12 N., R. 7 E. At Wood's quarry the quarry limestone caps a small ridge and exposes a thickness of 10 or 15 feet of limestone of brownish color, finely crystalline and rough surfaced. At Eiky's quarry about 20 feet of limestone occurs, containing a number of fossils, which Mr. R. P. Whitfield[1] regarded as unquestionably belonging to a horizon not lower than the Lower Magnesian. The succession of limestone and sandstone beds immediately beneath the quarry limestone at Wood's quarry, corresponding in relation to the Mendota limestone and Madison sandstone respectively, and the fossils in the limestone at Eiky's quarry would seem to leave but little doubt concerning the Lower Magnesian age of these quarry limestones. At numerous places at the west end of the district the writer observed impure limestone at approximately the same horizons as the limestone of the above localities, and it seems probable, therefore, that the valley between the quartzite ranges, as well as the area immediately outside, originally contained a variable thickness of Lower Magnesian limestone which has been removed by erosion. The original maximum thickness of nearly pure limestone of this horizon in the district, however, was probably much less than holds for the average of this formation in southern Wisconsin (about 100 feet) on account of its proximity to the adjacent shore line of the quartzite ranges, for which reason littoral mechanical deposits of sand and conglomerate and not limestone were deposited during the Lower Magnesian period. The Lower Magnesian formation in this district, therefore, includes much sandstone and conglomerate, as well as limestone.

ST. PETER SANDSTONE.

Immediately above the Lower Magnesian limestone formation is the St. Peter sandstone formation, which over a large part of southern Wisconsin has an average thickness of 80 to 100 feet, though varying greatly in different localities on account of the uneven floor of the Lower Magnesian limestone upon which it is deposited. The thickness of the St. Peter is known to vary from 212 feet to less than one foot. The great variation in the thickness of the St. Peter sandstone and the Lower Magnesian limestone is due to the unconformable rela-

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[1] Geol. of Wis., vol. 2, pp. 537, 594.

tion of the two formations, for the Lower Magnesian was elevated above the sea in which its sediments had been deposited and considerably eroded, before the St. Peter was deposited upon it. For this reason, therefore, the Lower Magnesian beds are often found at higher elevations than the St. Peter.

The St. Peter formation in this district consists of sandstone and conglomerate, the latter occurring only adjacent to the quartzite ranges. The conglomerate is similar in most, if not all, respects to the Potsdam conglomerate. The sandstone is also quite like the Potsdam sandstone, but is generally finer grained and less compact. A thickness of about 135 feet of the St. Peter occurs on Pine Bluff, a short distance southeast of the Lower Magnesian limestone at Eiky's quarry.[1] The summit of Pine Bluff has an elevation of 1320 feet, and therefore it probably extends some distance up into the overlying horizon of the Trenton formation. This interpretation would seem to be justified in view of the fact that on Gibraltar Bluff, two miles southeast of Merrimac, the uppermost beds of the St. Peter have an elevation of about 1240 feet, capped with the Trenton limestone. If the top of the St. Peter on Gibraltar Bluff is at an elevation of 1240 feet, it seems reasonable to presume that the top of this formation in the latitude of the Baraboo district, but a few miles farther north, is not more than 10 or 20 feet higher and may, therefore, be considered to be 1250 to 1260 feet. A similar result is arrived at by allowing the usual thickness of 250 feet for the Lower Magnesian and St. Peter combined; for, as already shown, the base of the Lower Magnesian is about 1000 feet above the sea in this district.

THE TRENTON AND GALENA FORMATIONS.

The Trenton limestone, about 100 feet thick, and Galena limestone, about 200 feet thick, are respectively the next formations above the St. Peter sandstone in southern Wisconsin. In the Baraboo district limestone of neither of these formations

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[1] Geol. of Wis., vol. 2, pp. 593-4.

is known to occur. The sandstone and conglomerate, however, occurring about the upper flanks of the quartzite ranges, may have been deposited during the Trenton and Galena epochs. The conglomerate and sandstone on the flanks and summit of the quartzite ranges, at elevations above 1250 or 1300 feet, probably belong with the Trenton and Galena formations.

CHAPTER VI.

THE GLACIAL DRIFT.

The eastern part of the district, east of the line of the terminal moraine extending irregularly north and south near Baraboo (see Pl. I), is quite generally covered with a mantle of glacial drift. In the eastern part of the district the drift covers not only the valley bottom between the quartzite ranges, but occurs in almost equal abundance over the quartzite ranges. In the western part of the district, west of the line of the terminal moraine above referred to, drift occurs mainly in the valley bottom and very sparingly over the adjacent uplands.

The drift[1] of the eastern part of the district, which will be described first, consists of a mixture of clay, sand, gravel, and boulders, this material occurring generally in quite unequal proportions, and being distributed unequally over the rock formations beneath. It is well known that the drift was deposited where it is now found by glacier ice, assisted by the accompanying waters, due to the melting of the ice. The stratified sands, clays, and gravels found in the drift were deposited by the glacier water, whereas the large boulders and unstratified material were largely deposited by the ice.

The eastern drift, including the terminal moraine, has an uneven surface and forms hills and ridges as well as depressions and basins. The terminal moraine is especially characterized

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[1] A general description of the origin of the drift, with considerable detail concerning the drift of the Baraboo district, is given in Bull. Wis. Geol. and Nat. Hist. Survey No. 5, Chap. 5, by R. D. Salisbury and W. W. Atwood.

by rounded hillocks and short ridges of drift, accompanied by depressions occupied by small ponds, lakes, and marshes. The terminal moraine extends across the Baraboo valley just west of Baraboo, and while not forming a prominent topographic feature, as compared with the rugged quartzite ranges, nevertheless, seen from the west, can readily be observed for some distance, appearing as a ridge, 30, 40, or even 50 feet in height. Seen from the west, it is always sharply marked from the flatlying land in front; but seen from the east, where the drift is abundant, there is generally no sharp line separating the terminal moraine from the ground moraine immediately back of it. The terminal moraine on the quartzite bluffs is generally a narrow, sharp ridge, from 20 to 30 feet high. East of the terminal moraine, as far as the district extends, and far beyond as well, the drift occurs in variable abundance, modifying greatly the topography of the hard rock surface of the region by its unequal distribution.

The maximum thickness of the drift of the terminal moraine in the valley probably does not exceed 300 feet. On the quartzite ranges the terminal moraine, as already stated, stands from 20 to 30 feet above the hard rock adjacent. East of the terminal moraine, in the area of the ground moraine, the maximum thickness of the drift is probably about 250 feet in the valley, and much less than this on the quartzite ranges.

The drift in the western part of the district, west of the terminal moraine, is quite similar in composition to that of the eastern part. It therefore consists of boulders, gravel, sand, and clay, the finer materials being usually, though not always, stratified. The drift occurs mainly in the valley bottoms, both within and without the quartzite ranges, but coarse drift also occurs along the sides of the quartzite bluffs at elevations of 50 to 100 feet above the valley bottoms, and fine gravels and also some coarse drift occur on the tops of the bluffs at elevations of about 200 feet above the level of the Baraboo River.

While this report is not primarily concerned with the drift phenomena of the district, yet certain observations were made concerning the glacial deposits, which may properly be recorded here.

Immediately[1] west of the terminal moraine, and fringing it in the valley, gravel and sand form a broad, level deposit, the character of which is that of an outwash plain, built up by waters flowing outward from the ice when the latter covered all of the area to the eastward and its edge stood where the terminal moraine is now located. The outwash plain was very obviously formed during the period of glaciation known as the Wisconsin stage, in which was built up the prominent terminal moraine and the accompanying drift of the eastern part of the district. But far out to the west of the terminal moraine, west of North Freedom, eight and ten miles from the moraine, huge boulders occur, some of them weighing several tons, whose large size and location upon the sides of the bluff, 50 to 100 feet above the valley bottom, indicate some origin other than that of outwash plain material. Salisbury and Atwood[2] have suggested the explanation that this coarse drift was carried thither by floating ice in a lake which occupied the valley between the quartzite ranges when the ice covered the eastern part of the district.

There is, however, coarse drift outside as well as within the valley between the quartzite ranges, as instanced by an abundance of coarse drift forming hills south of the South Range, north of Denzer in sec. 10, T. 10 N., R. 5 E. On the north slope of the North Range in the NE. ¼ of the NE. ¼ of sec. 36, T. 12 N., R. 4 E., a small boulder of gabbro was noted, six or seven inches in diameter, located about 50 feet above the level of Narrows Creek immediately adjacent. Similar gabbro was noted in much larger boulders mingled with boulders of other foreign rock on the sides of the quartzite ranges within the valley in the SE. ¼ of sec. 6, T. 11 N., R. 5 E. Outside of the map of this district, in the eastern part of the city of Reedsburg, occur accumulations of debris foreign to the country rock immediately surrounding, too coarse to be carried by water.

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[1] It is purposed by the writer to present in the Journal of Geology a more detailed account concerning the drift in the western part of the district.

[2] Bull. Wis. Geol. and Nat. Hist. Survey No. 5, p. 130.

The drift within the valley southwest of North Freedom, where numerous deep drill holes have penetrated to the sandstone and pre-Cambrian rock beneath, has a known maximum thickness of 218 feet, and often consists of good-sized boulders as well as of much gravel, sand, and clay, without peat or marl beds, the character of the whole being hardly consistent with the hypothesis that the formation is a lake deposit. Furthermore, there is developed in the coarse drift on the south slope of the sandstone hill about one-half mile southwest of North Freedom, in the SE. ¼ of the SE. ¼ of sec. 3, a typical "kettle" or depression, having a depth of 35 or 40 feet and a width at the top of 60 or 70 feet, similar to depressions and sags in terminal moraine. This kettle has an elevation of 50 or 60 feet above the flat valley bottom adjacent.

Without going further into details concerning the drift phenomena west of the terminal moraine and explanations thereof, it may be stated briefly that, in the opinion of the writer, the same explanation of origin very probably holds for the drift outside the valley as within the valley, and it seems highly improbable that the drift hills and knobs outside and south of the valley just north of Denzer were formed by icebergs in a lake, not only on account of the shapes and extent of such deposits but also on account of the fact that the topography of this vicinity is such as to indicate that no lake existed here in glacial time. The kettle on the slope of the hill within the quartzite ranges southwest of North Freedom could hardly have been formed by icebergs floating in a lake. The occurrence of unstratified gravel and clay upon the summits of the quartzite bluffs at various places in front of the pronounced Wisconsin terminal moraine should also be considered in connection with the origin and distribution of the drift here described. The most rational explanation, it seems to the writer, of the origin of the drift west of the Wisconsin terminal moraine, with the exception of that of the outwash plain fringing the terminal moraine, the presence of which indicates the absence of a lake or stagnant water in front of the ice margin, is that a glaciation earlier than that of the Wisconsin stage probably prevailed throughout the district.

CHAPTER VII.

THE GROUND WATER.

In the course of the present investigation close attention has been paid by the writer to the manner of the distribution and also to the approximate amount of underground[1] water in the various geological formations of the district. From the standpoint of the practical miner, ground water is one of the serious problems to contend with in sinking shafts to ore deposits and in the construction of the underground tunnels necessary to mining the iron ore. And from the standpoint of the geologist the underground water at present circulating through these rocks is of much interest, because it has come to be believed by many to have an important function in the origin of ore deposits.

The water that falls in rain upon the land in part passes off by immediate surface flow to adjacent streams, in part is returned to the air by evaporation, and in part sinks into the interstices of the ground to varying depths and later comes to the surface again at lower elevations to join the surface drainage. The open space in rocks holding the underground water varies greatly, ranging from a fraction of one per cent in granites and similar crystalline rocks to as much as 30 or 40 per cent in friable sandstone and fine-grained clays. The openings in rocks are of two kinds: the open spaces between the individual grains of the rock, such as occur between the grains of sand in ordinary sandstone, and the open fractures and joints, such as prevail in compact, crystalline rocks.

It is highly important to keep in mind the difference be-

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[1] The terms *ground water* and *underground water* are used synonymously.

tween the amount of pore space and other openings in rocks and the amount of flow that may take place through such openings. A rock may contain much pore space and yet be practically impermeable on account of the small size or the unfavorable disposition of the openings. In general, the fine-grained rocks, such as the clays and shales, are very slightly pervious, though they contain an amount of pore space usually much larger than that of ordinary sandstone. Large spaces, such as occur in sandstone, are more favorable to permeability than small spaces, such as occur in clays, on account of the smaller friction of the moving water along the walls of the openings. All rocks are more or less permeable, and yet most of the compact, crystalline rocks are practically impervious in comparison with such rocks as sandstones and other sandy formations.

In the Baraboo district there are three kinds of rock which from the standpoint of their water content, character of rock openings, and permeability, can best be treated separately. These kinds of rock are the incoherent glacial drift, the partially consolidated Potsdam sandstone, and the thoroughly consolidated and cemented pre-Cambrian rocks.

Ground Water of the Glacial Drift. The glacial drift in the valley between the quartzite ranges, as already shown, has a known depth, varying from a few inches up to 218 feet, and a probable maximum thickness not exceeding 240 feet. The drift consists of a loose mass of clay, sand, gravel, and boulders, the clay and sand being the predominent material. Professor F. H. King[1] has shown that the ordinary glacial sand of the drift about Madison, Wis., when packed as closely as tamping and jarring will permit, has a pore space amounting to from 30 to 38 per cent. The pore space of clay is known to run up as high as 45 per cent and even above 50 per cent, though, as already stated, the openings in clay are generally so small that it is practically an impermeable formation. The relative

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[1] King, F. H., Principles and conditions of the movement of ground water: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 98.

amounts and distribution of the clay and of the sand and gravel are so irregular in the drift formation that there is an entire lack of uniformity in conditions of the circulation of the ground water, even in areas of close proximity. Where clay is present very little water circulates, but where gravel and sand occur large amounts of water must be pumped, for the effective pore space in the loose sand and gravel probably equals on the average 34 or 35 per cent. The glacial sands are unconsolidated and move readily under water, and hence are quite generally known as quicksand.

On account of the great variation in distribution of pervious and impervious drift, and the general lack of uniform conditions for the circulation of water, no definite statement can be made concerning the amounts of water likely to be encountered in the drift at different depths. The general statement may be made that in the drift consisting of sand, or sand and gravel, more water will have to be pumped than from the Potsdam sandstone at the same depths below the water level, while from the drift consisting wholly of clay practically no water will flow into the shaft or tunnel, and that from drift consisting of mixed clay and sand intermediate amounts of water will percolate into the underground openings of the mines.

Ground Water of the Potsdam Sandstone. The Potsdam sandstone formation has a thickness in the valley varying from a few feet up to 569 feet, the latter depth probably being near the maximum for this formation below the level of the valley bottom. This formation is generally a coarse, friable, whitish sandstone. A variable thickness of conglomerate lies at the contact with the underlying pre-Cambrian rock, and considerable red shale occurs in the valley at depth of 240 feet. In the sandstone there is an effective pore space of 28 to 32 per cent, as calculated by Mr. W. G. Kirchoffer on data based on the flow of water in numerous wells of the state in the Potsdam formation. In general, there appears to be a pore space of about 30 per cent for the average Potsdam sandstone in the district, as indicated by conditions at the Sauk mine and elsewhere. Besides the pore space between the grains of sand in the sand rock there are also present a variable number of open joints, which are generally either parallel or normal to the bedding. The quantity of water flowing into the mining shafts from the sandstone is shown in the following table. This table is applicable only to the Potsdam formation, and is based on a formula derived from records of many flows in wells in this formation in different parts of the state and the flow into the Sauk mine.

TABLE I[1]—*Probable quantity of ground water flowing into a mining shaft in the pure sandstone, at different depths below groundwater level.*

Depth below water level and lowering of water in vertical shaft in feet.	Corresponding depth and lowering in 60° shaft in feet.	Corresponding depth and lowering in 45° shaft in feet.	Flow into shaft in gallons per minute.
25	28.85	35.35	32.47
50	57.70	70.70	126.3
75	86.55	106.05	272 0
100	115.40	141.40	453.9
125	144.25	176.75	658.5
150	173.10	212.10	871.7
175	201.95	247.45	1083
200	230.80	282.20	1282
225	259.65	328.15	1474
250	288.50	353.50	1628
275	317.35	388.85	1804
300	346.20	424.20	1945
325	375.05	459.55	2071
350	403.90	494.90	2183
375	432.75	530.25	2282
400	461.60	565.60	2370
425	490.45	600.95	2453
450	519.30	646.30	2520

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[1] This table, and also Table II, were furnished the writer by Mr. W. G. Kirchoffer, of Madison, Wis., who has made a special study of the water supplies of Wisconsin. Bull. Univ. of Wis., Engr. Ser.

The theoretical formula of the equation from which the above table is compiled is the same as that used by Professor C. S. Slichter and a number of French and German investigators of ground-water supplies. The essential factors in the formula are that the flow varies directly in proportion to the thickness of the water-bearing strata and to the lowering of the water, and inversely in proportion to a coefficient depending upon the amount of water flowing through the rock and the lowering of the water of the well. It should be remembered, of course, that the computation in this table begins at the ground-water level, which is at variable distances, though not far below the surface of the ground in the valley.

TABLE II—*Probable quantity of artesian water to be pumped from a mining shaft at different depths below the impervious shale layer.*

Vertical distance below the shale layer in feet.	Corresponding distance down a 60° shaft in feet.	Corresponding distance down a 45° shaft in feet.	Head of water in feet at this level.	Quantity flowing into shaft in gallons per minute.
1	1.15	1.41	251	7
25	28.85	35.35	275	164
50	57.70	70.70	300	324
75	86.55	106.05	325	469
100	115.40	141.40	350	623.6
125	144 25	176.75	375	759.2
150	173.10	212.10	400	888.0
175	201.95	247.45	425	1009
200	230.80	282.80	450	1120

In the above table is presented a statement of the probable quantity of water flowing into an open mine shaft at various depths below the impervious shale layer, where the water is under static pressure. With reference to the amount of flow of water under static pressure below the impervious shale layer at depth of about 240 feet, it may be stated that the artesian conditions at this depth make but little difference in the amount of flow of water into the shaft where a part or the whole of the overlying 240 feet is the ordinary, porous Potsdam formation.

In those places, however, where the formation above the impervious shale layer is entirely impervious, clayey drift, although this condition is extremely unlikely to occur, thus allowing a much smaller flow into the shaft than that indicated in Table I for the first 240 feet, there would necessarily be a marked increase in the amount of water to be encountered below the impervious layer, as compared with the amount flowing in above this layer.

It should be borne in mind that the above tables are applicable only to the ordinary, pure sandstone rock with porosity averaging between 28 and 32 per cent. As the lower portion of the Potsdam formation contains a variable amount of shale, the amount of water flowing into the shaft will be lessened in proportion to the decrease of effective pore space of such shale rock. As already stated, also, if there is much clayey drift to be penetrated, a smaller amount of water will flow into the shaft than if the entire depth were in the pure sandstone. The tables, therefore, give the probable maximum amount of water to be pumped at the various depths indicated.

Ground Water in the Pre-Cambrian Rock. The rocks of the pre-Cambrian sedimentary formations, the Baraboo quartzite, the Seeley slate, and the dolomite and iron-bearing rock of the Freedom formation, are thoroughly consolidated and cemented, as is usual with pre-Cambrian formations.

The thin sections of the quartzite show practically complete filling of the spaces between the original quartz grains by secondary quartz, and, as indicated by well data, the general movement of underground water through this formation seems to be entirely through open fissures in the formation. The Seeley slate is a fairly uniform, very fine-grained rock, consisting mainly of fine clay minerals, the chemical analysis of the slate showing a content of only 0.01 per cent of hygroscopic water (water driven off below 110°). While in ordinary analyses the amount of hygroscopic water in coarse, porous rocks gives no indication of the amount of pore space in such rocks, yet in the fine-grained rocks, like clay and crystalline rock, a close relation exists between the amount of pore space and the amount of hygroscopic water shown by analysis. The dolomite is a uniform, wholly crystalline rock, with close-fitting grains of carbonate, and, like all thoroughly crystalline limestone and marble, may be classed as practically impermeable, though having minute pore spaces amounting to less than one per cent. Water classed as hygroscopic in the analyzed sample of dolomite amounted to 0.08 per cent.

The iron-bearing rocks of the ferruginous horizon largely consist of a mixture, in various proportions, of hematite, quartz, carbonate, and chlorite. The content of hygroscopic water, as shown in the several analyses of phases of the ferruginous rock, varies from 0.06 to 0.76 per cent and approximates very closely the usual amount of hygroscopic water prevailing in igneous and metamorphic rocks. The thin sections show the phases of the ferruginous rock to be fine-grained, compact, thoroughly consolidated rocks and practically impermeable. Abundant veins of quartz, varying in thickness from a small fraction of an inch to several inches, ramify throughout the rocks and cut across the bedding at all angles. The rocks are generally brittle, and usually break with conchoidal fracture, though the soft phases of iron ore and phases of rock containing a comparatively large amount of clay mineral and carbonaceous matter as a rule readily part along bedding planes.

Observation concerning the character and distribution of the water passages in the slate and the iron-bearing formations in the tunnels of the Illinois mine seemed to indicate that most, if not all, the water which penetrates these formations comes through the open fissures and fractures. In all cases where the water was seen dripping from the walls and roofs of the tunnels it was seen to issue from fractures in the rock. The amount of water finding passage into the crosscuts and drifts in the 300 and 400 foot levels of the Illinois mine varies much from place to place, though at no place is this amount very large. No water whatever trickles through the Seeley slate exposed along the two crosscuts. In the ferruginous rock, however, which is a more brittle formation than the underlying Seeley slate, fracturing, which forms the passages for the water, is irregularly distributed. The first 10 feet of the paint rock in the first level is practically free from trickling water, but beyond this fracture and fissure zones occur at irregular intervals, through which water finds passage. In the second level the trickling water in the paint rock first occurs at about 20 feet from the contact with the underlying slate. There is much more water trickling through the walls and roof of the tunnels in the 300 foot level of the mine than in the 400 foot level, very probably on account of the greater proximity of the tunnels of the first level to the overlying, porous sandstone.

The amount of water being pumped from the Illinois mine (November, 1903) was about 500 gallons per minute. A considerable amount of this water flows into the mine at depth of 105 feet in the shaft, near the contact of the iron formation with the gray slate. Another important source of the water is from an open fissure near the east end of the drift of the first level, this fissure not unlikely being connected with the sandstone, which is located only 60 or 70 feet distant. The amount of open space below water level in the tunnels and shaft of the Illinois mine very probably is close to 200,000 cubic feet, and when it is considered that a large amount of the water which finds passage into this space comes in from two localized openings it can readily be seen that the amount of water trickling through the iron formation at this mine is not large but relatively very small.

Composition of the Ground Water. In order to ascertain the amount of mineral matter held in solution by the underground water of the district, and to see if any marked difference exists at the present time between the composition of the water circulating through the pre-Cambrian iron-bearing rocks and that circulating through the Potsdam formation, four water analyses were made by Professor W. W. Daniells, which are shown in the following table, in parts per 1.000,000 of water:

Analyses of ground water.

In parts per 1,000,000.

	I.	II.	III.	IV.
Silica	12.00	10.40	10.40	13.06
Alumina	0.13	0.17	0.50	0.60
Ferric Oxide	1.40	1.20	2.06	1.70
Lime	46.80	39.40	14.80	64.00
Magnesia	18.60	26.70	9.34	32.38
Potassium Oxide	0.69	1.10	1.20	1.12
Sodium Oxide	4.21	3.84	3.10	2.43
Chlorine	3.70	2.80	2.80	2.30
Sulphur Trioxide	5.84	0.206	1.28	0.62

I. Water from shaft of Illinois mine, from near junction of paint rock with underlying gray slate, about 105 feet below surface and 75 feet below ground-water level.

II. Water from end of crosscut in 400 foot level of Illinois mine, taken from a diamond drill hole extending horizontally northward 200 feet through the ore deposit and overlying paint rock, about 350 feet below ground-water level.

III. Water from shaft of Sauk mine in Potsdam sandstone, from depth of 85 feet and 40 feet below ground-water level.

IV. Water from exploration drill hole in the sandstone, 340 feet deep in the SW. 1/4 of the SW. 1/4 of sec. 2, T. 11, R. 5 E. This hole furnishes a vigorous artesian flow, deriving the principal flow at depth of about 250 feet and flowing at approximate rate of 310 gallons per minute.

The above analyses, with mineral matter stated in grains per gallon of water, in the form in which the elements probably occur in solution, as stated by Prof. W. W. Daniells, are given in the following table:

Analyses of ground water.

In grains per gallon.

	I.	II.	III.	IV.
Sodium carbonate	....	.0723	.0653	.0379
Potassium carbonate	....	.0723	.0140	.0084
Calcium bicarbonate	7.4381	5.6471	2.4965	10.7970
Magnesium bicarbonate	3.9592	5.6195	1.9880	6.8838
Iron bicarbonate	.1866	.1598	.2747	.2268
Sodium sulphate	.0566	....	....	....
Potassium sulphate	.0741	.0262	.1405	.0606
Calcium sulphate	.4560	....	....	....
Sodium chloride	.3557	.2729	.2729	.2216
Alumina	.0075	.0099	.0291	.0956
Silica	.6998	.6065	.6065	.7616

The silicia in solution is probably largely in the form of colloidal silicic acid.[1] The silica is apparently the least variable constituent present. There is appreciably less iron and alumina in the iron-bearing rock than in the sandstone. The amount of lime exceeds that of the magnesia, as is usual in ground water, the artesian water from the sandstone having considerably larger amounts of these constituents than the water from the Sauk mine. Sodium oxide occurs in excess of potassium oxide, there being a slightly less amount of these constituents in the sandstone than in the pre-Cambrian rock. Chlorine is present in the usual quantity occurring in underground waters. An appreciably larger amount of sulphur trioxide occurs in No. I than in the others.

The composition of the Baraboo city water, which is obtained from three large, shallow, open wells, 16 to 20 feet in diameter, the source of the water supply being quicksand and gravel of the glacial drift formation, is as follows:

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[1] Kahlenberg, L., and Lincoln, A. T., Solutions of silicates of the alkalies: Jour. of Phys. Chem., vol. 2, pp. 77–90.

	Grains per Gallon.
Calcium bicarbonate	13.067
Magnesium bicarbonate	11.013
Iron bicarbonate	.386
Sodium Sulphate	.274
Potassium sulphate	.396
Calcium sulphate	.087
Sodium phosphate	trace
Sodium chloride	.186
Alumina	.034
Silica	.874

This analysis is interesting, as it furnishes means of comparing the water of the glacial drift of the district with the waters from the sandstone and the pre-Cambrian formations. In comparison, it is at once seen that the drift water is quite similar though somewhat more mineralized than the deeper waters of the district. This slight difference is probably due to the fact that the drift material through which these waters have passed largely lies above the level of ground water and consists mainly of powdered igneous rock, rich in silicate minerals, from which the silica, iron, alumina, and alkalies could be obtained, as well as of boulders and fragments of limestone and dolomite, from which the lime and magnesia were taken in solution.

Considered as a whole, these various waters do not differ essentially from one another, nor from the usual deep-well waters from other parts of the state. For purposes of comparison, the composition of five artesian waters of the state, the only ones available, is shown in the following table:

Analyses[1] of Wisconsin artesian mineral waters.

In grains per gallon.

	I.	II.	III.	IV.	V.
Sodium carbonate	2.3327	....	....	....	....
Sodium bicarbonate	....	1.09	....	....	....
Calcium bicarbonate	8.1645	15.24	6.4150	8.69	....
Calcium carbonate	....	....	....	....	0.6222
Magnesium bicarbonate	6.9954	12.98	4.6654	6.63	....
Magnesium carbonate	....	....	....	....	10.9739
Iron bicarbonate	0.5832	0.21	....	0.13	0.2318
Sodium sulphate	....	0.29	4.0822	8.86	12.7978
Potassium sulphate	....	0.24	....	....	....
Calcium sulphate	1.7495	....	0.5832	14.55	15.3699
Sodium phosphate	....	trace	....	....	trace
Sodium chloride	5.5832	0.29	4.0822	0.64	90.2007
Potassium chloride	....	....	....	0.27	3.8064
Alumina	....	trace	....	0.19	0.0610
Silica	1.7495	[illegible]	0.5832	2.38	2.8430
Sodium bromide	....	....	....	....	0.1281

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[1] Bull. U. S. Geol. Survey No. 32.

I. Artesian Well, Madison. 830 feet deep, reaching the pre-Cambrian rock; water supply from the Potsdam sandstone. G. Bode, analyst.

II. City Well, Madison. 737 feet to the pre-Cambrian; water supply from the Potsdam sandstone. W. W. Daniells, analyst, 1882.

III. Wild's Artesian Well, Fond du Lac. Source of water is in the St. Peter sandstone. G. Bode, analyst.

IV. Jacob's Artesian Well, Milwaukee. 1,200 feet deep; source of water the Potsdam and St. Peter sandstone G. Bode, analyst.

V. Artesian Mineral Well, Prairie du Chien. 959 feet deep; source of water the Potsdam sandstone.

The analyses in this table should be compared with those in the table above, in which the composition of the Baraboo district water is stated in grains per gallon. A comparison of the analyses shows a quite general similarity, with no striking differences in amounts of iron, silica, or other constituents.

The Baraboo underground waters, when compared with stream and river waters, appear not to differ greatly from them. Unfortunately, no complete analyses of Wisconsin river waters are available. In order to furnish a means of comparison, therefore, analyses of New Jersey river waters are here presented, since the geological formations of these two states are in many respects quite similar.

Table of analysis of some New Jersey river waters.[1]

Parts in 100,000.

	Pequest at Belvidere, November, 1894.	Musconetcong at Bloomsbury, November, 1894.	Raritan at Finderne, October, 1894.	Millstone, near mouth, October, 1894.	Crosswicks at Crosswicks, July, 1894.	Back Creek at Lowry's Pond, July, 1894.	Great Egg Harbor at May's Landing, September, 1894.	Maurice River at Millville, September, 1894.
Total solids	16.94	9.17	10.81	8.05	10.40	6.71	4.31	3.81
Inorganic (salts)	13.83	6.13	7.47	5.20	4.36	4.10	2.06	2.04
Volatile organic	3.11	3.04	3.34	2.85	6.04	2.61	2.25	1.77
Silica	1.27	1.06	1.65	1.10	.94	.29	.74	.53
Oxides of iron and aluminium	.17	.19	.05	.10	.39	.15	.15	.17
Calcium oxide	4.24	1.70	1.72	.94	1.48	.45	.12	.15
Magnesium oxide	2.03	.86	.72	.34	.02	.29	.02	.10
Sulphuric trioxide	.96	.39	.45	.81	.14	.27	.17	.15
Chlorine	.21	.21	.19	.38	.08	.17	.03	.08
Sodium chloride	....	....	.53	.64	....	....	....	....
Hardness	12.12	6.61	6.45	4.60	4.10	2.45	1.23	1.65
Reaction	alk.	alk.	alk.	alk.	acid	acid	acid	acid

[1] Geol. Survey of New Jersey, Vol. 3, p. 300.

In this table the constituents are calculated in parts per 100,000. In comparison, the first five in the above table are quite similar in composition to the underground waters of the Baraboo district. The last three contain appreciably less mineral matter than the Baraboo underground water, with the exception of amounts of alumina and iron, which do not differ appreciably in the two kinds of waters.

In regard to the general composition of river waters, it is of interest to examine the well-known table of river water analyses compiled by Justus Roth.[1] Thirty-seven analyses of river water of western Europe in Roth's tables have an average composition, in parts per 1,000,000, as follows:

Calcium carbonate	91.61
Magnesium carbonate	14.64
Calcium sulphate	31.10
Magnesium sulphate	3.90
Sodium sulphate	2.77
Potassium sulphate	1.76
Sodium chloride	16.50
Potassium chloride	4.56
Magnesium chloride	3.21
Silica	9.53
Potassium silicate	.56
Ferrous carbonate[2]	.86
Ferric oxide	1.47
Alumina	.69

It is at once seen that on the average the river waters are about as highly mineralized as the Baraboo underground waters. It should be understood that the composition of the river waters from the various rivers and from different places along the same river greatly vary, as may be seen by examining Roth's tables. Some of the waters analyzed, such as those of the waters from the Rhine at Strassburg, contain several times as much lime, magnesia, silica, and iron as the underground water from the Baraboo district.

The iron was determined in 19 of the 37 waters analyzed, the amount varying from a trace up to 14 parts in a million, the

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[1] Roth, Justus, Allgemeine und chemische Geologie, Book I, pp. 456–457.

[2] In some of the analyses in Roth's tables the iron is stated as carbonate, and in others as the oxide.

average content considered as ferric oxide in the samples being slightly more than two parts per million.

Attention is here called to the fact that river waters, as shown by these analyses of New Jersey and European river waters, where the waters are exposed to the most favorable conditions of oxidation, can and often do hold in solution amounts of iron equal to and even greater than are contained in the underground waters from the iron formation of this district.

In this connection it may be of interest to inquire into the probable amount of iron capable of being held in solution by underground waters, and for this purpose attention is called to mineral spring waters classed as chalybeate. As shown by Thorp's[1] tables of analyses of mineral waters, waters are classed as chalybeate that contain from 200 to over 1100 parts of ferric oxide in parts per million of water. These chalybeate spring waters, it is well known, do not precipitate their iron and other constituents held in solution until the waters are exposed to the oxidizing action of the atmosphere at the mouth of the springs, and in some instances, at least, organisms such as iron bacteria aid materially in the deposition of the iron oxide from these chalybeate waters.

The Work of the Ground Water. The underground water circulating through the rock openings dissolves in small quantity the materials of the soils and rocks with which it comes in contact, and also carries on, to a variable extent, the processes of precipitation and diffusion of the material taken into solution. The amount of mineral matter held in solution in four underground waters, believed to be fairly representative of the district, is shown in the above table just referred to.

There appears to be no prominent difference between the composition of the two waters in the pre-Cambrian iron-bearing rock and that of the sandstone, with the exception that the water at a depth of 105 feet in the Illinois mine shaft has a much larger content of SO_3 than the other waters, and that the artesian water contains more lime and magnesia than the others, especially more than the water from the Sauk mine.

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[1] Thorp, Dictionary of applied chemistry, vol. 3, pp. 95–97.

So far as these waters are accomplishing work, the character of such work should be indicated by the mineral constituents held in solution by the water, and by the composition of the undoubted secondary material in the veins and pores of the rocks through which the ground water circulates. The consideration of the bearing of the underground water upon the origin of the iron ore deposits is referred to here in only a very general way.

When these waters are compared with other underground waters, they are seen to be quite similar to them. They are not especially rich in any one particular constituent, such as calcium, magnesium, silica, iron, or sulphur. So far, therefore, as the composition indicates the character of the work being done by these waters, either in the iron formation and ore deposits or in the sandstone formation, this work should be expected to be similar, on account of the close similarity in the composition of the waters from these formations. In like manner, the character of the work done by these underground waters might well be expected to be similar to the work accomplished by the similar underground water outside the district (see table of analyses, p. 114). In river waters of similar composition, however, on account of the presence of the oxygen of the air and decaying and living organisms, quite different kinds of work would very likely be carried on.

The fact that the average content of iron in the ground water of the iron formation is even less than the average content of iron in various river waters where conditions of oxidation and precipitation of the iron are especially favorable would also seem to indicate that no deposition of iron from the water circulating through the underground channels in the iron formation or the sandstone is now taking place. It is but reasonable to believe, in fact, that underground water far removed from the atmosphere should carry many times the amount of iron in solution that can be carried by river waters without precipitation of the same. The amount of iron capable of being held in solution in chalybeate mineral waters, and which is not precipitated until such iron-rich waters are exposed to the oxidizing action of the atmosphere and of organisms, is many times,—100 to 500 times, that known to occur in the water circulating through the iron formation.

Judging from the composition of the ground water of the district and its comparison with other underground water, with river waters, and with chalybeate spring waters, it seems reasonable to conclude that very probably no iron is being deposited from the underground waters now circulating through the iron formation.

The work of the underground waters, to a large extent, may be indicated by the character of the undoubted secondary material in the rocks. The water circulating through the Potsdam formation has, to a certain extent, but only to a minor extent, as evidenced by the incoherent and uncemented character of this formation, been depositing quartz largely in the pore spaces of the sandstone. The fact that the Potsdam sandstone still retains about 30 per cent pore space, on the average, and that the sandstone quite generally crumbles on exposure to the air, indicates in a remarkable manner what a small amount of cementation has taken place in this formation, though exposed to the incessant circulation of underground water from early Paleozoic up to the present time. So far, however, as cementation has taken place, it consists very largely of the deposition of quartz in the interspaces of the sandstone.

The vein material in the pre-Cambrian Freedom formation, which without doubt was deposited from circulating water, has already been fully described as being largely quartz and some calcite, and to a very minor extent iron sulphide, iron oxide, and chlorite. These veins were formed in pre-Cambrian time, very probably during the period of mountain-making movements to which the pre-Cambrian was subjected, and therefore under conditions of metamorphism quite unlike those existing in the district since the deposition of the Potsdam sandstone. In pre-Cambrian time, also, the Baraboo formation was changed from sandstone to the present quartzite by the secondary deposition of quartz from ground water circulating through the interstices of the sandstone. The mineral veins in the quartzite also almost entirely consist of quartz. The material deposited from ground water in the interstitial spaces in Potsdam sandstone, as well as in the interstitial spaces and veins of pre-Cambrian formation, has been almost entirely quartz, the principal exception being the small amount of calcite associated with the quartz in veins in the Freedom formation.

Causes of the Circulation of the Ground Water. The movements of the underground water are of three kinds: gravitational, thermal, and capillary. These kinds of movements cannot be here discussed in detail, but it may be mentioned briefly that above the level of ground water the operative forces are mainly gravity and capillarity, while below the level of ground water they are principally thermal forces and gravity.

The Ground-water Level. At certain depths below the land surface, in all humid regions, all the openings and pores in the rocks are filled with water. The upper surface of the ground water, generally called the ground-water level, is usually not far below the surface and is approximately at the level of the streams and lakes of the vicinity. The level of the ground water is usually not horizontal, but approaches, in a general way, the undulations of the land, though in all cases standing much farther from the surface in the hills than from the sides and bottoms of the valleys.

In the Baraboo district our main interest lies with the ground water in the valley between the quartzite ranges. Throughout the valley the level of the ground water is not far above the level of the Baraboo River and its tributaries. Southwest of North Freedom, where the principal exploration for iron ore has been carried on, the level of ground water is generally within five or 10 feet of the flat valley bottom, and approximately at an elevation of 850 to 900 feet above sea level. South and east of Baraboo the ground-water level in the valley is generally at an elevation of 800 to 850 feet. In general, it may be stated that the approximate level of ground water at the east end of the valley, at the Lower Narrows, is 800 feet above sea level, rising to 900 feet at the west end of the valley in the vicinity of Ablemans.

The ground water in the sandstone hills is approximately at the same level as the ground water in the valley, as shown by the farm wells, which have to penetrate the sand rock to the level of the adjacent valley bottom. On the quartzite bluffs the ground-water level is usually at the contact of the sandstone with the underlying, hard, impervious quartzite.

The Course of the Ground Water. The flowage of ground water above the level of ground water and the flowage below this level have distinctive features and should ordinarily be treated separately. Above the level of ground water the movement is mainly due to gravity and, to some extent, capillarity. In the valley between the quartzite ranges, to which our attention is especially drawn on account of the occurrence here of iron ore, the sandstone and drift are the only rocks above the level of ground water; and since this level is so near the surface, practically little need be said concerning the movement of the water above the ground-water level. So far, however, as the sandstone and drift lie above the level of ground water in the explorable district, the water tends to move vertically downward under the stress of gravity. When the water has reached the upper surface of the ground water the vertical movement is changed to movement in all directions, from verticality to horizontality, but mainly in nearly horizontal directions along the upper surface of the sea of ground water. The valley between the quartzite ranges has the structure of an enclosed basin, the sandstone in the valley resting on the quartzite along the border and dipping gently towards the interior. The general slope of the land and the dip of the Paleozoic rocks of southern Wisconsin is to the south, and hence the east-west quartzite ranges, especially the continuous South Range, form a barrier to the general course of the southward-moving underground water. There is probably very little connection between the porous sandstone of the interior valley and that without, except through the Lower Narrows and probably through the drift and sandstone filled gorge of Devils Lake. The flowage of underground water in the zone of surface flowage, which zone extends from the impervious shale layer at depth of about 240 feet to the upper surface of the ground water, is from the west end of the valley towards the east end, though at best this circulation must be very slow on account of the limited place of egress at the Lower Narrows. Besides the surface zone of underground water just referred to there is also present a zone in which artesian conditions prevail. This zone lies below the impervious shale layer referred to on page 105, within which zone the water is confined between impervious layers both above and below, and in which the water is held under hydrostatic pressure of about 250 feet. The principal conditions upon which artesian flows depend are (1) a stratum of porous rock through which water readily circulates, (2) confining impervious strata above as well as below, and (3) the arrangement of the pervious and impervious beds so as to form a basin, or at least the beds to be so inclined that the edge at which the water enters will be higher than the surface at the well. All these conditions are furnished by the strata of the Potsdam formation in the valley between the quartzite ranges. The beds have a slight dip downward from the quartzite ranges towards the interior of the valley, and the presence of several thicknesses of shale about 250 feet below the valley bottom, and thus below the depth at which pre-glacial erosion penetrated, furnish the upper confining impervious strata below which the water is held under pressure.

CHANGES IN GROUND-WATER LEVELS.

It has already been stated that in humid regions the surface of ground water, or the ground-water level, conforms closely to the shape of the land surface. The ground-water level in porous rock, as in drift and Potsdam sandstone occuring in the valley between the Baraboo quartzite ranges, practically coincides with the level of the streams and rivers of the vicinity. The level of ground water can never be below the adjacent stream valley; otherwise, the stream waters would sink into the ground adjacent, just as wells "go dry" when ground water sinks below their bottoms. Also, the ground water can not stand far above the level of the adjacent streams in the valleys, because of the tendency to rapid lateral seepage into the streams, whence it is borne away to the large rivers and finally to the sea. The valley bottoms in which are located the rivers and streams, therefore, furnish a good index of the level of ground water of the vicinity, and so far as changes in the elevation and location of streams have taken place in past geological periods, as indicated by valleys now buried beneath later rock formations, such buried valleys indicate clearly in like manner the lowest levels of ground water when such valleys were formed.

Present Level of Ground Water. The present level of ground water in the valley between the quartzite ranges, as already stated, closely approximates the level of the Baraboo River and adjacent streams. The level of ground water coincides exactly with the level of the streams at the streams, but rises gradually as the distance from the the streams is increased. The present elevation of the Baraboo River at the Lower Narrows is 800 feet above the sea and at Ablemans about 850 feet. The ground-water level in the valley bottom probably varies from 800 to 900 feet above the sea, being from 850 to 900 feet above the sea southwest of North Freedom.

Lowest Level of Ground Water in Post-Cambrian and Pre-Glacial Time. At the beginning of glacial time the valleys, and therefore the rivers and streams of the Baraboo district and immediately adjacent region, were about 225 feet lower than they are at present. This depth of the pre-glacial valleys is indicated by the known thickness of 218 feet of drift in the valley bottom southwest of North Freedom, and the fact that the maximum depth of the pre-glacial erosion in the district cannot be greater than about 240 feet below the valley bottom; otherwise, the general artesian conditions at this depth could not prevail. Hence, the probable depth of the pre-glacial rivers and valleys in the district is placed at about 225 feet; and, since the ground-water level is at and slightly above the rivers and valley bottoms of the region, we can conclude that the lowest pre-glacial level of ground water was at a depth of about 225 feet below the present valley bottom, or at an elevation of 625 to 675 feet above the sea at the west end of the valley, and probably 25 to 50 feet lower than this at the east end.

It is not to be understood that throughout pre-glacial time the level of the ground water stood at the above indicated elevation. It is meant that this level, from middle Potsdam to glacial time, is the lowest level which erosion and the ground-water surface reached. Indeed, it must have been at this lowest level but a very short period compared to the time it was above this elevation, for it was above this during all the time succeeding the deposition of the Potsdam beds at this particular horizon, throughout nearly the whole of the Paleozoic age and the whole of the Mezozoic and Cainozoic ages, until the beginning of the glacial age and the deposition of the glacial drift.

Lowest Level of Ground Water in Post-Freedom and Pre-Potsdam Time. As the valley bottoms at the present time and at the beginning of pre-glacial time indicate the lowest levels of ground water in these particular periods, so the pre-Potsdam valleys in the older pre-Cambrian crystalline land furnish us the necessary data by which we can determine the lowest level of ground water in post-Freedom and pre-Potsdam time.

The probable maximum thickness of the sandstone is about 570 feet in the district, as already pointed out (see p. 93). It is believed that the pre-Cambrian land of this and the surrounding region was quite generally reduced to base level previous to the encroachment of the Paleozoic sea, and that the Baraboo quartzite ranges and other similar hard rock formations stood as monadnocks in this nearly base-leveled pre-Cambrian plain. The location of this pre-Cambrian peneplain, as already stated, is at the base of the Potsdam formation, about 570 feet below the present valley bottom, and thus very probably about 300 feet, relatively, above the present sea level.

The level of ground water in pre-Potsdam time, from the deposition of the latest pre-Cambrian formation of the district, the Freedom dolomite member, to the beginning of the Potsdam epoch, could not have been lower at any time than the pre-Cambrian peneplain, which, as just stated, has a relative elevation above the sea at the present time of about 300 feet. During this long period between the deposition of the Freedom formation and the deposition of the Potsdam sandstone, the former, with the associated underlying pre-Cambrian formations, the Seeley slate and Baraboo quartzite, were folded into a vast synclinal fold and later reduced by long continued erosion to the form assumed by these formations in the district at the present time. The level of ground water was probably never at any time far below the surface of the various parts of the district, the surface of the table of ground water probably approaching very closely the form of the topography, as is usually the case in compact, crystalline rocks of the character of the pre-Cambrian formations.

CHAPTER VIII.

THE IRON ORE DEPOSITS AND THEIR ORIGIN.

SECTION I.

The Iron Ore Deposits.

DISTRIBUTION.

The iron ore of the Baraboo district occurs in the lower member of the Freedom formation, which formation, as already described, consists of two members, a lower one of iron-bearing rock and an upper member of dolomitic marble. The ore-bearing member lies immediately upon the uniform gray slate of the Seeley formation, and thus between the dolomitic marble above and the gray slate below. The iron-bearing member, as already stated, has at least a thickness of 400 to 500 feet and may have a thickness much greater than this. The distribution of the Freedom formation and the Seeley slate in the western part of the district is shown on the general map (Pl. I), and the probable distribution of these formations in the eastern portion of the district not yet explored by deep drilling is discussed on pages 150–6.

The location of the Illinois and Sauk mines is shown on the map (Pl. I), and the occurrence of the ore deposits of these mines and of some of the other ore bodies of the western part of the district is indicated in the cross sections of Plate XII. Definite and detailed knowledge concerning the distribution of the ore, as shown in numerous drill holes in the explored district, is presented in pages 71–81, as well as in the cross sections referred to. No workable deposits of ore have yet been found lying immediately upon the Seeley slate, there being in all cases a variable thickness of transition paint rock between the ore and the gray slate. In drilling through the member of ferruginous rock, one or more deposits of ore have been struck. It is true, also, that in many places the entire horizon is penetrated without finding workable deposits of ore.

KINDS OF ORE.

The Baraboo iron ore is mainly red hematite with a small amount of hydrated hematite. The ore in its prevailing aspects is more like the hard phases of ore of the old ranges of the Lake Superior district than the soft, hydrated hematite ore of the Mesabi district. It is believed by the writer that on account of the location of the iron ores of this district below the belt of weathering, hydration of the ore will be found to be of slight extent. The ore is usually of Bessemer grade.

The common phases of the ore are soft granular ore, hard banded ore, and hard blue ore. The soft granular phases generally carry the highest percentage of iron, the banded and hard blue ore containing usually a larger amount of silica.

MINERAL COMPOSITION OF THE ORE.

The principal mineral of the ore is hematite, Fe_2O_3, having a prevailing red color but varying to shades of bluish gray, and having a crystalline structure. Besides the hematite, there occur as iron-bearing minerals in the ore small amounts of hydrated hematite and of iron carbonate, the latter in isomorphous combination with variable amounts of manganese, calcium, and magnesium carbonate. Next to hematite in abundance is quartz, which occurs either in bands in the ore or is quite uniformly distributed throughout the ore. The quartz in the ore has generally the finely granular character of the quartz in the chert. Small amounts of chlorite, mica, and kaolin also occur in the ore in varying but usually small quantities.

The vein material in the ore is to a very large extent quartz, to a small extent calcite or ferro-dolomite, and to a very small extent iron sulphide and iron oxide. The quartz of the veins has the usual interlocking granitic texture of vein quartz, and is quite generally very much coarser than the finely granular cherty quartz in the ore and in the banded ferruginous chert. The carbonate of the veins is also much coarser than the carbonate of the beds.

CHEMICAL COMPOSITION OF THE ORE.

A complete analysis of the iron ore, representing a mixture of five samples of the various common phases of the iron ore taken from the stock pile of the Illinois mine, was made by Dr. Victor Lenher and is shown in the following table:

Ferric oxide, Fe_2O_3	88.62
Ferrous oxide, FeO	0.92
Alumina, Al_2O_3	0.68
Manganese monoxide, MnO	0.265
Silica, SiO_2	8.06
Lime, CaO	0.12
Magnesia, MgO	none
Titanium oxide, TiO_2	none
Sulphur, S	trace
Chromium oxide, Cr_2O_3	none
Water, at 110°, H_2O	0.21
Water, at red heat, H_2O	0.55
Carbon in carbonaceous matter, C	0.04
Carbon dioxide, CO_2	0.51
Phosphoric oxide, P_2O_5	0.004
	99.979
Total iron	62.75

Ferric oxide and silica constitute the principal portion of the ore. Ferrous oxide is the next most abundant constitutent. As the ore is not appreciably magnetic, and as there is present a larger amount of CO_2 in the ore than is necessary to satisfy the valency of the lime and maganese monoxide, it is certain that a large portion of the iron of the ferrous oxide, after deducting the amount necessary to satisfy the trace of sulphur, must occur as carbonate. As there is alumina present, there may be present one or more of the common aluminium silicates, such as chlorite or mica, which may be and very probably are combined with a variable amount of the calcium, manganese, and iron. The sulphur present is very probably present as iron sulphide. The mineral in which the phosphorus occurs in the ore is not known, but it may occur as the iron phosphate dufrenite, or as apatite. That carbon is present as carbonaceous matter is interesting, for it is believed by the writer to have an important bearing as evidence of the conditions under which the iron ore was deposited. Carbonaceous matter in the ore was reported by Mr. D. G. Donahue, chemist and engineer at the Illinois mine, as occurring in considerable quantities as a scum on some of the solutions of the ores analyzed, though the quantity was not determined. Dr. Lenher, in conducting some of the ore analyses, likewise noted the occurrence of carbonaceous matter in the dissolved ore in the process of analysis. Carbonaceous matter has been observed in the ores of some of the districts of the Lake Superior region, though so far as known no complete analyses of these ores are on record, and hence the exact amount in any ore analyzed is not known. Slates bearing carbonaceous matter occur with the associated ferruginous rocks, and are also often found associated with the iron formations in the Lake Superior district, and hence the occurrence of carbonaceous matter in the ore should be expected.

In the following table are presented two incomplete analyses of the ore:

Incomplete analyses of skip samples of iron ore from Illinois mine.

	I.	II.
Iron, Fe	59.68	56.33
Phosphorus, P	0.041	0.053
Manganese, Mn	0.15	0.16
Silica, SiO_2	9.60	14.95
Alumina, Al_2O_3	2.09	1.59
Lime, CaO	0.50	0.20
Magnesia, MgO	0.25	0.14
Ignition	1.40	1.60

I. Average sample made up from skip samples, representing 130 tons of ore from crosscut of first level of Illinois mine. Analysis furnished by the Illinois Iron Mining Company.

II. Average sample made up from skip samples of 126 tons of ore from second level of Illinois mine. Analysis made by Mr. Parsons, chemist of the South Chicago Furnace Company.

Both of these samples show a low content of matter classed as ignition, thus indicating but a comparatively small amount of hydrated hematite present.

An analysis of paint rock from thirty-nine samples of drillings from a drill hole east of the Illinois mine, furnished by Mr. W. G. La Rue, is as follows:

Ferric oxide, Fe_2O_3	64.29
Phosphoric oxide, P_2O_5	0.017
Sulphur, S	0.020
Manganese monoxide, MnO	0.24
Manganese dioxide, MnO_2	0.38
Silica, SiO_2	28.46
Alumina, Al_2O_3	3.71
Lime, CaO	0.38
Magnesia, MgO	0.39
Carbon dioxide, CO_2	0.47
Volatile matter	2.22
	100.63

On the assumption that all the iron present occurs as ferric oxide, the amount present is 45.00 per cent. There is probably a small amount of ferrous oxide present, and this would tend to slightly increase the total amount of iron. The occurrence of 0.47 per cent of CO_2, which indicates about one per cent of carbonate, is worthy of note. Judging from the small amounts of the calcium and magnesium present, as compared with the 3.71 per cent of alumina, the latter probably occurs largely as kaolin or other clay mineral. The high percentage of silica, 28.46 per cent, indicates this phase of the iron formation to be a ferruginous chert or lean siliceous ore.

The analysis of a mine sample collected and analyzed by Mr. R. N. Dickman of Chicago, the sample representing 40 feet of the ore deposit 200 to 240 feet from the shaft in the first level of the Illinois mine, is as follows:

Iron, Fe	54.49—54.85
Phosphorus, P	0.050

The above mine sample was collected from both sides and the roof of the crosscut, the merchantable ore body at this place being about 35 feet thick across the bedding. At the time this sample was collected, a sample representing 133 feet of the paint rock between the ore deposit and the Seeley slate, 67 to 200 feet from the shaft, was collected and analyzed by Mr. Dickman, with the following result:

Iron, Fe	32.340—31.95
Phosphorus, P	0.055— 0.043

The later analysis shows the average iron content of the strata of the ferruginous beds between the Seeley slate and the ore deposit, and indicates the general amount of iron in the paint rock below the ore deposit.

In the following is presented the determination of iron, phosphorous, and sulphur in some of the phases of ores taken from the stock pile of the Illinois mine by the writer and analyzed by Dr. Victor Lenher:

Partial analyses of phases of iron ore.

	I.	II.	III.
Ferric oxide, Fe_2O_3	93.39	71.00	56.96
Ferrous oxide, FeO	1.85	2.78	2.66
Manganese monoxide, MnO	0.32	0.18	0.26
Phosphorus, P	0.015	0.008	0.016
Sulphur, S	trace?	trace?	trace?
Total metallic iron	66.80	51.84	41.94

I. Soft granular ore; II. Hard blue ore; III. Banded cherty ore.

Several samples of ore picked at random from the stock pile of the Illinois mine and analyzed by Mr. Andrew S. Mitchell, chemist, of Milwaukee, contained the following:

Iron, Fe	57.63
Silica, SiO_2	12.67
Phosphorus, P (Soluble, 0.025; Insoluble, 0.0048)	0.0298

One of the finest picked specimens selected by Mr. Mitchell was analyzed by his assistant, Mr. J. H. Mathews, as follows:

Iron, Fe	66.52
Silica, SiO_2	2.19
Phosphorus, P (Soluble, 0.015; Insoluble, 0.0045)	0.0195

Analyses of ores of Illinois mine.

Location of sample.	Kind of sample.	Iron.	Phosphorus.
Crosscut, 220–227 feet from shaft	Skip sample, 30 tons	62.80	0.046
Crosscut, 220–227 feet from shaft	Skip sample, 30 tons	61.20	0.034
Crosscut, 227-233 feet from shaft	Skip sample, 25 tons	61.50	0.034
Crosscut, 227-233 feet from shaft	Skip sample, 25 tons	60.00	0.058
Crosscut, 233–237 feet from shaft	Skip sample, 10 tons	57.00	0.034
Crosscut, 233–237 feet from shaft	Skip sample, 10 tons	56.60	0.042
Crosscut, 237–240 feet from shaft	Skip sample, 10 tons	54.40	0.029
Crosscut, 237–240 feet from shaft	Skip sample, 10 tons	54.30	0.034
Crosscut, 236–240 feet from shaft	Drift sample	57.90	0.014
Crosscut, 220–231 feet from shaft	Drift sample	62.90	0.050
Crosscut, 231-236 feet from shaft	Drift sample	57.50	0.024
Crosscut, 236–240 feet from shaft	Drift sample	57.90	0.023
Crosscut, 231-236 feet from shaft	Drift sample	52.50	0.026
Crosscut, 231–236 feet from shaft	Drift sample	52.55	0.047
	Skip sample, 15 tons	61.30	0.050
East drift	Soft blue ore	62.85	0.062
East drift	Ore and jasper	55.23	0.065
East drift	Banded siliceous ore	50.46	0.064
East drift	Banded siliceous ore	50.09	0.066
East drift	Hard blue ore	68.03	0.042
East drift	Skip sample, 20 tons	63.80	0.045
East drift	Skip sample, 20 tons	64.00	0.039
East drift	Skip sample, 35 tons	62.60	0.043
East drift	Skip sample, 15 tons	63.00	0.030
East drift	Skip sample, 15 tons	63.60	0.045
East drift	Skip sample, 15 tons	61.20	0.040
East drift	Skip sample, 25 tons	61.90	0.035
East drift	Skip sample, 25 tons	62.80	0.040

In the preceding table is presented a series of determinations of iron and phosphorus from the crosscut and drifts of the first level (300 foot level) of the Illinois mine, the analyses being furnished by the Illinois Iron Mining Company, through the kindness of the superintendent, Mr. C. T. Roberts.

The above analyzed ores are entirely from the first level of the Illinois mine, the ore in the second level being identical with the above in all respects.

PETROGRAPHIC RELATIONS OF THE ORE TO ADJACENT ROCKS.

The kinds of rocks occurring in the Freedom formation, and therefore associated with the iron ore, have already been fully described in Section III of Chapter IV. It is intended to point out in this place with somewhat greater detail the relations of the iron ore to the associated rocks.

The rocks associated with the ore are various phases of ferruginous slate, ferruginous chert, and ferruginous dolomite. Several phases of these associated rocks are presented in Plates VIII–XI. The microscopic character of some of the phases of associated rocks is shown in the photomicrographs, Plates XXII, XXIII.

Relation of the Ore to the Ferruginous Slate. The relation of the ore to the slate is that of gradation, all phases of transition from typical clay slate with a content of five per cent hematite to typical iron ore being present. An intermediate phase is represented by the ferruginous slate (see pp. 52–53), which consists of about 67.05 per cent of clay mineral and 27.51 per cent of hematite. A phase of the ferruginous slate is represented in figure 2, Plate VIII, in which a thin lamina of iron oxide is seen interstratified in the red ferruginous slate. As the ore deposit is approached across the bedding, the clay minerals become less and less abundant and the hematite becomes the predominant constituent. As seen in thin sections, the iron oxide may be present as an intimate mixture through the chlorite and other minerals of the slate, or it may be concentrated in layers of variable thickness from mere leaves to strata an inch or more in thickness.

Relation of the Ore to the Ferruginous Chert. The relation of the ore to the ferruginous chert is likewise that of gradation, the banded siliceous ore being nothing more than a ferruginous chert containing sufficient hematite to be classed as ore. Ferruginous chert and jaspilite are perhaps the most common associates of the pre-Cambrian iron ores of the Lake Superior region, and they are also abundantly associated with the ore of this district. In figure 1, Plate IX, a typical ferruginous chert or jaspilite is shown, in which the character of this phase of rock is well illustrated. Along the borders of the strata of hematite is a zone of varying width of the red, irony chert, or jasper, marking the transition of the strata of hematite to the chert. In figure 1, Plate VIII, is a ferruginous chert (see analysis, p. 56) in which the cherty material is generally in very thin layers, the thicker strata of chert being associated with yellow ochre. In thin sections the ferruginous chert shows very clearly the intricate interlineation of hematite with cherty quartz. While the banding and stratification of the ferruginous chert is the most characteristic structural feature of this rock, there are nowhere layers of chert entirely free from fine crystalline hematite. At the junction of the layers of chert and ore there is seen to be an intimate mixture of the hematite and cherty quartz, showing clearly the gradation of cherty layers to hematite layers.

Relation of the Ore to the Ferruginous Dolomite. The occurrence of dolomite, closely associated and conformable to the stratified iron ore deposits, is believed to be unusual among the known pre-Cambrian iron-bearing districts of the United States and Canada, although limestone, dolomite, and calcareous shale is often associated with the post-Cambrian iron ore deposits, as illustrated by the Clinton iron ore formation of Upper Silurian age, which has a wide distribution over a large portion of the eastern half of the United States. Among the chief phases of rock mentioned by Professor C. R. Van Hise[1] commonly associated with the iron ore in the iron-bearing formations of the Lake Superior region, ferruginous dolomite is not mentioned,

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[1] Van Hise, C. R., The iron ore deposits of the Lake Superior region; Twenty-first Ann. Rept., U. S. Geol. Survey, pt. 3, pp. 318, 319.

although cherty iron carbonate is referred to as one of the most important rocks associated with the ore. In the Baraboo district the iron-bearing member grades upward into pure dolomite, and a large part of the ferruginous horizon itself consists of beds of dolomite and ferruginous dolomite, associated with slate, ferruginous chert, and iron ore in their various phases. The iron formation of this district, therefore, has a much greater similarity to the Upper Silurian Clinton horizon of iron-bearing rock than have the other pre-Cambrian iron-bearing formations of the Lake Superior region.

All phases of rock showing the gradation and transition of thin strata of iron oxide to thin strata of ferruginous dolomite are present. The carbonate mineral associated with the iron oxide in the various phases of ferruginous dolomite is largely, if not entirely, an isomorphous mixture of the carbonates of calcium, magnesium, iron, and manganese, in the proportions to constitute ferro-dolomite and manganic-ferro-dolomite (see analyses p. 63). Sometimes the layers of iron oxide are mere films in the dolomite, and at other times they are half an inch or more in thickness (see fig. 2, Pl. IX), intercalated between strata of dolomite.

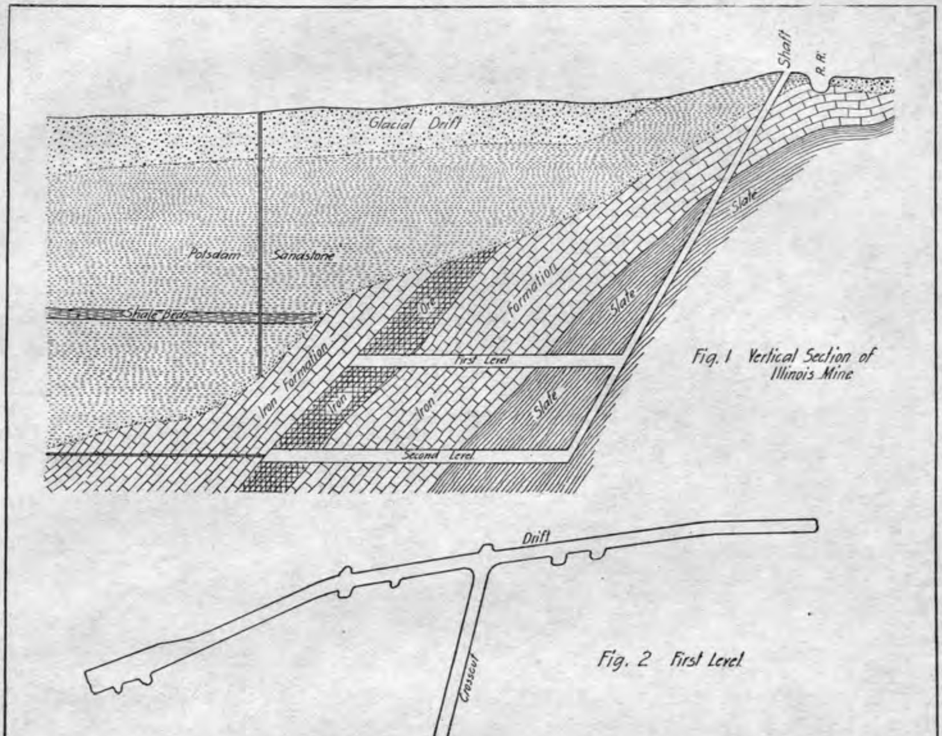
In thin sections the iron oxide is seen to be variously mixed with the carbonate along the junction of the alternating thin beds of dolomite and hematite. Farther out from the junction, the character of the strata of dolomite soon comes to be approximately pure dolomite or ferro-dolomite, and likewise the iron oxide layers come to be nearly pure oxide in the middle of the hematite bands. Sometimes concretions or nodules of hematite occur, entirely surrounded by pure dolomite, though usually such nodules are not far from adjoining thin strata of hematite. The association of the iron oxide with the carbonate in the ferruginous dolomite, like that of the fine grains of cherty quartz with the carbonate in cherty dolomite, and of the clay minerals with the carbonate in dolomitic slate, has the appearance and distribution of material contemporaneously deposited with the carbonate mineral, as is usually characteristic of sedimentary rock.

STRUCTURAL RELATION OF THE ORE TO ADJACENT ROCKS.

The iron ore has already been described as having typical bedded structure with all the characteristic features of stratified rock. The petrographic relation of the ore to the various associated ferruginous phases of rock has also already been described as that of gradation through all possible stages of transition, not only to ferruginous chert and ferruginous slate but also to ferruginous dolomite, the gradation to all of these phases of rock often occurring within the short space of a few feet and in many instances in a single hand specimen two or three inches in thickness.

Relation of the Ore Deposits to the Associated Strata. If it is true that the iron ore is a bedded formation showing all gradations to the various kinds of rock associated with it (and this fact of gradation is well known to be true of all the pre-Cambrian iron ore deposits), it should be expected that the ore deposits would be conformable in their structural relations to the adjacent rocks. Assembling all the available data concerning the structural relations of the iron ore to the associated rocks, the following may be stated:

1. The hematite, as seen in thin sections of the ferruginous rock and lean iron ore, occurs either finely disseminated throughout the rock, mingled irregularly with the various associated minerals, or as aggregations in the form of lenses and small pockets of nearly pure hematite. The hematite, whether occurring in single separated crystals or in aggregates of various shapes and forms, closely resembles in all particulars the forms and distribution of the cherty quartz, the carbonate, and the clay mineral in the various phases of ferruginous rocks. Sometimes the lenses have abrupt endings, but more usually they gradually thin out until they finally disappear and their place in the line of stratification is taken by clay, carbonate, or cherty quartz. Very often the lenses of iron oxide appear as a series of lenses along the lines of stratification, each lens being joined by a thin film of the hematite. In those thin sections showing folding and



CROSS SECTION OF THE ILLINOIS MINE AND GROUND PLAN OF THE FIRST AND SECOND LEVELS.

crumpling of the rock, the minute lenses and seams of hematite are seen to conform to all the foldings of the enclosing rock.

2. In hand specimens and large fragments of the ore and associated rock, each individual stratum of iron ore is seen to have a variable thickness as it is followed along the strike of the formation. The alternating layers of iron oxide are likewise seen to vary much in thickness as the bedding is crossed. The varying thickness of a single ore stratum is especially well shown in figure 2, Plate IX, and the folding of the hematite strata is shown in the specimen illustrated in figure 1, Plate VIII. The layers of carbonate and of chert and of slate alternating with the ore likewise are of variable thickness, parallel to the bedding as well as across the bedding. The individual layers of hematite in the ore often thin out to mere films in the cherty ore, just as the minute lenses of hematite thin out in the ferruginous chert, as seen in the microscopic sections.

3. The ore deposits themselves, so far as direct observation can be applied at the present time, appear to have, as would be expected, those general structural shapes and relations that are exhibited by the smaller bodies of hematite seen in the hand specimens and in the thin sections. The generalized cross sections of Plate XII show fairly well the structural relation of the ore deposits to the adjacent rocks. At the Illinois mine the workable ore deposit lies about 100 feet above the Seeley slate and has a thickness of about 35 feet across the bedding, both levels of the mine having the same thickness of ore. The wall rock, both below and above the deposit, consists of the various kinds of ferruginous rock already described, into which the iron ore grades. The ore deposit in the two levels of the mine (see Plate XV), 300 and 400 feet below the surface, lies at the same distance, about 100 feet, above the gray slate formation, and conforms to the dip and strike of the surrounding rock, and also conforms to the minor folding of the adjacent rock, as is very conspicuously shown in both crosscuts of the mine. About 75 to 100 feet above the first level the ore deposit is truncated by the pre-Potsdam erosion. Below the second level the ore deposit

continues downward for some distance, as shown by exploratory drilling, with dip and strike conformable to the stratification of the ore and wall rock adjacent. About a quarter of a mile north of the Illinois mine two workable ore deposits are said to occur at depths between 800 and 1200 feet below the surface. The ore deposit at the Sauk mine (see cross section E–F, Pl. XII), as shown by exploratory diamond drilling, lies nearly flat over a low anticline and in a shallow syncline. The ore on the property of the Wisconsin Iron Mining Company (see cross section G–H, Pl. XII) lies nearly flat over a considerable area and then dips to the north as the middle of the valley to the north is approached. At the west end of the explored district the ore deposit on the Judevine farm (see cross section M–N, Pl. XII), apparently lies on the north side of a shallow syncline with a low dip to the south, while farther to the south, towards the South Range, the ore deposit of the Patterson prospect dips in the opposite direction at a considerably higher angle.

Whereever exploratory work has proven the occurence of ore deposits, their general shape and structural relations are shown to be exactly similar to those of the deposit at the Illinois mine. That is, they occur at variable distances above the Seeley slate, within the ferruginous member, and their bedding is conformable to the overlying and underlying stratified rock, with the greatest dimensions of the deposits in the plane of the bedding and the smallest normal to the bedding.

Relation of the Ore Deposits to the Associated Mineral Veins. The iron ore and associated ferruginous rock contain numerous veins which permeate the ferruginous horizon in all directions. As already described (see p. 109), fractures and fissures filled with water, as well as numerous mineral veins, are present throughout the brittle Freedom formation in both the dolomitic and iron-bearing members. In striking contrast to the brittle Freedom formation, the underlying, dry Seeley slate, a soft rock with well-developed schistosity, is comparatively free from veins and water-filled fractures and fissures. This notable difference between the two formations is without doubt due to the difference in texture and mineral composition of the two formations, on account of which the soft, fine-grained Seeley slate when subjected to great pressure and consequent folding became deformed by shearing, with the development of schistosity, while the brittle dolomite and iron-bearing rock was deformed by intense fracturing. Considered quantitatively, the amount of vein material in the iron ore and related ferruginous rock is large. Microscopic study shows that from two-thirds to three-fourths of the slides of this formation contain mineral veins, and hardly a hand specimen can be collected, unless it be of the soft, clay slate phases, that does not contain one or more veins. The amount of vein material in single specimens of the ferruginous rock and ore varies generally from a fraction of one per cent to several per cent. Many specimens occur, also, containing more than a score of veins, the material of which constitutes, without doubt, as much as five or 10 per cent of the rock, and in zones of fracture where excessive movement and readjustment have taken place the percentage of vein material is even larger than this.

A study of the composition of the vein material, it was believed by the writer, might throw some light on the origin of the iron ore deposits, and hence a systematic examination of the vein material in the ore and in the adjacent rocks was made. In the 66 slides cut from rocks of the ferruginous member, examined by the writer, 46 contained veins and 20 were free from veins. Of the 46 containing veins, 13 contained veins of quartz only, 11 contained veins of carbonate only, 16 contained veins of quartz and carbonate, three contained veins of quartz, carbonate, and iron oxide, one cut from a clay slate phase contained a vein of kaolin, one contained a vein of chlorite, and one contained veins of iron oxide.

In the hand specimens quartz veins are the principal ones apparent. In a few of the specimens minute veins of iron sulphide are present. As seen under the microscope, the larger veins are quite generally veins of quartz, and the veins containing quartz with other mineral are largely quartz, and hence quartz is believed to be by far the most abundant vein material in the rock. Considered quantitatively, and upon this point only an approximation can be hazarded, quartz probably constitutes from 90 to 95 per cent of the vein material; the carbonate, which is very probably mainly calcite or dolomite, probably forms from two to five per cent, and the remaining material, such as iron sulphide, iron oxide, and the hydrous alumino-silicates, from two to three per cent.

The structural relation of the veins to the iron ore and related rocks is an interesting one, and can best be seen by a study of the several reproductions of some of the important phases of the ferruginous rock and a perusal of the descriptions accompanying the plates. The veins, consisting largely of quartz, cut across the bedding of the ore and adjacent ferruginous rock at all angles, though most of the veins have a marked tendency to cut approximately normal to the stratification. Sometimes there appear to be small veins parallel to the bedding, but such are not abundant. In many instances, along the convex sides of small folds in the strata there are numerous fractures nearly normal to the bedding, due to tensional stresses, thus proving conclusively that such fractures were formed contemporaneously with the folding of the strata. In the Illinois mine is a large vein of quartz, a foot or so in thickness, cutting directly across the bedding of the ore. This prominent vein of quartz is accompanied by many smaller ones running parallel to and slightly divergent from the large vein, indicating the presence of a prominent zone of fracturing at this place. Very probably the excessive fracturing was accomplished when the general folding and tilting of the pre-Cambrian formations into their present position took pace. Certainly this fracturing and development of the veins took place before Cambrian time, as no fracturing and veining comparable to it is known to occur in the Paleozoic formations of the district.

The relations of the mineral veins to the ore deposits are unlike the conformable relations of the stratified rocks in the ore deposits, since they penetrate at random and irregularly through and across the stratification of the ore deposits and associated rocks. The fracturing and fissuring and the development of the veins in the ore deposit and associated rocks were long subsequent to the origin of the stratified ore and associated rock, since the veins cut across the bedding in all directions like later intrusive igneous rock. Veins, of course, have always been recognized as secondary formations, and the writer wishes merely to emphasize the fact that the veins in these ore deposits were developed later than the ore itself, as well as later than the stratification lines in the ore, just as they are later than the stratification of the surrounding rock. The significance of the composition and the structural features of the mineral veins, is interpreted as evidence opposed to the theory that the iron ore originated like the mineral veins, as the work of ground water.

Shape and Size of the Ore Deposits. The forms of the large ore deposits, like the forms assumed by the small aggregates of hematite seen in thin sections and hand specimens, are very probably lens shaped, as indicated by the fact that they have a much greater extension along the strike and dip of the beds of the ore than across the stratification. The exact shapes and sizes of the ore deposits, of course, cannot be definitely proven at the present time like the shapes and sizes of numerous small bodies of ore seen in fragments and thin sections; but, reasoning from our knowledge of the forms of the small bodies and of the large deposit of the Illinois mine (see Plate XV), and from the fact that the ore deposits are stratified, it is but reasonable to suppose that the ore deposits cannot be other than lens shaped, as are all bodies of sedimentary rock. If the ferruginous chert bodies, deposits bearing say 90 per cent silica, could be examined as to the shapes they assume, they would probably be found to be lens shaped, and likewise the ferruginous dolomite bearing 60 to 75 per cent carbonate, and the ferruginous slate bearing 40 to 50 per cent clay mineral, would also probably have lens shapes and grade into the adjacent rocks in directions parallel as well as normal to the bedding.

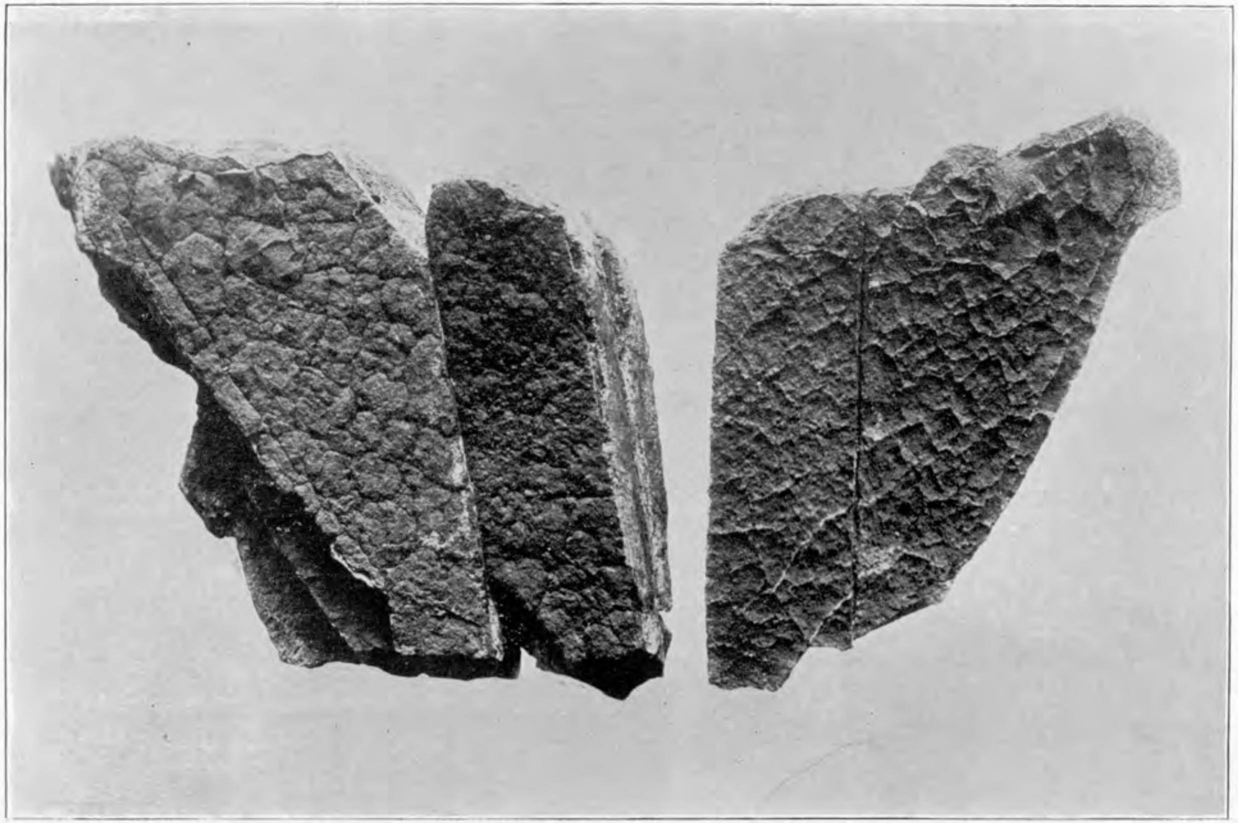
The size of the iron ore deposits is known to vary considerably in the different parts of the district. At the Illinois mine the deposits (see Pl. XV) has a thickness of about 35 feet across the bedding, while along the strike the ore body has been tunnelled preparatory to mining the ore for a distance of about 700 feet on the first level and about 400 feet on the second level, and along the dip the ore extends from its truncation at contact of the overlying sandstone above for a distance of nearly 300 feet downward. It is not to be understood that 300 feet along the dip and 700 feet along the strike on the first level, and 400 feet on the second level, measures the extent of the ore in these directions, but that only to this extent has the deposit at present been opened to mining. The extent of the workable ore deposits at other places is not known, except in a general way. The deposit on the Judevine farm, in the SW. ¼ of sec. 17, has a thickness across the bedding of approximately 200 feet, averaging 45 per cent iron and containing one horizon at least 15 to 20 feet thick, bearing about 54 per cent of iron. The extent of this ore deposit along the bedding is not known. Rich ore is reported in the Patterson prospect (record 30, p. 88, Pl. XII) on the Goll farm, located near the center of the NW. ¼ of sec. 20. The deposit of ore is probably not continuous between the above localities, although it may be. The distribution of the ore deposit parallel to the bedding on the Iroquois Mining Company property is considerable compared with the thickness of the ore, and the same is true of the deposit on the Wisconsin Iron Mining Company property.

The fact, as shown by exploratory work, that the ore bodies are not found at the same horizons in the iron-bearing formation in the various parts of the district, and the further fact that they are found not to be continuous at the same horizons in the formation, should be expected if they are lens-shaped or lenticular accumulations.

SECTION II.

Origin of the Iron Ore.

It is believed by the writer that the iron ore of the Baraboo district was originally a deposit of ferric hydrate, or limonite, formed in comparatively stagnant, shallow water, under condi-



SUN CRACKS IN SHALE OF THE FREEDOM IRON-BEARING FORMATION.

Natural size. Specimen 7018. From the Illinois mine. near the iron ore deposit. The left-hand portion of the specimen shows the sun cracks, the right-hand portion the surface immediately overlying and containing the impressions of the sun cracks.

tions similar to those conditions existing where bog or lake ores are being formed to-day, and that through subsequent changes, long after the iron was deposited as limonite, while the formation was deeply buried below the surface and subjected to heat and pressure, the original limonite became to a large extent dehydrated and changed to hematite. The conditions surrounding the original deposition of the iron ore as limonite and the subsequent changes involved in the partial loss of the combined water and development of hematite are briefly outlined below.

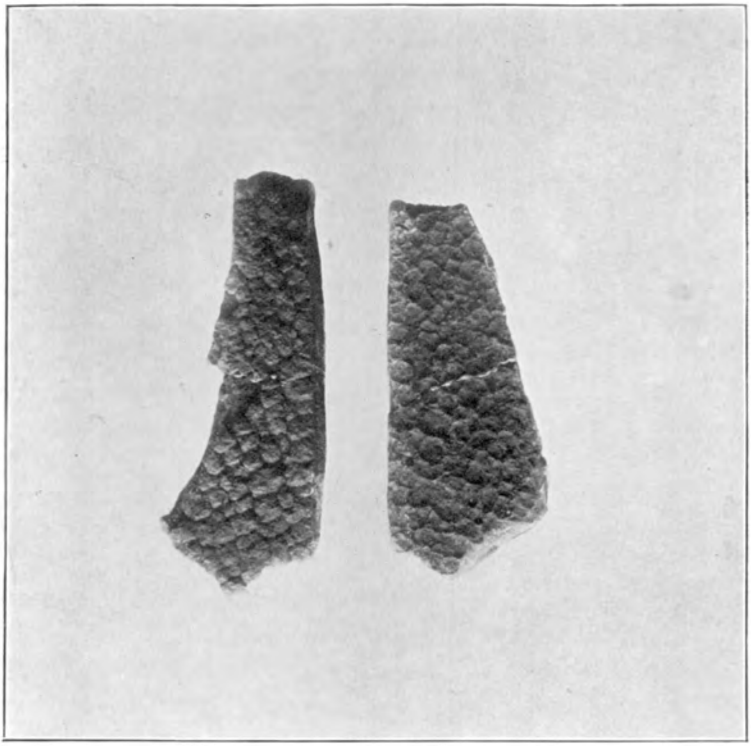
Conditions of Sedimentation. The physical conditions under which the iron-bearing member was deposited were evidently changeable, as evidenced by the alternation of the different kinds of rock strata, such as thin beds of slate, cherty quartz, iron oxide, and dolomite. Previous to the deposition of the ferruginous member, during the period of the deposition of the remarkably uniform, gray Seeley slate, conditions of deposition were rather uniform, the sinking of the bottoms in which the clay was accumulating keeping pace approximately with sedimentation. The development of the dolomite horizon immediately succeeding the formation of the ferruginous member was likewise under conditions of uniform rate of subsidence and sedimentation, as evidenced by the uniform composition of this member. On the other hand, the iron-bearing member lying between the strata of gray slate below and the pure dolomite above, with its alternating beds of varying composition, such as chert, dolomite, slate, and iron ore, is evidence of changing conditions of sedimentation, and of a period in which no long continuous, uniform relations existed between deposition of strata and subsidence of the land.

Sedimentation and subsidence are without doubt slow processes in nature, and the conditions under which these processes of change in sedimentation would be the most sensitive would very likely be in regions of shallow water adjacent to shore lines, or in broad, shallow lagoons or bays, in which slight changes in the subsidence or elevation of the land would soon be reflected in the character of the deposits. Not only is the varying composition of the strata of the ferruginous member evidence of shallow-water conditions, but there is abundant evidence in the iron-bearing rock itself pointing to conditions of shallow water for its deposition. The occurrence of carbonaceous matter in the sediments of this member, not only in the slate and ferruginous dolomitic slate, but also in the iron ore, is strong evidence of the superficial conditions under which these rocks were formed. Furthermore, the presence of sun cracks in the strata (see Plates XVI, XVII) immediately associated with the iron ore furnishes undoubted evidence of the very shallow water in which these rocks must have been formed,—water so shallow, indeed, that the accumulating sediments were actually brought above water level at times and laid bare to the sun and air and dried before the next layer above was deposited upon it.

The composition of the various alternating strata is such as is often found in comparatively shallow and quiet waters about us to-day. Clays containing carbonaceous matter are accumulating in lakes and estuaries at the present time. Carbonate deposits like marl, and siliceous deposits of diatomaceous earth, and hydrated peroxide of iron, or limonite, as bog-iron ore, are all common deposits in lakes, lagoons, and marshes.

The evidences above cited of the varying character of the composition of the strata of the iron formation, the presence of carbonaceous matter in the rocks and iron ore, and the occurrence of sun cracks in the strata immediately associated with the iron ore, considered together, render the conclusion probable and justifiable that the iron-bearing member was deposited in comparatively shallow, and very probably, nearly stagnant water, and thus under conditions similar to those under which like deposits are being formed in lagoons and marshes about us at the present time.

The processes involved to-day in the accumulation of sediments that are similar to those in the pre-Cambrian ferruginous member include, to a large extent, the work of living organisms as well as the action of decaying vegetable matter, and, if the present can in any degree furnish us the key to the past, there is good reason for believing that the presence of life must have exerted no less powerful an influence in forming these ancient



SUN CRACKS IN SHALE OF THE FREEDOM IRON-BEARING FORMATION.

Natural size. Specimen 7018. From Illinois mine, near the iron ore deposit. The left-hand portion of the specimen shows the sun cracks, the right-hand portion the surface immediately overlying and containing the impressions of the sun cracks.

deposits. It is a well-known fact that organisms have the power to abstract and deposit mineral matter from very dilute mineral-bearing solutions,—from solutions, indeed, bearing much less mineral matter than could possibly be precipitated by purely chemical processes. It is quite generally accepted that limonite is often deposited in stagnant surface waters by the well-known action of iron bacteria.[1] It is the belief of the writer that organisms played an important part in the formation of the strata of hematite, as well as of the strata of dolomite and chert. It may be urged that the pre-Cambrian crystalline formations furnish no fossils or other indubitable evidence of life in that early geologic period. However, it is a well-known fact that the comparatively high development of life on the globe, shown by the fossils of the oldest fossiliferous Cambrian formations, points unmistakably to the existence of life for a very long period previous to the formation of these oldest Cambrian fossil-bearing rocks. The pre-Cambrian crystalline rocks are in all respects similar to some of the crystalline rocks of post-Cambrian age, which we have every reason to believe were once fossiliferous, but which, through metamorphism and recrystallization, have lost all evidence of fossils.

Subsequent to its deposition, the ferruginous horizon became buried beneath the later dolomite horizon, and probably other thick deposits as well. Still later, through earth-movement forces, the associated pre-Cambrian strata were elevated into mountain folds, and the accompanying forces, such as heat and pressure, metamorphosed the beds into crystalline rock. Through the processes of metamorphism the plastic clay beds lost, to a large extent, both their hygroscopic and constitutional water and were changed to slate, the marl beds became consolidated and were crystallized into dolomite and ferruginous dolomite, the siliceous deposits were changed to compact chert, and the limonite became largely dehydrated and changed to crystalline hematite.

The above is a general outline of the probable conditions of

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[1] Lafar, F., Treatise on technical mycology, pp. 355–362.

original sedimentation of the iron ore and related rocks, and the subsequent changes they have passed through. The explanation here offered for the occurrence of the iron ore is, in brief, the hypothesis that the iron ore was a superficial deposit formed under conditions similar to the conditions under which the bog and lake ores are being deposited to-day over various parts of the world. It is not believed that the Baraboo ore was necessarily formed as a lake deposit or a bog deposit, but that conditions of origin were similar to those in which lake and bog deposits are being formed, that is, the presence of shallow, quiet water containing considerable iron in solution, derived from the surface weathering of iron-bearing rocks of adjacent land areas, in which organisms could readily thrive. Under these conditions, by action of living, dead, and decaying organisms, assisted perhaps to some extent by chemical precipitation, were built up, it is believed, the ferruginous deposits with which are intercalated a variable amount of the clay of purely mechanical origin.

The hypothesis here adopted by the author as the most probable explanation of the origin of the Baraboo iron ore is one that has been accepted for years by many geologists as fully explanatory of the stratified crystalline iron ores.

It will be found, on examination of the literature[1] of the iron ores, that there are differences in the origin of various deposits, as generally indicated by the nature of the deposit. Some iron ore deposits are clearly mineral veins, and thus of undoubted secondary origin. The stratified crystalline ores, however, are not veins. The crystalline iron ores have been generally referred to either of two theories of origin, which may be stated as follows:

1. The theory that the iron ore was originally deposited as ferric hydrate and subsequently merely dehydrated through the process of deep-seated metamorphism.

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[1] Kemp, J. F.. The ore deposits of the United States, 1895.

Winchell, N. H. and V. H., The iron ores of Minnesota: Bull. Minn. Geol. Survey No. 6. Pt. 5 contains a very complete bibliography on the iron ores.

Phillips, J. A., Treatise on ore deposits.

2. The theory that the ore, as it now occurs, is mainly a secondary alteration or replacement deposit.

The latter theory has been quite generally applied as the explanation of the pre-Cambrian iron ores of the Lake Superior district by C. R. Van Hise[1] and his associates on the United States Geological Survey. A modification of the latter theory for the Mesabi iron ore is held by J. E. Spurr,[2] formerly of the Minnesota Geological Survey. On the other hand, T. Sterry Hunt,[3] J. S. Newberry,[4] J. A. Phillips,[5] J. Le Conte,[6] A. Geikie,[7] T. C. Chamberlin,[8] and others have held that the crystalline iron ores are probably mainly original sedimentary deposits.

The evidence supporting the hypothesis adopted by the writer that the iron ore is largely an original sedimentary deposit of limonite may be briefly summarized as follows:

1. The iron ore deposits are bedded and, to all appearances, stratified like other sedimentary deposits.

2. The stratified iron ore deposits are not set off sharply from the surrounding associated stratified rocks, such as slate, chert, and dolomite, but grade into them through all possible gradations. The iron ore is not especially associated with any particular kind of the various rocks adjacent, and the stratification of these various kinds of rock is always conformable to that of the iron ore. Since the slate, dolomite, and chert are original sedimentary deposits, and since the iron ore grades into them and is conformable to them, it is believed that the iron ore has the same origin as these conformable interstratified deposits of related rock.

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[1] Van Hise, C. R., The iron ore deposits of the Lake Superior region: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 313–434.

[2] Spurr, J. E., The Mesabi iron-bearing rocks; Bull. Minn. Geol. Survey No. 10, 1894.

[3] Hunt, T. S., Chemical and geological essays, pp. 220–235.

[4] Newberry, J. S., Genesis of iron ores: School of Mines Quarterly No. 2, 1880, p. 1.

[5] Phillips, J. A., Treatise on ore deposits, 1896, pp. 35–51.

[6] Le Conte, J., Elements of geology, pp. 150, 151.

[7] Geikie, A., Textbook of geology, 3d ed., pp. 483, 632.

[8] Chamberlin, T. C., Geology of Wisconsin, vol. 1, pp. 82–83.

3. That the physical conditions in the district at the time the iron formation was deposited were favorable for the formation of such shallow-water deposits as iron ore is indicated by the presence of sun cracks in the rocks of the iron formation immediately adjacent to the iron ore and also by the presence of carbonaceous material, probably decayed vegetable matter in the iron ore and associated ferruginous rocks. Furthermore, the rapid alternation in the various strata of the iron formation indicates changing conditions of sedimentation,—a common characteristic of shallow-water deposits, and the composition of the iron-bearing formation itself, with its chert, carbonate rock, and slate, is identical with the composition of shallow-water deposits being formed to-day.

4. That the iron ore deposits originated long antecedent to the folding and fracturing of the iron formation and the deposition of the mineral veins is shown by the fact that the strata of iron ore are generally folded, crumpled, and fractured, and that the mineral veins cut across the stratification and also across the folds of the iron ore and associated rocks. The folding of the ore deposits appears to conform in all respects to the folding of the associated rocks (see ground plan of mine, Pl. XV and cross sections, Pl. XII), and the ore deposits appear to have the position and distribution which they should have if formed before the general folding of the pre-Cambrian formations into their present position took place.

5. The change in the ore subsequent to its original deposition as limonite, as shown by the microscopic and chemical study of the rocks, is believed to be mainly a change to hematite by dehydration of the limonite under deep-seated conditions of metamorphism. This change is exactly parallel to the dehydration of the original clay minerals of the gray Seeley slate formation and of the clay minerals in the slate phases of the iron formation, which now contain very little water of constitution, only two or three per cent, but which originally must have contained from 10 to 25 per cent. This change of limonite by dehydration is also analogous to the probable dehydration of the original siliceous deposits now constituting the chert layers.

The geological data which led the writer to believe that the Baraboo iron ore was very probably deposited as limonite under conditions similar to those under which bog and lake ore are formed to-day, and later merely partially dehydrated to form hematite, have just been briefly outlined. The principal evidence believed to be directly opposed to the theory of the secondary development of the iron ore as replacement and alteration deposits by work of the underground water is mainly furnished by the character of the work of the underground water at present, as indicated by its chemical composition, and by the work of the ground water of the past, as indicated by the character and composition of the mineral veins in the ore and associated rocks.

From the study of the composition of the ground water now circulating through the iron-bearing rock and associated formations in the district, and its comparison with that of ground water outside the district and with river waters and with chalybeate mineral waters (pp. 110–120), it has been concluded that very probably the present work of the ground water in the iron formation is not that of depositing iron ore. It is quite generally accepted that mineral veins are deposited from underground water circulating through fractures in rocks; and the fact that the mineral veins (see pp. 138–141) in the iron ore and associated rocks are largely quartz and not iron ore is interpreted as evidence that the work of the ground water of the past was very probably not that of depositing iron ore. If the work of circulating ground water of the past could have or did develop the iron ore deposits, why should not the work be now in progress since ground water is now circulating through the ore deposits and associated rocks as it has in the past; and if the iron ore could have been or was developed by the work or agency of ground water, why should not the mineral veins that ramify through the ore deposits and associated iron-bearing rocks be composed largely of iron ore instead of quartz?

Aside from stating that by microscopic study the writer was unable to detect any conclusive evidence of the development of the iron ore deposits by processes of alterations or replacements, it is desired merely to call attention to the amount and distribution of ground water in the pre-Cambrian crystalline rocks (pp. 108–110), to the absence of any definite relation between the occurrence of ore deposits and the levels of ground water in the district (described pp. 122–125), both present and past, and to the location of the iron-bearing formation and ore deposits in the bottom of the synclinal valley between the quartzite ranges where adverse conditions for vigorous circulation of underground water must almost necessarily have prevailed since the folding of the Baraboo series. These references to the geology of the ore deposits are here made merely to call attention to the fact of their entire harmony with the facts of the composition of the ground water and of the mineral veins as evidence opposed to the theory of the secondary origin of the ore.

CHAPTER IX.

EXPLORATION.

The iron ore of the Baraboo district is wholly confined to the iron-bearing member of the Freedom formation, in which the ore deposits have a somewhat irregular distribution. The finding of iron ore in the Baraboo district, as it has been in all other iron-bearing districts, is partly a matter of chance, not only because the workable deposits of ore have an irregular distribution in the iron-bearing member, but also on account of the heavy blanket of sandstone and drift which entirely covers the ore-bearing rock. Since the iron ore is found entirely within the iron-bearing member of the Freedom formation, the location and distribution of this member is a matter of great importance.

Method of Exploration. Exploration in the district is done entirely by churn drilling and diamond drilling. Churn drilling is quite generally applied in penetrating the soft formations of drift and sandstone. As soon as the hard, pre-Cambrian crystalline rock is met with, diamond drilling is substituted for churn drilling. In diamond drilling the cutting is done by the rotating of a steel bit set with amorphous diamonds in such manner as to cut cylindrical cores from the rock. The usual cost of churn drilling is about $1.00 per foot, and of diamond drilling $3.00 to $4.00, depending upon the depth and character of the rock.

Known Distribution of the Iron-bearing Rock. The distribution of the Freedom formation known at the present writing is shown on the general map (Pl. I). It should be borne in mind that this formation, as mapped and described, includes two members, the upper consisting of dolomitic marble and the lower of iron-bearing rock. Since the ore-bearing member lies below the dolomite, the area mapped as Freedom formation is therefore wholly explorable territory. The central portion of the valley, where this formation occurs, generally contains both the dolomitic marble member and the ferruginous member, while nearer the sides of the valley, adjacent to the underlying Seeley slate, only the ferruginous member is present. The thickness of the iron-bearing member is at least 400 to 500 feet, while the width, which is variable in different parts of the valley, depends upon the dip of the iron-bearing strata. Along the south side of the valley the dip is probably as a rule less than 45° to the northward, and along the north side of the valley, in the vicinity of the quartzite ridges, the dip is generally at a steeper angle in the opposite direction, as shown in the cross sections. The width of the iron-bearing member, though not the thickness, beneath the sandstone and drift, is therefore greater along the south side of the valley than along the north side. The width of the iron-bearing member beneath the sandstone, however, is a matter of importance only in so far as it indicates the nearer proximity of this member, and therefore of the iron ore, to the surface. Since the dolomite member overlies the iron-bearing member, it is apparent that exploration through the dolomite and into the iron-bearing member below should for the same reasons be conducted with equal care as the exploration of the iron-bearing member where not overlain with dolomite.

The chances for finding ore deposits in this district are probably as good as the chances have been in other districts. An iron-bearing member like the Freedom formation, with a thickness of 400 to 600 feet, may reasonably be expected to contain a number of ore deposits. From five to ten million tons of ore, at least, have been located, and it seems reasonable to believe that the district will become as important as some of the iron ore districts about Lake Superior.

The fact that the iron-bearing rock and associated formations are closely folded and covered with a much greater thickness of drift and sandstone than the iron-bearing members of other districts, makes the finding of the ore-bearing strata about as difficult as the finding of ore deposits in this member after it is once located.

Distribution of the Iron-bearing Member in Unexplored Parts of the District. The known distribution of the iron-bearing member at the present writing, as already stated, is shown on the accompanying map (Pl. I). Based upon our knowledge of the structure of the series of pre-Cambrian rocks within which the ore-bearing rock occurs, and also upon what is already known concerning the distribution of the iron-bearing member, certain inferences can be deduced from these established facts concerning the probable or improbable occurrence of this member in other parts of the district. In treating this subject the land deserving of exploration for iron ore within the valley between the quartzite ranges will be discussed first, and then that without the valley along the outer border of the quartzite ranges.

Explorable Land Between the Quartzite Ranges. Beginning at the west end of the district, it may be seen by a glance at the general map that a large part of the area between the quartzite ranges east, north, and west of North Freedom is unmapped. While this unmapped area is known to be covered with a thick mantle of drift and sandstone, the nature of the underlying pre-Cambrian rock is unknown, and hence the map is here uncolored. This unmapped portion is certainly underlain with one or more of the three formations: Baraboo quartzite, Seeley slate, and Freedom formation. All this unmapped area should be classed as explorable territory, although the chances for finding iron formation in the various parts of it are by no means equally good. A single drill hole put down in certain parts of the area may throw out a large portion of the area left in blank; and yet until definite knowledge can be obtained by such drilling, the unmapped area should to that extent be classed as explorable. In general, the broader the portions of unmapped area between adjacent quartzite outcrops, the more likely are they to contain the iron formation. Where the unmapped area is narrow between quartzite exposures there is less likelihood of the occurrence of the iron formation. The fact that iron formation occurs between the quartzite outcropping at the village of North Freedom and the quartzite in the SW. 1/4 of sec. 3 indicates that iron formation will probably be found north of North Freedom, between this village and the main North Range of quartzite farther north.

It has already been shown in a former chapter of this report (see Ch. IV and especially pp. 37–44) that not only the valley between the quartzite ranges west of North Freedom, where the younger rocks of slate and iron-bearing rocks and dolomite are known to occur, is a synclinal valley, but that the valley south and east of Baraboo is also structurally a continuation of the same synclinal valley. Unless, therefore, the formations overlying the quartzite, such as the Seeley slate and Freedom formation, were eroded in pre-Potsdam time, these formations should be found throughout the continuation of this synclinal valley. Whether the iron-bearing rock occurs in the valley south and east of Baraboo is at present not known and cannot be known until exploratory work has been carried on to such an extent as to prove the occurrence or non-occurrence of the iron-bearing member in this part of the valley. That the iron-bearing member was once present in this part of the valley there can be no doubt. There is a possibility, however, that it may have been eroded by the long continued erosion preceding the deposition of the sandstone formation in the valley. It seems unlikely, however, that erosion in the broad, and therefore deeper, parts of the valley between the quartzite ranges should have extended much farther in the eastern portion of the valley than in the western part, west of North Freedom, where an abundance of the formations younger than the quartzite are found. On the whole, therefore, there are very good reasons for the exploration of the unmapped portion between the quartzite ranges south and east of Baraboo.

It is probable that the narrow portion of the valley in the vicinity of the mouth of Skillet Creek is underlain with quartzite or the Seeley slate, and the same may be true of other narrow portions of the valley. Where the quartzite of the adjacent parts of the ranges has a steep dip in oposite directions, there is much more likelihood of the occurrence of the iron-bearing rock between than where the dip of the adjacent quartzite is shallow. In other words, the steeper the dip of the adjacent quartzite the deeper is the intervening valley likely to be, and therefore the more likely is it to contain the younger formations of slate and iron-bearing rock. Other factors being equal, there is more likelihood of the occurrence of the iron formation where the valley between the ranges is broad than where it is narrow, for the broader the valley the deeper is it likely to be, and therefore, the more likely to contain the iron-bearing member.

In the exploration of the unmapped area in the valley between the quartzite ranges it should be borne in mind that the rock underlying the explorable unmapped area may be wholly the quartzite, or wholly the quartzite and the Seeley slate, or the quartzite, the Seeley slate and the Freedom formation. The boundary of the mapped and unmapped area within the quartzite ranges is the approximate border of known quartzite, and hence next to this quartzite border later exploration may show the quartzite to extend still farther towards the interior of the valley. The next formation above the quartzite, and therefore extending towards the interior of the valley from both the north as well as the south of the valley, is the Seeley slate, with a probable thickness of 500 to 800 feet, and therefore a width of surface (beneath the sandstone) of usually from one-sixth to one-half of a mile, depending upon the dip of the strata. The next formation above the Seeley slate is the iron-bearing formation, which, if present, will be found to occupy the middle of the valley. In exploratory work, therefore, it is not advisable to drill within one-fifth or one-fourth of a mile of the border of the quartzite. In starting exploration in a section somewhat removed from the known location of iron-bearing rock or slate, it is more advisable to place the first drill about midway between the adjacent quartzite ranges or in the middle of the valley than to attempt to keep within a certain distance of the quartzite.

Since small anticlines and intervening synclines may occur in the unexplored portion of the valley, as they are known to occur in the explored portion, the occurrence of the Seeley slate or even of the quartzite formation in the middle of the valley, where the valley is more than a mile in width, may not be sufficient proof that such portion of the valley is barren of iron-bearing rock or iron ore, because the quartzite or slate found may represent portions of anticlinal folds, and either to the northward or southward may be intervening synclinals in which may occur the iron-bearing rocks. Such a condition is represented in the following drawing (fig. 2).

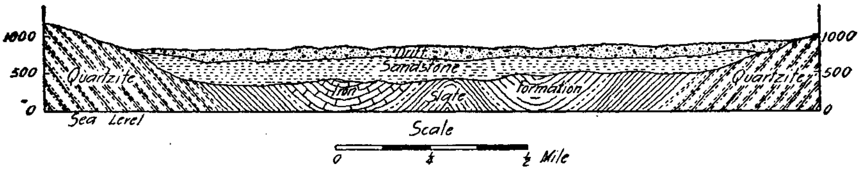

FIG. 2.—Ideal section across the Baraboo valley. Drawn to represent possible folding, on account of which the Seeley slate would occur in the middle of the valley and the iron-bearing formation both north and south of it.

In a somewhat similar manner the underlying slate and possibly the quartzite might occur in the interior of the valley and the iron-bearing formation nearer the border, on account of differences in amount of erosion, combined with certain structural features of the formation. The maximum pre-Potsdam erosion extended to a depth of about 570 feet below the present valley, and conditions might readily arise, therefore, on account of differences in erosion, for the occurence of hills of the iron formation between adjacent areas of the underlying slate struck at lower levels in drilling. A condition such as that just outlined is represented in the drawing (fig. 3).

The above examples of conditions probably represent exceptional cases and not the usual ones. In exploratory work, however, such cases should always be considered, especially if the drill records of any particular area furnish any reasons for believing that the above conditions may occur.

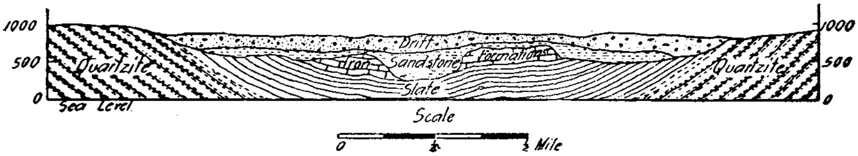

FIG. 3.—Ideal section across the Baraboo valley. Drawn to represent possible differential erosion, on account of which the Seeley slate would occur in the middle of the valley and the iron-bearing formation both north and south of it.

Explorable Land Outside the Valley Between the Quartzite Ranges. The question as to whether the iron-bearing formation occurs outside the valley between the quartzite ranges is an interesting one, and this query has been put to the writer a number of times in the course of the preparation of this report. The answer to this question is in the negative, for reasons based upon facts concerning the structural relations of the iron-bearing rocks to the associated pre-Cambrian formations of the district.

In the chapter on the structural features of the thick quartzite formation, the synclinal structure of this formation in the district is proven (see Ch. IV and especially pp. 37–44). The evidence indicating the synclinal structure of the pre-Cambrian sedimentary series in the district is the fact that the prevailing dip of the strata of the South Range, the North Range, and the West Range is towards the interior of the basin between the quartzite ranges, and the further fact that the igneous rock on the outer border of the North and South quartzite ranges constitutes the basement rock upon which the quartzite rests. These two lines of evidence are entirely in harmony, and, considered together, render the conclusion of the synclinal structure inevitable. Surrounding the quartzite ranges therefore on all sides, lie the rock formations of rhyolite, granite, and diorite, and also probably some sedimentary rocks, all of which are older than and unconformably below the Baraboo quartzite. Within the interior of the valley between the ranges, on the other hand, are the younger formations of slate, iron-bearing rock, and dolomite, lying above the quartzite.

Perhaps a comparison of the structural features and relations of the rock series of this district with those of some of the other pre-Cambrian iron-bearing districts may be instructive.

On account of the synclinal structure of the pre-Cambrian of the Baraboo district, the formations surrounding the Baraboo quartzite ranges bear the same relation to the rocks between the ranges as the complex mass of igneous rocks north and south of the Marquette district bears to the rocks within the Marquette iron-bearing district; or as the series of igneous rocks north and south of the Menominee district bears to the iron-bearing rocks within the Menominee district; or as the granite and other igneous rocks of the Giants Range of the Mesabi district bear to the iron-bearing rocks of the Mesabi district; or as the igneous complex of the southern Gogebic district bear to the Penokee-Gogebic iron-bearing series.

As the older basement rocks either wholly or partly surrounding the iron-bearing series of the districts above referred to are classed as unworthy of exploration, so the area of older basement rocks outside the Baraboo quartzite ranges should be similarly classed.

It may be stated,[1] therefore, with a considerable degree of certainty, based upon knowledge of the structure of the Baraboo district, that the Freedom iron-bearing formation will not be found in the region immediately outside of the quartzite ranges.

Since sedimentary series older than the Baraboo series are known to contain ore in other districts, it might be urged that the surrounding area should be explored for such older formations of iron ore. But the chances of finding ore in the older series under the thick Paleozoic sedimentaries are so slight as to make the expense attending such exploration entirely unwarrantable.

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[1] Since going to press, information has been received that rhyolite was struck in exploring north of the Lower Narrows of the North Range, and in the SE. ¼ of the SE. ¼ of sec. 8, and in the NE. ¼ of the SW. ¼ of sec. 17, of T. 11 N., R. 8 E., south of the South Range.

Exploration outside the District. Since the discovery of iron ore in the Baraboo district, considerable interest has arisen concerning the possibilities of finding ore in adjacent portions of the state where superficial ore deposits or areas of quartzite were known to occur.

At Ironton,[1] Sauk county, iron ore occurs in small quantities. A deposit in this vicinity furnished sufficient ore to operate a small furnace for a number of years between 1850 and 1880. This deposit of ore, however, occurs in the Potsdam sandstone, and thus in quite a different formation from the iron-bearing rock in which the iron ore at North Freedom occurs.

In central and northern Wisconsin are numerous outcrops of quartzite and slate of pre-Cambrian age, which may or may not have iron ore associated with them. Among some of these areas may be mentioned the ferruginous slates at Black River Falls,[2] the quartzite areas in Barron and Chippewa counties,[3] the quartzite and slates near Wausau,[4] and the quartzite at Necedah.[5] Since there are quartzites and slate formations deposited at various periods of the pre-Cambrian age, the quartzite and slate of various parts of the state may or may not be equivalent to the formations of corresponding character in the Baraboo district. While iron ore may be found in any of the several pre-Cambrian sedimentary series, the succession of formations is generally different for each series, and hence the iron-bearing formation and iron ore, if present, are likely to bear a relation to associated formations quite different from that existing in the Baraboo district. The extreme complexity of the various series of pre-Cambrian sedimentary rocks, when considered as a whole, should be kept in mind by those engaged in exploration in these old metamorphic rocks.

About 35 miles southeast of the Baraboo district, in the vicinity of Waterloo,[6] are numerous outcrops of quartzite, the

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[1] Chamberlin, T. C., vol. 1, p. 625.

[2] Irving, R. D., vol. 2, pp. 493–499.

[3] Geol. of Wis., vol. 4, pp. 575–581.

[4] Irving, R. D., Geol. of Wis., vol. 2, pp. 484–486; vol. 4, pp. 661–669.

[5] Irving, R. D., Geol. of Wis., vol. 2, p. 523.

[6] Chamberlin, T. C., Geol. of Wis., vol. 2, pp. 252–256.

character of which very closely resembles that of the Baraboo quartzite ranges. The quartzite about Waterloo is surrounded by and buried beneath an even greater thickness of later Paleozoic rocks than the pre-Cambrian about Baraboo. The dip of the quartzite about Waterloo is variable but is generally to the eastward. The thickness of the Waterloo quartzite seems to be very considerable, like that of the Baraboo quartzite. It is very probable that the Baraboo and Waterloo quartzites are equivalent formations, and if this is true, the equivalents of the Seeley slate and Freedom formation should be found overlying the Waterloo quartzite.

Buell, I. M., Geology of the Waterloo quartzite area. Wis. Acad. Sci., Arts, and Letters, vol. 9, pt. 2, pp. 255–275.

CHAPTER X.

RÉSUMÉ OF GEOLOGY AND CORRELATION OF THE PRE-CAMBRIAN.

SECTION I.

Résumé of Geology.

The oldest rocks of the Baraboo district are the igneous rocks, represented by the isolated areas of rhyolite, granite, and diorite distributed about the outer borders of the quartzite ranges. For a long period these igneous rocks, very probably with still older sedimentary rocks not now occurring at the surface, formed the land surface of the district and were subjected to the usual geological processes common to land areas the world over. Finally, this old land of the district sank below the level of the adjacent seas and the overlying sedimentary Baraboo series was deposited upon it.

The first rock deposited in the on-coming sea was the conglomerate forming the base of the Baraboo quartzite, and this was followed by the succeeding beds of finer ripple-marked sands, now metamorphosed into quartzite. After the deposition of the enormous accumulation of stratified sand, represented by the quartzite, having a thickness of 3,000 to 5,000 feet, a gradual change occurred in which the deposition of sand gave place to the deposition of finer sediments of clay, viz, the Seeley slate, having a thickness of 500 to 800 feet.

Following the deposition of the clay slate, a change in physical conditions was gradually wrought, and very probably organisms came to play an important rôle in forming the deposits of the succeeding siliceous, ferruginous, and calcareous sediments, having a probable thickness of 500 feet or more.

After the ferruginous strata including the iron ore were deposited, a gradual change to the deposition of nearly pure calcareous and magnesian strata took place and the 400 or 500 feet of the dolomite horizon were accumulated.

A vast period of time must have elapsed during the deposition of the Baraboo series of sedimentary rock, having a probable thickness of 5,000 to 7,000 feet. Following this period of sedimentation, in which the Freedom formation of iron-bearing rock and dolomite was the last to be accumulated, a change took place. The series was folded into vast mountain folds like those of the Alps or the Rockies, and a large portion of the pre-Cambrian land was elevated above sea level. These mountain folds were subjected to a long period of erosion, of such extent that the softer rocks were finally degraded to approximate sea level, and none but the hardest rocks, like the Baraboo quartzite, remained as elevations projecting above the widespread plain of erosion. These events are all clearly evidenced by the upturned strata and truncated folds of this series of formations.

Following the long period of elevation and subsequent erosion, a period very probably equal to or much longer than that of the deposition of the Baraboo series of formations, the sea again gradually came over the land, and deposition of the Paleozoic series, beginning with the conglomerate and sands of the Potsdam epoch, was inaugurated. The thickness of the Potsdam formation in the district is probably nowhere greater than 700 feet. The upper horizon contains thin beds of limestone followed again by strata of sandstone. Upon the Potsdam formation a thickness of 50 or 60 feet of Lower Magnesian limestone was laid down. After the deposition of the Lower Magnesian formation, the land was elevated above the sea for a comparatively short time, and the Lower Magnesian was partly eroded, then sank again below the sea, and upon its uneven surface the St. Peter sands were deposited. Following the deposition of the St. Peter sandstone were formed the Trenton and Galena formations, which outside the district are of limestone, but adjacent to the quartzite ranges of this district are wholly represented by sandstone and congomerate. The later formations of Cincinnati shale and Niagara limestone, and even the complete series of the Silurian rocks, were probably deposited in the district, thus not only burying deeply the valley between the quartzite ranges, but also covering to considerable depths the topmost peaks of the quartzite.

Finally, the deposition of the Paleozoic strata ceased, the sea receded from the land, and the accumulated strata were elevated to form a vast plateau. This elevation following the deposition of the Paleozoic series in this part of the continent was evidently a steady, simple, upward movement without tilting of the strata, quite unlike the complex movements accompanying the elevation of the pre-Cambrian series into complex mountain folds. The work of erosion of the comparatively soft, Paleozoic rocks, accompanied the slow elevation above the sea, and continued long after the upward movement ceased. Valleys were cut into the horizontal strata by the running streams, and, particle by particle, the accumulated sediments were carried down to the adjacent seas. As degradation proceeded, the buried islands of quartzite began to appear at the surface and arose again as ridges in the landscape. The rivers, following lines of least resistance and cutting more rapidly into the softer Paleozoic rocks than into the harder quartzite, were shunted to the drainage lines in the older pre-Cambrian land, and finally the surface of the district came to assume more and more the features attained in pre-Cambrian time. The pre-Cambrian river valleys extending east and west between the quartzite ranges and the gorges at the Lower Narrows and at Devils Lake, as well as the sharp ravines extending back into the quartzite ranges, for a second time came to be occupied by rivers and creeks, until these streams had cut down not only to the present valley bottom, but also over 225 feet below. This long period of erosion, during which more of the Paleozoic sediments were removed from the district than now remain, extended very probably from middle Paleozoic time, throughout the Mezozoic and Tertiary time, with possible slight intermissions, to the beginning of Quaternary time. This long period of erosion with little doubt lasted much longer than the period in which the Paleozoic sediments of the district were deposited.

The glacial period, during which the next important changes in the district were wrought, was not ushered in by subsidence of the land and encroachment of the sea, but by marked climatic changes, the development of a prevailing frigid temperature, and the formation and advance of great ice fields and continental glaciers over the surface of the land. The beginning of the glacial period found the valleys of the district about 225 feet below their present levels, and these were filled as we now find them with the boulders, gravel, sand, and clay carried by the ice and accompanying waters from the regions to the northeast, from which the glaciers came. During the period of glaciation the valleys were not only filled with glacial debris, but hills and ridges of drift were built up, including the frontal ridge and zone of drift hills known as the terminal moraine formed along the front of the ice sheet and extending irregularly north and south across the middle of the district. The courses of the rivers in the district east of the terminal moraine were changed, and in place of a large river flowing southward across the district through the Lower Narrows and the Devils Lake gorge, we now have the latter gorge blocked at both ends and the Lower Narrows occupied by the Baraboo River, probably a much smaller stream than the pre-glacial one. The glacial period, while short as compared with those previously sketched, was a complex one and in this district may have been represented by more than one stage of glaciation and deglaciation, in common with other portions of Wisconsin in which occurred not only one or two but even four or five distinct glaciations.

Since glacial time the ordinary weathering and erosive agents have been at work upon the drift and underlying rock, weathering them into soils and removing the drift and rock to lower levels, as in all the earlier periods of degradation. Especially rapid has been the change in the aspect of the district since it has been occupied by civilization, through the natural forces of

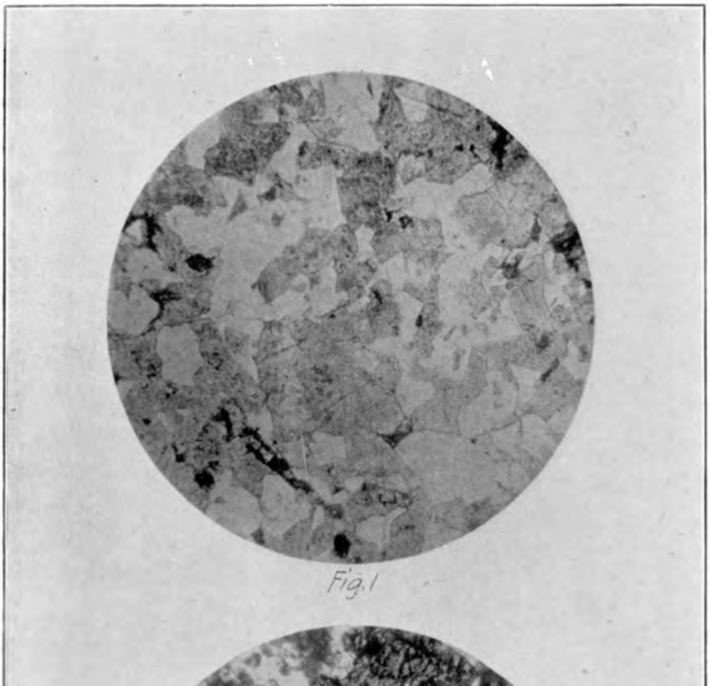

Fig. 1

Fig. 2

PHOTOMICROGRAPHS OF GRANITE AND DIORITE.

erosion combined with the action of man in removing the forest growth of the land and loosening the surface by cultivation.

Such, in brief outline, is the geologic history of the district, as shown by the succession, structure, and character of the rock strata and geography of the region. The geologic changes and formations in this district subsequent to the deposition of the Potsdam sandstone can readily be compared and correlated with other well-known regions, since these formations have been subjected to little change except erosion, and are known to be in stratigraphic continuity with well-known and well-defined Paleozoic horizons. With respect to the pre-Cambrian formations, however, the relative position in the stratigraphy of the pre-Cambrian cannot be determined so definitely.

SECTION II.

CORRELATION OF THE PRE-CAMBRIAN.

In the Lake Superior region C. R. Van Hise[1] and his associates on the United States Geological Survey have discriminated four great pre-Cambrian series:

1. The Archean, consisting mainly of igneous rocks, but also containing some sedimentary formations.
2. The Lower Huronian, mainly a sedimentary series, resting unconformably upon the Archean.
3. The Upper Huronian, likewise mainly a sedimentary series, resting unconformably upon the Lower Huronian and Archean.
4. The Keweenawan, or copper-bearing series, consisting of intercalated lavas and sediments, resting unconformably upon all the underlying rocks.

In the several monographs[2] of the United States Geological Survey on the Lake Superior iron-bearing districts, the general

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[1] Twenty-first Ann. Rept., U. S. Geol. Survey, 1901, pt. 3, pp. 316–318.

[2] The Penokee iron-bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, vol. 19, 1892.

The Marquette iron-bearing district of Michigan, by C. R. Van Hise character and relations of these series have been fully described. In each of the districts described, the Penokee-Gogebic district, the Marquette district, the Crystal Falls district, the Mesabi district, the Vermilion district, and the Menominee district, two or more of the above series are known to occur. In the Mesabi and Marquette districts all of the pre-Cambrian series are believed to be present.

None of the above districts, however, in which the succession of pre-Cambrian series has been determined is located nearer than 200 miles from the Baraboo district, the intervening region being occupied with overlying Paleozoic rocks or with unmapped pre-Cambrian formations. The stratigraphic position of the Baraboo pre-Cambrian formations, on account of their isolation and complete separation from the main pre-Cambrian region farther north can be determined, therefore, only conjecturally or approximately (see Pl. XVIII).

The region of the pre-Cambrian of northern Wisconsin is about 60 miles north of the Baraboo district. In this nearest pre-Cambrian district, which may be conveniently designated as the north central Wisconsin district, the writer has been occupied the past few years in mapping the pre-Cambrian and later formations. While the final report upon north central Wisconsin is not yet completed, the succession of the pre-Cambrian rocks has been fairly well determined, and it may, therefore, be of interest to first compare the pre-Cambrian succession in

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and W. S. Bayley, including a chapter on the Republic trough, by H. L. Smyth: Mon. U. S. Geol. Survey, vol. 28, 1897. With atlas.

The Crystal Falls iron-bearing district of Michigan, by J. Morgan Clements, and H. L. Smyth, with a chapter on the Sturgeon River tongue, by W. S. Bayley, and an introduction by C. R. Van Hise: Mon. U. S. Geol. Survey, vol. 36, 1899.

The Mesabi iron-bearing district of Minnesota, by C. K. Leith: Mon. U. S. Geol. Survey, vol. 43, 1903.

The Vermilion iron-bearing district of Minnesota, by J. Morgan Clements: Mon. U. S. Geol. Survey, vol. 45, 1903.

The Menominee iron-bearing district of Michigan, by W. S. Bayley: Mon. U. S. Geol. Survey, vol. 46, 1904.

north central Wisconsin with that of the Baraboo district before considering the correlation of the latter district with that of the Lake Superior districts which are farther removed though better known.

The district of north central Wisconsin includes the counties of Marathon, Portage, Wood, Clark, Taylor, and Lincoln. The pre-Cambrian rocks of this region consist in large part, fully 75 per cent, of igneous rock, intrusive in older sedimentary and igneous formations; and hence the region is one of complicated igneous intrusion as well as of intricately folded sedimentary strata. The sedimentary rocks occur in isolated patches and are difficult to correlate even in adjoining vicinities, the correlation being mainly by comparison of petrographic character and of structural relations with intrusive igneous rock. The rock formations and their succession in north central Wisconsin appear to be as follows:

I. Banded, foliated and contorted gneisses, of igneous origin, of both basic and acid character, with no determined sedimentary rock. These gneisses are intruded by the generally massive igneous rocks described under III.

II. Sedimentary formations of massive, vitreous, coarse, white quartzite, fine-grained reddish quartzite, carbonaceous and ferruginous slate, staurolite and cordierite bearing slates, feldspathic quartzite, and some calcareous chert.

III. Igneous formations of (a) massive and schistose rhyolite, (b) diorite, gabbro, and aphanitic greenstone, and (c) massive granite, quartz-syenite, nepheline and sodalite syenite, and related rocks. These igneous rocks constitute from two-thirds to three-fourths of the rocks of the district, and are mainly, if not entirely, intrusive in the above gneisses and sedimentary rocks.

IV. Conglomerate, quartzite, and slate, resting unconformably upon the intrusive, igneous rocks and the sedimentaries referred to under II.

No correlation can here be suggested between the formations here separated under different headings and the several unconformable series of pre-Cambrian near Lake Superior. It can be stated, however, that the various sedimentary rocks referred to under II and the later complex and varied igneous rocks under III, taken together, constitute about 90 per cent of the pre-Cambrian rocks of northern Wisconsin and must represent a very long period of pre-Cambrian time. But however complex may be the geology of the series of north central Wisconsin referred to under I, II, and III, it need not here be discussed; for, as shown in what follows, the rocks referred to under I and II do not occur in the Baraboo district, and only to a very small extent are those formations referred to under III believed to be present.

In the Baraboo district there are only two unconformable pre-Cambrian series, an underlying series of igneous rock represented by rhyolite, granite, and diorite, and an overlying sedimentary series consisting of quartzite, slate, and iron-bearing rock and dolomitic marble.

The rhyolite of the Baraboo district is very similar to that of north central Wisconsin which occurs abundantly near Wausau, with respect to general massive character, comparative deformation, and metamorphism, and is also practically identical in chemical composition, the rhyolite from both districts being unusually rich in soda. The granite and diorite of the Baraboo district are massive and not schistose rocks, and can be readily duplicated among the prevailingly massive and abundant granite and diorite rocks farther north. The lithological similarity of the igneous rocks of the Baraboo district to the massive igneous intrusives of central Wisconsin is, on the whole, quite marked.

The sedimentary formation immediately overlying the igneous rocks in both districts is conglomerate and quartzite. The character of the Baraboo quartzite is very similar to the uppermost quartzite of north central Wisconsin occurring at North Mound, west of Babcock, and at Arpin. In each, as seen under the microscope, the quartzite reveals about the same amount of metamorphism and the original clastic grains can readily in all cases be distinguished from the secondary interstitial quartz material. On the other hand, the Baraboo quartzite and the older quartzites farther north, such as the white quartzite of Rib Hill, are strikingly dissimilar, not only in structural relation to the associated igneous rocks, but also in the general texture of the rock, for the older quartzites have throughout been wholly recrystallized and all trace of boundaries between the original clastic sand grains and secondary interstitial quartz material has been obliterated. It may be added that the conglomerate of the Baraboo quartzite formation, like the conglomerate at the base of the quartzite of the upper sedimentaries in north central Wisconsin, contains pebbles and fragments of older highly metamorphosed quartzite as well as of slate and jaspilite, thus indicating that in the Baraboo region there are sedimentary rocks older than the Baraboo quartzite, similar to the older quartzites and slates in the central Wisconsin region.

On the basis of unconformable relationship to similar igneous rock and to older sediments, and of similar lithological character, the Baraboo quartzite formation might well be the equivalent of the quartzite of the uppermost sedimentary series of the pre-Cambrian in the north central Wisconsin district. At the same time, it should be noted that the upper quartzite in north central Wisconsin, so far as known, is nowhere such an extensive or thick formation as the Baraboo quartzite and also is nowhere known to be associated with overlying slate, iron formation, or dolomite, or other later conformable sediments, as is the case with the Baraboo quartzite. Formations later than the upper quartzite of central Wisconsin may once have been present, however, which have been removed by erosion, just as without doubt is the case with the entire series of the Baraboo quartzite and overlying formations in the region immediately surrounding the Baraboo district. On the whole, therefore, while the question of the equivalency of the Baraboo pre-Cambrian series to other series must remain unsolved for the present, it seems probable that the Baraboo series is contemporaneous with the uppermost series of pre-Cambrian sediments in north central Wisconsin.

When a comparison and correlation of the Baraboo pre-Cambrian series with the pre-Cambrian series of the several iron-bearing districts in the vicinity of Lake Superior is attempted, a difficult problem is met with. The Baraboo pre-Cambrian sedimentary series, it will be remembered, consists from the base upward of thick formations of quartzite, of slate, and of iron-bearing rock grading up into dolomite. When this series is compared with any one of the various sedimentary series of the Lake Superior districts, it is found that the character and succession of the Baraboo series is not exactly like any of them, although in one of the Lake Superior districts there is one series whose principal features are the same as those of the Baraboo series.

If a comparison of the Baraboo series be made with the series the most like it in character and succession of formations in the several Lake Superior districts, it is found that the Baraboo series is more like the upper half of the Lower Marquette series in the Marquette district than any other series in the Lake Superior region. In this connection attention is called to the fact established by Prof. A. E. Seaman that the Lower Marquette series, as described by Van Hise, consists of two unconformable series instead of one. It is this upper portion of the Lower Marquette series, which can be conveniently referred to as Middle Marquette (Middle Huronian), that resembles the Baraboo series, as shown in the following table:

<table>
<tr><th>BARABOO DISTRICT.</th><th>MARQUETTE DISTRICT.</th></tr>
<tr><td colspan="2">Unconformity.</td></tr>
<tr><td>Freedom formation (dolomite and iron bearing formation).</td><td>Negaunee formation (iron-bearing formation).</td></tr>
<tr><td>Seeley slate.</td><td>Siamo slate.</td></tr>
<tr><td>Baraboo quartzite.</td><td>Ajibik quartzite.</td></tr>
<tr><td colspan="2">Unconformity.</td></tr>
</table>

While the character and succession in these two series are nearly identical, there is some variation in the thickness of the individual formations in the two districts. The Ajibik quartzite is probably between 700 and 1,000 feet thick, while the Baraboo quartzite is probably from 3,000 to 5,000 feet thick. The Siamo slate and Seeley slate have approximately the same thickness of 500 to 1,000 feet. The Negaunee iron-bearing formation has a thickness of 1,000 to 1,500 feet, while the Freedom iron-bearing formation has a known thickness of 1,000 feet and may have a thickness considerably greater. It should be noted in regard to the iron-bearing formation of the two districts that it is only the lower member of the Freedom formation that is iron bearing, whereas the Negaunee formation is ferruginous throughout its whole thickness of 1,000 to 1,500 feet. There is, however, considerable ferruginous carbonate and ferruginous chert throughout the Negaunee formation, thus indicating conditions of origin similar to those of the dolomite of the Freedom formation. While there is more or less dissimilarity between the Baraboo series and the Middle Marquette series, on the whole their main features, the general character of the formations and the succession, are the same, and hence it is not unlikely that the two series are stratigraphically equivalent.

When the Baraboo series is compared with the series in the other districts, it is seen to have some similarity to the Lower Menominee (Lower Huronian) of the Menominee district and the Lower Huronian of the Crystal Falls district. It has little in common with any of the series in the Penokee-Gogebic and the Mesabi districts, though it resembles the Upper Huronian of these districts more than the Lower Huronian.

On the whole, therefore, the definite correlation of the Baraboo series with the series of the Lake Superior pre-Cambrian districts must be left undecided. The Baraboo quartzite has heretofore been considered as of probable Upper Huronian age, although its relations to the older and younger formations associated with it have never been determined. If the Huronian system, instead of consisting of two series of Upper and Lower Huronian, really consists of three unconformable sedimentary series, which may be tentatively referred to as the Upper, Middle, and Lower Huronian, as our present knowledge seems to indicate, then it seems to the writer that the Baraboo series is with little doubt either Middle Huronian or Upper Huronian, and more probably the former than the latter.

PLATE XIX.

PLATE XIX.

PHOTOMICROGRAPHS OF RHYOLITE AND CONGLOMERATE.

Fig. 1.—Rhyolite. In polarized light x 20. Specimen 6938. From the SE. ¼ of sec. 11, T. 10 N., R. 5 E. The rhyolite consists of a background, or groundmass, of fine-grained quartz and feldspar containing porphyritic crystals of feldspar.

Fig. 2.—Conglomerate. In polarized light x 20. Specimen 6946. From the NW. ¼ of the NE. ¼ of sec. 3, T. 11 N., R. 8 E. The thin section shows portions of rounded fragments of rhyolite in a cementing matrix of fine-grained material, mainly consisting of water-worn grains of quartz and numerous small rounded grains of rhyolite and feldspar.

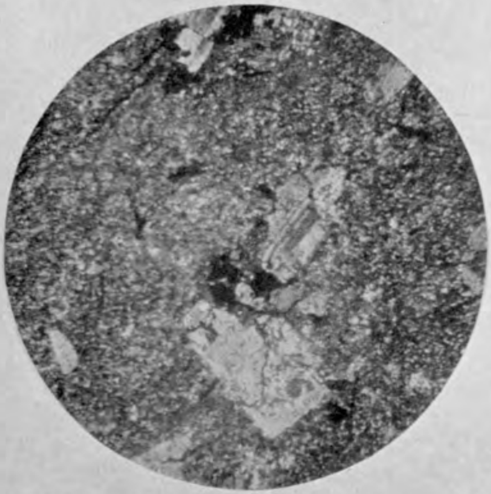

Fig. 1.

Fig. 2

PHOTOMICROGRAPHS OF RHYOLITE AND CONGLOMERATE.

PLATE XX.

PLATE XX.

PHOTOMICROGRAPHS OF GRANITE AND DIORITE.

Fig. 1.—Granite. In ordinary light x 20. Specimen 6926. From the NE. ¼ of the SE. ¼ of sec. 32, T. 11 N., R. 6 E. The colorless crystals are quartz, the grayish are feldspar, and the black are mica and chlorite.

Fig. 2.—Diorite. In ordinary light x 20. Specimen 6901. From the center of the SE. ¼ of sec. 9, T. 10 N., R. 5 E. The colorless mineral is quartz, the grayish minerals are feldspar, and the darkest are hornblende and mica.

MAP OF PRE-CAMBRIAN IRON-BEARING DISTRICTS.

The map shows geographic relation of the Baraboo district to the Lake Superior districts.

PLATE XXI.

PLATE XXI.

PHOTOMICROGRAPHS OF THE BARABOO QUARTZITE AND SEELEY SLATE.

Fig. 1.—Baraboo quartzite. In polarized light x 20. Specimen 6921. From the NW. ¼ of the NW. ¼ of sec. 21, T. 12 N., R. 7 E. The subangular crystals appearing as dark and light grains are entirely of quartz, firmly cemented together by the background, or matrix, of very fine-grained quartz.

Fig. 2.—Seeley slate. In polarized light x 60. Specimen 6893. From Illinois mine. The slate mainly consists of minute gray and colorless flaky crystals of chlorite, kaolin, andalusite, tourmaline, and apatite, which cannot be differentiated in the photograph.

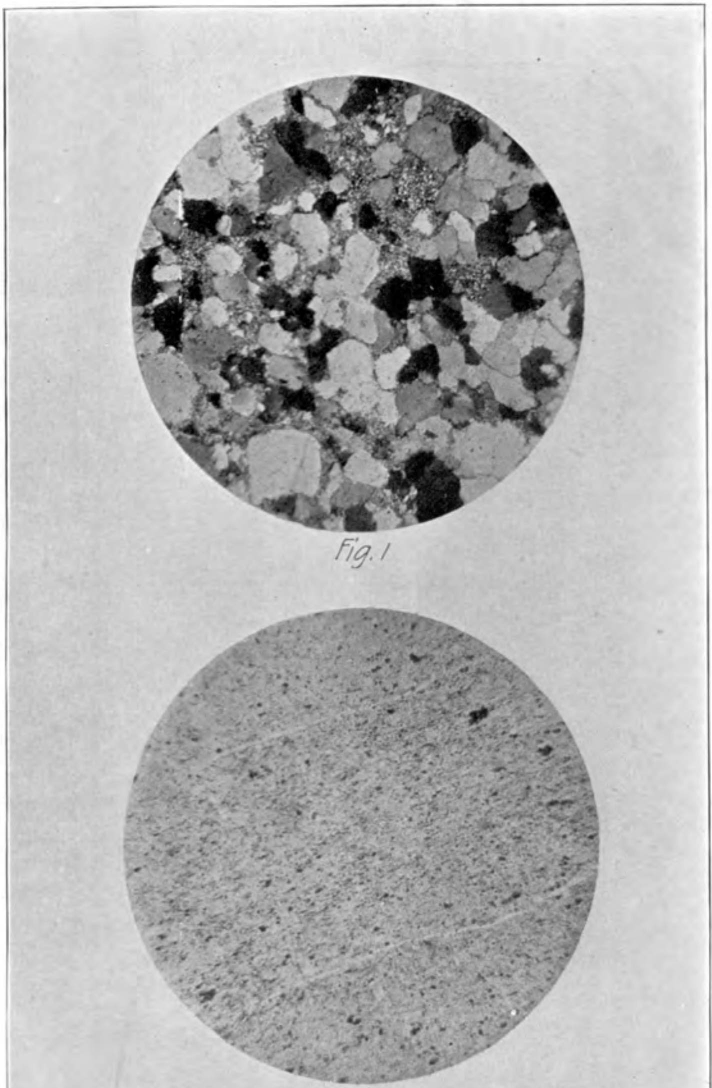

Fig. 1

Fig. 2

PHOTOMICROGRAPHS OF THE BARABOO QUARTZITE AND SEELEY SLATE.

PLATE XXII.

PLATE XXII.

PHOTOMICROGRAPHS OF CHERT AND FERRUGNIOUS CHERT.

Fig. 1.—Chert. In polarized light x 20. Specimen 6887. From Illinois mine. This thin section is from a cherty layer in ferruginous chert. The photomicrograph shows the finely granular character of the quartz crystals common to chert, a character quite unlike that of quartz in veins.

Fig. 2.—Ferruginous chert. In ordinary light x 20. Specimen 6888. From Illinois mine (see fig. 1, Pl. IX, and analysis, p. 56). The photomicrograph shows a portion of the rock at contact of layer of chert and hematite. The layer of chert, the principal portion of the section, contains numerous rounded forms of hematite.

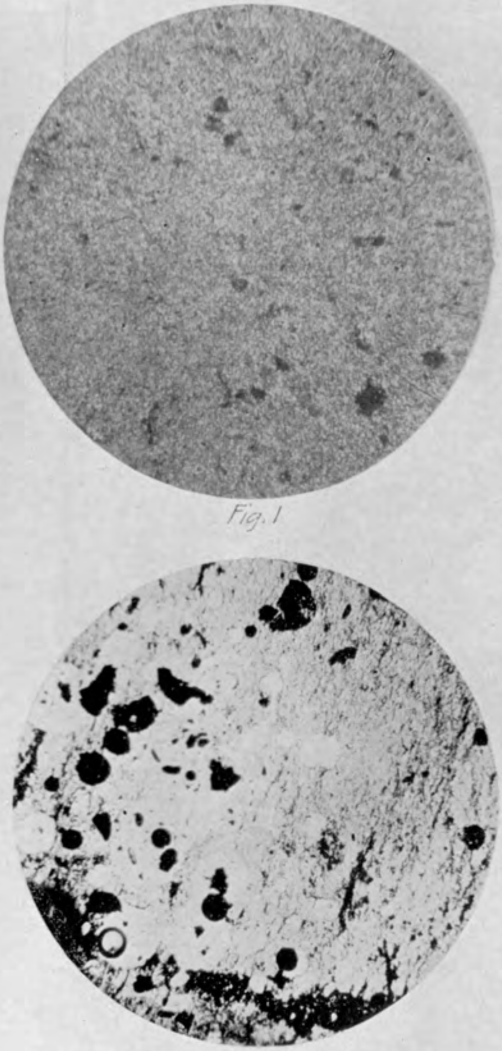

Fig. 1

Fig. 2

PHOTOMICROGRAPHS OF CHERT AND FERRUGINOUS CHERT.

PLATE XXIII.

PLATE XXIII.

PHOTOMICROGRAPHS OF CHERTY DOLOMITE AND DOLOMITE.

Fig. 1.—Cherty dolomite. In polarized light x 20. Specimen 6895. Drill core from hole 3 in the NW. ¼ of the NW. ¼ of sec. 11, T. 11 N., R. 5 E. The rock consists of fine grains of cherty quartz scattered through fine-grained dolomite containing a small amount of clay mineral.

Fig. 2.—Dolomite. In polarized light x 20. Specimen 7000. Drill core from drill hole of record 10 (see p. 82). This is a thin section of the nearly pure dolomitic marble (see analysis, p. 68). The photomicrograph shows large crystals of dolomite in finely granular dolomite. Some of the fine gray mineral is an alumino-silicate.

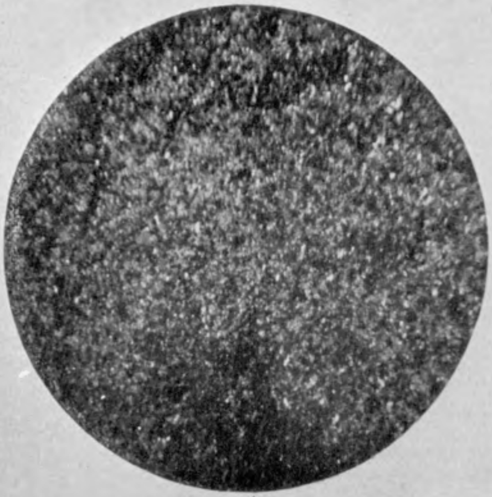

Fig. 1

Fig. 2

PHOTOMICROGRAPHS OF CHERTY DOLOMITE AND DOLOMITE.

INDEX.

PUBLICATIONS

OF THE

Wisconsin Geological and Natural History Survey.

The publications of the Survey are issued as (1) bulletins, which are numbered consecutively, (2) biennial reports, and (3) hydrographic maps. These publications are independently paged and indexed, no attempt being made to group them in volumes.

1. BULLETINS.

The bulletins are issued in three series:

Scientific Series.— The bulletins so designated consist of original contributions to the geology and natural history of the state, which are of scientific interest rather than of economic importance.

Economic Series.— This series includes those bulletins whose interest is chiefly practical and economic.

Educational Series.— The bulletins of this series are primarily designed for use by teachers and in the schools.

The following bulletins have been issued:

Bulletin No. I. Economic Series No. 1.

On the Forestry Conditions of Northern Wisconsin. Filibert Roth, Special Agent, United States Department of Agriculture. 1898. Pp. vi, 78; 1 map. Sent on receipt of 10 cents.

Bulletin No. II. Scientific Series No. 1.

On the Instincts and Habits of the Solitary Wasps. George W. Peckham and Elizabeth G. Peckham. 1898. Pp. iv, 241; 14 plates, of which 2 are colored; 2 figures in the text. Sold at the price of $1.50 in paper and $2.00 bound.

Bulletin No. III. Scientific Series No. 2.

A Contribution to the Geology of the Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin. Samuel Weidman, Ph. D., Assistant Geologist, Wisconsin Geological and Natural History Survey. 1898. Pp. iv, 63; 10 plates; 13 figures in the text. Out of print.

Bulletin No. IV. Economic Series No. 2.

On the Building and Ornamental Stones of Wisconsin. Ernest Robertson Buckley, Ph. D., Assistant Geologist Wisconsin Geological and Natural History Survey. 1898. Pp. xxvi, 544; 69 plates, of which 7 are colored, and 1 map; 4 figures in the text. Sent on receipt of 30 cents.

Bulletin No. V. Educational Series No. 1.

The Geography of the [illegible]ion About Devil's Lake and the Dalles of the Wisconsin, with some notes on its surface geology. Rollin D. Salisbury, A. M., Professor of Geographic Geology, University of Chicago, and Wallace W. Atwood, B. S., Assistant in Geology, University of Chicago. 1900. Pp. x, 151; 38 plates; 47 figures in the text. Sent on receipt of 30 cents.

Bulletin No. VI. Economic Series No. 3. Second Edition.

Preliminary Report on the Copper-bearing Rocks of Douglas county, and parts of Washburn and Bayfield counties, Wisconsin. Ulysses Sherman Grant, Ph. D., Professor of Geology, Northwestern University. 1901. Pp. vi, 83; 13 plates. Sent on receipt of 10 cents.

Bulletin No. VII. Economic Series No. 4.

The Clays and Clay Industries of Wisconsin. Part I. Ernest Robertson Buckley, Ph. D., Geologist, Wisconsin Geological and Natural History Survey. 1901. Pp. xii, 304; 55 plates. Sent on receipt of 20 cents.

Bulletin No. VIII. Educational Series No. 2.

The Lakes of Southeastern Wisconsin. N. M. Fenneman, Ph. D., Professor of General and Geographic Geology, University of Wisconsin. 1902. Pp. xv, 178; 36 plates; 38 figures in the text. Sent (bound) on receipt of 50 cents.

Bulletin No. IX. Economic Series No. 5.

Preliminary Report on the Lead and Zinc Deposits of Southwestern Wisconsin. Ulysses Sherman Grant, Ph. D., Professor of Geology, Northwestern University. 1903. Pp. viii, 103; 2 maps; 2 plates; 8 figures in the text. Sent on receipt of 10 cents.

Bulletin No. X. Economic Series No. 6.

Highway Construction in Wisconsin. Ernest Robertson Buckley, Ph. D., State Geologist of Missouri, formerly Geologist, Wisconsin Geological and Natural History Survey. 1903. Pp. xvi, 339; 106 plates, including 26 maps of cities. Sent on receipt of 30 cents.

Bulletin No. XI. Economic Series No. 7.

Preliminary Report on the Soils and Agricultural Conditions of North Central Wisconsin. Samuel Weidman, Ph. D., Geologist, Wisconsin Geological and Natural History Survey. 1903. Pp. viii, 67; 10 plates, including soil map. Sent, paper bound, on receipt of 10 cents; cloth bound, 20 cents.

Bulletin No. XII. Scientific Series No. 3.

The Plankton of Lake Winnebago and Green Lake. C. Dwight Marsh, Ph. D., Professor of Biology, Ripon College. 1903. Pp. vi, 94; 22 plates. Sent, paper bound, on receipt of 10 cents; cloth bound, 25 cents.

Bulletin No. XIII. Economics Series No. 8.

The Baraboo Iron-bearing District of Wisconsin. Samuel Weidman, Ph. D., Geologist, Wisconsin Geological and Natural History Survey. 1904. Pp. x, 190; 23 plates, including geological map. Sent, paper bound, on receipt of 10 cents; cloth bound, 20 cents.

In Preparation.

The Geology of North Central Wisconsin. Samuel Weidman, Ph. D., Geologist, Wisconsin Geological and Natural History Survey.

The Lead and Zinc Deposits of Southwestern Wisconsin. Ulysses Sherman Grant, Ph. D., Professor of Geology, Northwestern University.

The Clays of Wisconsin. Heinrich Ries, Ph. D., Professor of Economic Geology, Cornell University.

2. BIENNIAL REPORTS.

The Survey has published three biennial reports, which relate to administrative affairs only and contain no scientific matter.

First Biennial Report of the Commissioners of the Geological and Natural History Survey. 1899. Pp. 31.

Second Biennial Report of the Commissioners of the Geological and Natural History Survey. 1901. Pp. 44.

Third Biennial Report of the Commissioners of the Geological and Natural History Survey. 1903. Pp. 35.

3. HYDROGRAPHIC MAPS.

There have been prepared hydrographic maps of the principal lakes of southern and eastern Wisconsin. This work is in charge of L. S. Smith, C. E., Assistant Professor of Topographic and Geodetic Engineering, University of Wisconsin.

The maps are as follows:

		Size of Plate, Inches.	Scale, Inches per mile.	Contour Interval, Feet.
No. 1.	Lake Geneva	17.5x10.8	2	10
No. 2.	Elkhart Lake	15.5x13.1	5	10
No. 3.	Lake Beulah	22.5x20.0	6	10
No. 4.	Oconomowoc-Waukesha Lakes	29.8x19.1	2	10
No. 5.	The Chain of Lakes, Waupaca	21.7x20.6	6	10
No. 6.	Delavan and Lauderdale Lakes	22.5x16.8	4	10
No. 7.	Green Lake	26.0x17.8	3.2	20
No. 8.	Lake Mendota	23.7x19.5	6	5
No. 9.	Big Cedar Lake	18.0x13.5	2.9	10
No. 10.	Lake Monona	17.6x17.3	4	5

In all of these maps the depth of the lakes is indicated by contour lines, and by tints in all except No. 1. They are sent on receipt of 15 cents each, except Nos. 4 and 8, for which 20 cents are required. They may be had either mounted in a manilla cover, or unmounted.

All correspondence relating to the Survey should be addressed to

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