CONTENTS.

LETTER OF TRANSMITTAL..................................................... 3
OUTLINE OF MONOGRAPH..................................................... 3

CHAPTER I.—INTRODUCTION.................................................. 10
Scope and date of work done ............................................. 10
Acknowledgments ............................................................. 10
Limits of the Menominee area............................................. 11
Relations to other iron-bearing areas .................................. 11
Shape and size of the Menominee tongue............................. 11
Economic importance of the district .................................... 11
Previous work in the district .............................................. 12
Method of work ................................................................. 12
Classification of formations .............................................. 13
Names of the formations .................................................... 13
References to Marquette monograph .................................. 13

CHAPTER II.—BIBLIOGRAPHY AND ABSTRACT OF LITERATURE................................................................. 13

CHAPTER III.—PHYSIOGRAPHY.............................................. 47
Topography ................................................................. 47
Drainage ........................................................................ 48
Origin of the Topography .................................................. 48
Pre-Cambrian Topography .................................................. 49

CHAPTER IV.—THE ARCHEAN SYSTEM................................. 49
Section 1. Quinnesec schists ............................................. 49
Relations to overlying formations ....................................... 49
The southern area ............................................................ 50
Distribution ................................................................. 50
Topography ................................................................. 50
Composition and structure of the rock series ....................... 51
Lithology ................................................................... 51
Greenstone-schists and associated greenstones ................. 51
Coarse-grained varieties .............................................. 52
Gabbros and their derived schists .................................. 52
Diabases and their derived schists ................................ 53
Diorites and their derived schists ................................ 53
Fine-grained varieties .................................................. 54
Origin of the schistosity ............................................... 54
Basic lavas and their derived schists ............................... 54
Basic tuffs and their derived schists ............................... 55
Chlorite-schists ........................................................... 55
Amphibolites ................................................................ 56
Origin of the basic schists ............................................. 56
Acid intrusives and their derived schists ......................... 57
Gneissoid granite and granite-gneisses ....................... 57
Porphyries and felsites and their schistose phases .......... 59
Sericite-schists ............................................................. 59
Interesting localities ....................................................... 59
Sturgeon Falls ............................................................ 59
Little Quinnesec Falls ................................................... 60
Big Quinnesec Falls ..................................................... 60
Horserace Rapids ....................................................... 60
The western area ........................................................... 61
Distribution ................................................................. 61
Topography ................................................................. 61
Lithology ................................................................... 62
Fine-grained greenstones and their derived schists .......... 62
Coarse-grained greenstones and their derived schists ..... 64
Fragmented schists ....................................................... 64
Origin of the rocks ......................................................... 64
Interesting localities ....................................................... 65
Chapter V.—The Algongian System

Section 1. Lower Menominee Series

Section 2. Northern Complex

Folding

Lithology

Relations to underlying formations

Thickness

Interesting localities

Chapter V.—The Algongian System

General character and definition

Unconformity within the system

Section 1. Lower Menominee Series

Succession and distribution

Sturgeon quartzite

Distribution and topography

Lithology

Conglomerates

Arkoses and graywackes

Quartzite

Dolomitic quartzite

Veins and dikes in the quartzite

Folding

Thickness

Relations to underlying formations

Relations to underlying formations

Interesting localities

The "rock dam" on Pine Creek

Black Creek

North half of sec. 7, T. 39 N., R. 28 W

West half of sec. 8, T. 39 N., R. 28 W

Falls of the Sturgeon

Randville dolomite

Distribution and topography

The northern belt

The central belt

The southern belt

Distribution

Topography

Lithology

Dolomite and dolomitic sandstones

Dolomite breccias and conglomerates

Talcose schists

Argillaceous rocks

Cherty quartz rocks

Conclusions from microscopical study and comparison with similar rocks in the marquette and gogebic districts

Folding

Major folding

Cross folding

Minor folding

The northern belt

The central belt

The southern belt

Marginal folds

Walpole fold

Pewabic fold

Quinnesec fold

Norway fold

Aragon fold

Other secondary folds at the southern margin

Secondary folds at the northern margin

Interior folds

Thickness

Relations to adjacent formations

Relations to underlying Sturgeon quartzite

Relations to overlying Negaunee formation

Relations to basal member of the Upper Huronian

Relations to other formations

Interesting localities

In the northern belt

Northeast quarter of sec. 3, T. 40 N., R. 30 W

Northeast quarter of sec. 14, T. 40 N., R. 30 W

In the central belt

Southwest quarter of sec. 22, T. 40 N., R. 30 W

Iron Hill

In the southern belt

Southeast side of Lake Antoine

Southeast quarter of sec. 32 and southwest quarter of sec. 35, T. 40 N., R. 30 W

North and northeast of Quinnesec

Northwest quarter of sec. 9, T. 39 N., R. 29 W

S. 12 and 13., T. 39 N., R. 29 W

Negaunee formation

Distribution

Lithology

Relations to adjacent formations

Conclusions from foregoing study

Illustrations

Plate I. Geological Map of part of the Lake Superior region, showing relative position of the Menominee with respect to other Huronian areas

II. General outline map of the region between the Menominee River and the north side of the Felch Mountain district, showing position of the Menominee trough with respect to other Huronian troughs to the north

III. Portion of the geological map of the Menominee iron region, by T. B. Brooks, 1872

IV. Portion of the geological map of the Menominee iron region, by T. B. Brooks and C. E. Wright, 1879

V. Outline geological map of the Menominee iron region, by R. D. Irving, 1890

VI. Organic markings in the Lake Superior iron ores. From a photograph. After W. S. Gresley

VII. Organic markings in the Lake Superior iron ores. From a photograph. After W. S. Gresley

X. A, View from brink of Sturgeon Falls, looking down stream; B, Menominee River above Sturgeon Falls
CHAPTER I.  The Menominee district is situated on the Michigan side of the Menominee River. It occupies an area of 112 square miles, living principally in townships 39 and 40 north and ranges 28, 29, 30, and 31 west. It consists of a narrow tongue, widening to the west into the broad expanse of the Crystal Falls district, and merging to the northwest into the southwestern end of another ore-bearing district known as the Calumet area. The importance of the Menominee district as an ore producer may be inferred from the fact that since the first regular shipments of ore were made in 1877 the total quantity of ore raised from its mines has aggregated about 29,000,000 tons, nearly all of which was of Bessmer grade. The gross product in 1902 was over 3,000,000 tons.

The rocks of the district belong to the Archean, the Algonkian, and the Paleozoic systems. The iron-bearing beds are Algonkian. These are bounded on the north by a complex of gneisses and schists and on the south by a series composed mainly of greenstone-schists cut by dikes of granite, porphyry, gabbro, and diabase. The
Algonkian rocks are divided into a lower and an upper series, distinguished as the Lower Menominee and the Upper Menominee, separated by an unconformity. These correspond to the Lower Marquette and the Upper Marquette series in the Marquette district and to the Lower Huronian and the Upper Huronian on the north shore of Lake Huron. The Paleozoic rocks are represented by the Lake Superior sandstone and an Ordovician limestone.

CHAPTER II. An abstract of the literature devoted to the discussion of the geology of the district is given in this chapter. It begins with a reference to a report by George N. Sanders, printed in 1845, and ends with a reference to a general article on the iron-ore deposits of the Lake Superior region by C. R. Van Hise, which was issued in 1901.

CHAPTER III. This chapter treats of the physiography of the district. The topography is simple. It consists essentially of two longitudinal ridges, with elevations of about 1,500 feet, separated by valleys, the floors of which are about 1,000 feet above the sea. Both the tops of the ridges and the floors of the valleys slope gradually to the southeast, representing, it is believed, two plains. The ridges are thus remnants of a higher plain that once occupied the entire area under discussion. The plan of the topography corresponds closely with the geological structure of the district. The residuals of the high plain are composed of hard dolomites, while the valleys are carved in soft slates.

The drainage is mainly longitudinal. The main drainage course is the Menominee River. The smaller streams are branches of this. All the streams possess the characteristic features of antecedent streams. Their courses are arranged without regard to the geology. It is evident that the present topography could not have been produced by the present drainage. It not only antedates the Glacial epoch, at the close of which the present drainage was inaugurated, but it even antedates in great measure the latest epoch of the Cambrian period, during which the Lake Superior sandstone was deposited. During this time the entire district was under water and the sand deposit covered all the hills as well as filled all the valleys that had been made prior to this period. Later, the land was raised above the water surface and erosion swept away the sandstone, except that on the tops of the hills, and the old topography was again brought to view. The present topography of the district is therefore similar to that which existed prior to Upper Cambrian time.

CHAPTER IV. The Archean crystallines bordering the Algonkian tongue are greenstone-schists on the south and a complex of gneisses, granites, and various schists on the north. The southern schists—the Quinnesec schists—occur in two areas. A southern area lies along the Menominee River and stretches southward into Wisconsin. A western area constitutes a wedge entering the Huronian beds from the west and extending for 6 or 7 miles along the middle line of the Menominee tongue. The Quinnesec schists of the southern area are coarse- and fine-grained basic rocks, characterized by a schistose structure of varying degrees of perfection. The coarser phases were originally gabbros, diabases, and diorites; the finer phases were basalts, diabases, and basic tuffs. Associated with these are chlorite-schists, amphibolites, gneisses, schistose porphyries, schistose felsites, and sericite-schists. The acid schists, except perhaps the sericite-schists, are apophyses from a great boss of granite which is intruded in the basic rocks south of the Menominee River. The basic schists are cut by dikes of various basic rocks and by granites.

In the western area the rocks are more massive. They are dense, grayish green in color, and uniform in their features. Some of them are ellipsoidal. All are apparently fine-grained basic lavas that have suffered extreme alteration. Most of the rocks are schistose, some slightly so but others markedly so. Their schistosity, as well as that of the southern schists, is ascribed to pressure.

The northern complex of gneisses and schists is of the usual character of Archean complexes. Banded gneisses and gneissoid granites, hornblende-schists, greenstone-schists, and a few mica-schists are intruded by dikes of diabase and by veins and dikes of granite. The gneissoid granites are of a pink and a gray variety, of which the former appears to partake largely of the nature of pegmatite. It intrudes the gray variety in irregular stringers and in series of narrow parallel veins.

When in the form last named, the two rocks together give rise to banded gneisses. A few localities are described at which the Quinnesec schists and the northern complex can be seen in good exposures.

CHAPTER V. The Algonkian rocks comprising the Menominee tongue are almost exclusively sedimentary, and are mainly mechanical sediments. They are separated from the underlying granites and gneisses of the northern complex by conglomerates composed largely of the débris of the underlying rocks. Their relations with the Quinnesec schists are not known, since the two series are not in contact. It is believed, however, that the sedimentary series is much younger than the schist series, because of the lithological analogies existing between the two series and corresponding series in the Marquette district.

Moreover, within the Algonkian series there is an unconformity, which is revealed by the presence of a coarse quartzite containing pebbles of jasper, which must have been furnished by beds under the quartzite. No such beds in this stratigraphic position are now known to exist in the district, and hence it is assumed that they have been removed by erosion, and that a portion of their débris is now incorporated in the quartzites. This unconformity corresponds with that between the Upper Marquette and the Lower Marquette in the Marquette district, and between the Upper and Lower Huronian in the Crystal Falls area. In this district the two series are called the Lower Menominee and the Upper Menominee.
Section 1. The Lower Menominee series is subdivided from the base upward into three formations—the Sturgeon quartzite, the Randville dolomite, and the Negaunee formation (iron bearing).

The Sturgeon quartzite is found only along the northern side of the Menominee trough, where it forms a southward-dipping monocline bordering the south side of the Archean complex, and separated from it by an unconformity. Its topography is rugged. At its base the formation consists of conglomerates composed largely of the débris of granite and gneiss. These grade upward into quartzites through arkoses and graywackes. The conglomerates, the arkoses, and the graywackes are nearly always schistose, but the quartzites are practically always massive. This difference in structure is explained as due to the fact that the conglomerates, arkoses, and graywackes are nearer the contact plane with the underlying Archean than the quartzites, and hence were nearer the zone of accommodation in which movement occurred during the folding of the district.

The quartzites are principally white vitreous or saccharoidal varieties, composed of plainly fragmental quartz grains that often are enlarged by the addition of quartz on their peripheries. A few schistose quartzites differ from the predominant massive varieties in containing much sericite. At the top of the formation the quartzites pass into dolomitic quartzites, and these in turn grade into quartzose dolomites at the base of the Randville dolomite.

The major folding of the quartzite is simple. Within the formation a few divergencies of strike and dip are noted, but in the main the beds are nearly vertical. They constitute one limb of a synclinorium, the other limb of which should appear adjacent to the southern area of Quinnesec schists, and also around the western area. Its absence from these positions is supposed to be the result of the erosion which intervened between Lower Menominee and Upper Menominee time. At the western end of the district the quartzite belt turns northward around the end of the Archean anticline, separating the Menominee from the Calumet tongue. At this turn it is folded into a number of synclines and anticlines pitching west.

The thickness of the formation is estimated to be between 1,000 and 1,250 feet. The most interesting occurrences of the quartzite are to be found at the rock dam on Pine Creek and at the falls of Sturgeon River.

The Randville dolomite is identical with a similar dolomite series in the Felch Mountain and the Crystal Falls districts. It occupies three belts, called, respectively, the northern, the central, and the southern. The northern belt lies immediately south of the Sturgeon quartzite, in the valley of Pine Creek. Few exposures have been seen, as the area underlain by the belt is covered with the sands distributed by the stream. The central belt is narrow; it occupies the axis of the trough extending from a point north of Lake Antoine eastward to the bluff known as Iron Hill, in sec. 32, T. 40 N., R. 29 W.

The southern and most important belt stretches from a point near the Menominee River, west of Iron Mountain, eastward to the end of the district, where it is lost under a covering of Paleozoic sediments. The most important mines of the district are just south of its southern border. On account of its resistant nature the dolomite in the southern belt, and, to a less extent, that in the central belt, gave rise to the elevations which stretch through the district in the form of the two ridges already mentioned, and which are explained as residuals of a plain once existing over the entire Menominee area.

The dolomite formation comprises an interbedded series of dolomites, quartzose dolomites, dolomitic quartzites, dolomitic slates, cherty quartzites, and talcose schists. The dolomites predominate. At the base of the series they are more or less richly quartzose. The cherty quartzites are fine-grained cherty rocks that are usually brecciated. In color they vary somewhat, but white and red shades are most prevalent. These rocks occur in but a few places, but always above the dolomites. Their absence from much of the region is accounted for by the erosion which removed them from over the most exposed portions of the surface during the interval between the Upper and Lower Menominee epochs. The slates are light-colored talcose and sericitic varieties. They are not very prominent. Occasionally they are found well down in the series, but usually they are limited to its upper portions, where they are in contact with closely similar slates belonging in the Upper Menominee series. The talcose schists have been observed only at the upper contacts of the Randville formation, where the purer dolomites are immediately beneath the basal layers of the Upper Menominee rocks, and more particularly in places where severe folding has taken place. They are soft, dark, much-jointed rocks, composed largely of serpentine and talc. They were formed, in all probability, in consequence of the fact that the dolomites were in a zone of movement where the conditions were favorable to active chemical processes. In many places the dolomites were crushed into breccias, and at one place, Iron Hill, a well-defined dolomitic conglomerate occurs.

The cherts of the Randville dolomite are identical in character with those in the Gogebic and Marquette districts and have the same stratigraphic position as these. In all three districts they are supposed to be of organic origin.

The folding of the Randville dolomite "is the key to the knowledge of the folding of the entire series of Algonkian rocks in the district." The formation occurs as a monocline in the northern belt and as anticlines in the central and southern belts. The northern belt follows closely the distribution and the folding of the Sturgeon quartzite. The central belt is the top of an anticline which is connected with the northern and the southern belts by synclines. It is terminated at both ends by plunging beneath the overlying beds. At its east end the eastward plunging anticline is plicated into several minor folds. Thus the central belt is affected by a broad anticline with
between the two is sudden. There is no recognizable contact is with the Vulcan formation—the transition is the basal member of the series—that is, when the Upper Menominee series. When the overlying formation remain in the Menominee district the exact nature of the transition of the purer dolomites into quartzose phases observed at the top of this formation, together with the underlying Sturgeon quartzite, but the gradation from the upper series there is usually a conglomerate or coarse quartzite containing pebbles of chert and jasper that must have been derived from some formation beneath. Their existence is regarded as proof that there was once above the dolomite a jaspilite formation, like the Negaunee formation in the Marquette district. Thus, it is believed, there was an erosion interval preceding the deposition of the Vulcan rocks and at some time during the period when erosive agents were at work the Randville dolomite formed a land surface.

In many places the dolomite is in contact with the Hanbury slate, which normally lies above the Vulcan beds. This is the case at one place on the southern side of the southern belt and very generally along its northern side. It is also the case at the east end of the central belt, and possibly along its northern side. The absence of the Vulcan beds from those places at which it would normally be expected to occur is explained as the result of overlap along a sinking shore.

At a number of places along the contact, especially where the contact is between the dolomite and the Vulcan beds, the rocks on both sides of the contact line are severely brecciated. Both the underlying and the overlying beds are shattered and the line between them is often completely obliterated.

The Negaunee formation is represented in the district only by the pebbles in the quartzite at the base of the Upper Menominee series. There area few jaspilites near the Curry mine, however, that are slightly different from most of the corresponding rocks in the Vulcan beds. Since their jasper layers are identical in character with the jasper pebbles in the quartzite, these jaspilites are described as affording a fair idea of the nature of the Negaunee beds that formerly must have existed in the district.

Section 2. The Upper Menominee series comprises all the beds between the top of the Randville dolomite and the bottom of the Lake Superior sandstone. It includes two formations—the Vulcan formation (iron bearing) and the Hanbury slate.

The reason for the separation of this series from the Lower Menominee series is the presence of a stratigraphical break between the Randville dolomite and the bottom of the Vulcan formation.

The rocks of the Upper series occupy the synclinal areas between the anticlines of dolomite and those between the dolomite and the two areas of Quinnesec schists. From the distribution of the series it is clear that it must occur in three synclines and two anticlines with east-west axes and the same number of similar folds with north-south axes.

Since the Vulcan formation occurs immediately above the dolomite, it should surround the dolomite areas in a continuous belt under normal conditions. At many places, however, the rocks of the Vulcan formation are lacking in this situation, and the Hanbury slate occupies the position they would naturally be expected to occupy.
Wherever found, however, the Vulcan beds always lie between the dolomite and the slate. The lack of continuity of the Vulcan belt is ascribed to overlap of the Hanbury slate.

Lithologically the Vulcan formation is separable into three members, which are, in ascending order, the ore-bearing Traders member, the Brier slate, and the ore-bearing Curry member. The first comprises slates, conglomerates, quartzites, and jaspilites: the second is composed exclusively of slate, and the third consists of jaspilites and slates. Ore deposits occur in both the Traders and the Curry beds.

The Traders member is not as widely distributed as the other two members of the formation. Where one member is absent, it is the Traders member. Although this is not as continuous as the other members, nearly all the large mines of the district obtain their ores from its deposits.

The slates of the Traders member are always found in its basal portions, where they are associated with quartzites and conglomerates. These are usually light colored phases that are with great difficulty distinguishable from some of the talcose slates at the top of the Randville dolomite. In a few places the slates are black, heavy varieties that are merely very quartzose fragmental ores. The light-colored slates grade into the quartzites and conglomerates. The latter rocks contain abundant jasper and ore pebbles. Where these constitute the main portion of the deposits the rocks pass into jaspilites, which are banded rocks, composed of alternating layers of red jasper and black ore. When the structure of the jaspilites is fairly coarse, the small grains of jasper and ore composing them can be distinguished on their bedding surface as small oval areas, producing a distinct mottling. Where shearing has taken place the ore bands have been rendered schistose, or micaceous, producing specular ores, and the jasper bands have been mashed so that the tiny grains of jasper have assumed lenticular shapes. In some places brecciation has occurred, and the rock is now a mass of jasper fragments in an ore matrix. Much of the material in the Traders jaspilites is thus of fragmental origin. In addition to the fragmental material in them, however, there is also much crystallized quartz and a good deal of newly deposited hematite. As the grain becomes finer the fragmental structure of both jasper and ore disappears, the quantity of secondarily deposited quartz and hematite increases, and the jaspilites become more like the typical jaspilites of the Marquette area, which were formed mainly by the decomposition of a cherty, ferruginous carbonate.

Under the microscope a few nodular masses of jasper and ore are observed in thin sections of the Traders rocks, and these are thought to be pseudomorphs of siderite or greenalite concretions. Their presence is evidence that some of the silica and hematite in the Menominee jaspilites was derived from an iron carbonate by metasomatic replacements. In all cases the ore bands differ from the jasper bands mainly in the greater abundance of their ferruginous component.

The Brier slate is an even-banded, heavy, black slate, occupying a belt of country adjacent to the Traders jaspilites. The rock consists of quartz grains and hematite crystals, embedded in a matrix composed of quartz, decomposed feldspar, kaolin, and a little chlorite. Here and there are a few large plates of brown biotite and white muscovite. Some specimens contain a great deal of dolomite. The Brier slate grades into the jaspilites of the Curry member through increase in the quantity of crystallized silica in the matrix and decrease in the amount of fragmental quartz present.

The Curry member is probably more widely distributed than either the Traders or the Brier member. It is found in all places where any portion of the Vulcan beds have been discovered. Lithologically the member is an even-banded series of jaspilites and quartzose slates, besides ore deposits. Of the jaspilites two varieties are recognized. In one the jasper is dark red or purple and very fine textured and the ore a dense black hematite. These are very like the Traders jaspilites. In the other variety the jasper may be dark red, pinkish, or white. Both the jasper and the ore are sandy textured and look as though made up largely of loosely cohering grains. When examined microscopically the sandy jaspers are found to contain many oval and round masses of cherty quartz, surrounded by narrow zones of hematite and embedded in a finely crystalline aggregate of quartz. In the ore layers the zones of hematite around the chert nuclei are very broad, and the interstitial quartz is small in quantity. The quartzose slates differ from the jaspilites in being more homogeneous. They consist of a series of very thin alternating siliceous and ore layers, so that there is little or no distinction between ore and jasper bands. These rocks are found at the base of the Curry member, and are in a way gradation phases between the Curry jaspilites and the Brier slates.

The oval masses in the sandy phases of the Curry jaspilites are much more numerous than they are in the Traders jaspilites. As in the case of the Traders rocks, they are believed to be pseudomorphs of siderite or greenalite concretions. They are similar in all respects to the concretions that have been described in the Gogebic and Marquette jaspers and in the Mesabi and Gunflint Lake cherts. In the vicinity of the Curry mine all the rocks of the Curry member are cut by veins of red crystalline dolomite, and the ores are saturated with the same material to such an extent that their siliceous component has entirely disappeared, and in its place is a matrix of dolomite.

Where no marked disturbances in their relations exist the members of the Vulcan formation grade into each other by transition forms. Where, on the contrary, the members are closely folded the contact between the Traders and the Brier members is often sharp, and the rocks on both sides of the contact line are severely brecciated. This is true at the Norway mine and in the
slates are those of complete conformity.

Chapin mine. Their relations with the overlying Hanbury shown by the presence of dolomite bowlders within the structural unconformity. That the Vulcan beds were laid older series, where the two are not separated by a Randville dolomite are those of a younger series to an

The relations of the Vulcan beds to the underlying older series, where the two are not separated by a Randville dolomite are those of a younger series to an older series, where the two are not separated by a structural unconformity. That the Vulcan beds were laid down on a shore composed partly of the dolomite is shown by the presence of dolomite bowlders within the iron formation on the seventh and eighth levels of the Chapin mine. Their relations with the overlying Hanbury slates are those of complete conformity.

After the Traders beds had been laid down to a thickness of several hundred feet in some places the conditions of deposition changed. The cherty material ceased to be precipitated, and the Brier slates were laid down. At the end of Brier time the conditions that prevailed at the end of Traders time recurred, and chemical sediments were again precipitated. In this period they were less contaminated with fragmental material. The abundance of concretionary ore in the Curry beds shows that some of these must have consisted almost exclusively of the chemical precipitate. Jaspilites were produced from the carbonate and the greenalite in the same manner as in the Traders beds, and some of these, after enrichment, became ore bodies.

The major folding of the Vulcan beds follows closely the folding of the subjacent dolomite. Within the formation, however, the beds are crumpled and crinkled into small folds, and upon these are superposed still smaller fluteings.

Wherever folding is observed it is best preserved in the jasper bands. The ore layers between these were sheared and made schistose. Where the folding was very severe both ore and siliceous layers developed a slaty cleavage. In some places the jasper was fractured and a breccia of jasper fragments in a micaceous ore matrix resulted.

The total thickness of the Vulcan formation averages about 650 feet, divided as follows: Traders member, 150 feet; Brier slate, 330 feet; Curry member, 170 feet. The Brier and Curry members maintain an almost uniform thickness in all portions of the district where they have been encountered. The Traders member, however, varies widely in thickness, as would be expected of a series of beds deposited against a shore.

The relations of the Vulcan beds to the underlying Randville dolomite are those of a younger series to an older series, where the two are not separated by a structural unconformity. That the Vulcan beds were laid down on a shore composed partly of the dolomite is shown by the presence of dolomite bowlders within the iron formation on the seventh and eighth levels of the Chapin mine. Their relations with the overlying Hanbury slates are those of complete conformity.

In a few places the Hanbury slate is against the dolomite, the Vulcan beds being nowhere present in the vicinity. This is true east of Quinnesec and at the east end of the central dolomite belt. It is also believed to be true at a number of other places where the slate and the dolomite series have not been seen in actual contact or in exposures very close to one another. Faulting of the slate beds over the iron-bearing beds will not explain the phenomenon, because faulting is of minor importance in the district. The only explanation that suggests itself to account for all the facts of distribution of the Vulcan and the Hanbury formations is that of unconformity between the Lower Menominee and the Upper Menominee series, with a gradual advance of the Upper Menominee sea, the deposits of which slowly overlapped the earlier deposits and gradually buried the higher lands composed of the Lower Menominee rocks.

The Traders and the Curry ores are not very different. Practically all are of Bessemer grade, though some are highly siliceous and others contain but little silica. The former are especially rich portions of the jaspilites that have had their ferruginous component increased by processes of enrichment. These lean ores differ very little in appearance from the jaspilites, of which they are essentially a part. They are banded, brecciated, and often specular. The brecciated ores may consist of jasper fragments in a mass of hematite, or of hematite fragments in a mass of dolomite, or they may be composed of fragments of ore, jasper, and slate in a mass consisting largely of slate débris that has been strongly ferruginized.

The rich ores are usually bluish-black, porous, fine-grained aggregates of crystallized hematite, occurring in the troughs of pitching folds or in other situations toward which descending water is likely to be directed. Comparisons of analyses of all the ores of the district show them to consist principally of hematite, with additional varying amounts of magnetite, silica, alumina, lime, magnesia, carbon dioxide, phosphorus pentoxide, and water. Most of the ores contain also manganese, potash, and soda, and a few of them titanium and carbon. The minimum silica reported in the ores of 1900 is 2.75 per cent and the maximum 88.65 per cent. Twelve analyses of cargoes of typical ores are given and four complete analyses. The latter indicate that the richer ores are mixtures of hematite, magnetite, muscovite, serpentine, dolomite, apatite, pyrite, quartz, and some manganese oxide.

All the minerals occurring as constituents of the ores are found also as visible masses either in veins cutting the ore bodies or in vugs or pores within them. Dolomite, calcite, and pyrite sometimes exist in excellent crystals, and serpentine as large, white, almost pure masses. Talc also occurs in thick seams of almost ideal purity, and chalcopyrite in small crystals associated with pyrite. The carbonates and sulphides are found near water courses and the silicates mainly in the lower portions of the ore bodies.
The ores when exposed to the action of the atmosphere become coated with a white efflorescence, consisting of a mixture of the sulphates of sodium, magnesium, and calcium, in which the first named is greatly in excess.

The larger ore deposits all rest upon relatively impervious foundations, which are in such positions as to constitute pitching troughs. Within this district such pitching troughs may be made by (1) the marginal folds in the Randville dolomite; (2) the slate forming the bottom part of the Traders member; and (3) the Brier slate beneath the Curry beds. The dolomite is especially likely to furnish a suitable basin for the accumulation of ore bodies, where its upper member has been transformed into a talcose schist.

Smaller ore bodies may occur at contacts between the different members of the Vulcan formation and at places within the iron-bearing member where severe brecciation has occurred.

The forms of the ore bodies vary with their positions. While very irregular in shape they nevertheless conform in a general way to the shape of the foundation on which they rest. The deposits in troughs have in general a U-shaped cross section, very thick at the bottom. Where much compressed, the arms of the U may unite at the center and produce a lens-shaped deposit. Contact deposits are usually broad and sheet like, with irregular projections extending from their upper surfaces.

From the distribution, associations, and composition of the ores and the shapes of the ore deposits it is evident that the ores of the Menominee district, like those in the Gogebic and Marquette districts, were concentrated by descending waters flowing in definite channels. A portion of the iron oxide in the Traders member is of fragmental origin, being the débris of an older jaspilite formation, and perhaps a portion of that in the Curry member had a similar origin. These ferruginous bodies, however, were enriched by the addition of hematitic material from some overlying stratum, from which it was dissolved by meteoric waters and transported downward, finally being precipitated between the fragmental grains of the original sediments.

The processes of concentration were the same as those worked out by Van Hise for the Gogebic and the Marquette districts. Oxygenated meteoric waters descending through the rocks of the Hanbury and Vulcan formations dissolved iron carbonates and silicates and precipitated the metal as oxide in or near the position of the original compounds. Carbon dioxide was thus liberated and dissolved in the descending waters. These took up more iron salts. In their downward passage they were converged into trunk channels by plunging synclines, or were directed into definite courses by the contact planes between adjacent beds or by zones of brecciation. At these places the iron-bearing waters, which necessarily must have taken circuitous routes, were intermingled with water which had descended more directly from the surface, and which, therefore, had retained its oxygen, or most of it.

Here the dissolved iron carbonate was decomposed and iron oxide precipitated. Thus are found pseudomorphs of hematite in place of original ferruginous concretions, and great deposits of ore in the troughs of synclines within the iron-bearing formation. Continued passage of water along the same channels purified the deposits by removing from them deleterious substances.

Topographically the ores are usually found below the crests of hills, on their slopes or in valleys which once had below them lower valleys in which the descending waters may have found an outlet. In the Menominee district, however, this relation between the position of ore bodies and the topography is not as clear as it is in the other Lake Superior iron districts.

The beginning of the concentration of the ores must have been at the close of Upper Huronian time, that is, after the folding of the Huronian rocks. It was practically completed before the beginning of the Upper Cambrian.

A critical study of the geological relations of the ore deposits of each of the mines in the district indicates that all deposits of any magnitude are situated in just such positions with respect to the surrounding rocks, as might have been prophesied, on the assumption that they were accumulated by the action of descending ground water.

The Hanbury slate occupies nearly all the low ground within the Menominee trough. It occurs in three synclinal belts lying between the anticlines of dolomite and between the southern dolomite belt and the south area of Quinnesec schists. The slate belts widen toward the west because of the westward plunging of the entire synclinorium.

The formation comprises clay slates, calcareous and graphitic slates, graywackes, thin beds of ferruginous dolomite, and small bodies of chert and hematite. The formation is cut by a few greenstones that are now greatly decomposed.

The clay slates are normal rocks. When sheared and much weathered they become light-colored sericite-schists. Many specimens are stained red in irregular patches, producing a red and white mottled rock known locally as calico slate. The calcareous and graphitic slates appear to be limited to the lower horizons of the formation, the former being nearly always associated with ore bodies. The quartzites are very siliceous dolomites. The cherts and hematite are usually closely associated. The former are gray or white. The latter is a dense-black or dark-brown variety. Where the slates are cut by greenstone they have suffered some contact metamorphism, with the production of a little biotite and actinolite.

The folding of the formation is very complicated. Folds of high orders are common—practically universal. In the eastern portion of the area the pitch of these small folds is to the east and in its western portion to the west. The distribution of the folds and their varying pitches corresponds closely to the major folding of the district. No approximately correct estimate of the thickness of the
slate formation is attempted, because of the difficulty of eliminating the effects of the close folding. It is safe to say, however, that the Hanbury formation is the thickest of all the formations in the district.

Like the other members of the Menominee series, the slates are unconformably beneath the Lake Superior sandstone.

No workable ore deposits have thus far been discovered within the slate area, but there are seven or eight places at which lean ores have been obtained. These are widely distributed. Because of the interest naturally attached to the discovery of ores of any kind in the great slate areas, each of these localities is briefly described.

It is possible that ore deposits of workable size occur in the slates in very favorable situations, though no indication of their presence has yet been observed in this district. From the fact, however, that large deposits are known to exist in the Hanbury slates of the Florence, Crystal Falls, and Iron River districts, it is possible that similar deposits may occur in the Menominee district.

In exploring within the Hanbury area only the most favorable localities need be tested. These are the places where ferruginous dolomites occur, where the rocks are folded or brecciated, and where the folds involve an impervious stratum.

CHAPTER VI. Above the folded Algonkian rocks lie the horizontal beds of the Paleozoic sediments, with a profound unconformity between the two series. The Paleozoic series comprises the Lake Superior sandstone below and the Hermansville limestone above. These once extended over the entire district. East of Waucedah they still cover all the older rocks, but west of this place they are now found capping only the higher hills.

The Lake Superior sandstone is mainly a red sandstone. Its thickness is estimated to be 300 feet. In its lower portions are conglomerates, which, where they lie on the Vulcan beds, contain ore bowlders in such quantity that they may occasionally become sources of ore.

Fossils are extremely rare. A few fragments of trilobites and a few shells of brachiopods have been found in a few places. The former have been identified as *Dicelloccephalus misa* and the latter as *Lingulepis pinniformis*. They indicate the St. Croix horizon of the Upper Mississippian series.

The Hermansville limestone is a sandstone with calcareous cement, interbedded with pure dolomite. Its maximum thickness is about 100 feet. The series is of little importance within the limits of the Menominee district, but is widely spread farther east. Rominger identified it as corresponding to the Chazy and Calciferous formations of the Eastern States.

CHAPTER VII. This chapter contains an outline of the geological history of the district. Comparison of the succession of formations in the Menominee district with the succession in the Marquette and the Gogebic districts shows that the geological history of the three districts, while alike in its major features, was very different in minor features. The attempt to correlate the events that transpired in the various iron-bearing districts of the Lake Superior region is left for a succeeding publication.
Limits of the Menominee area.—The Menominee district proper is bounded on the west by the Menominee River; on the south by the same river and the south line of the northern tier of sections in T. 38 N., Michigan; on the east by the east line of secs. 2, 11, 14, 23, 26, and 35, T. 39 N., R. 28 W., and their continuation north and south, and on the north by the north line of T. 40 N., Michigan. On the general map (Pl. II) the area represented includes a region extending 8 miles farther north, to the north side of the second tier of sections north of the south line of T. 42 N., and as far west as the west line of Ts. 41 and 42 N., R. 30 W. The geological map (Pl. IX) includes only the area of the Menominee district proper.

Relations to other iron-bearing areas.—The area designated above as the Menominee district proper constitutes a tongue of sedimentary deposits lying between a granite area to the north and a green schist area to the south. This tongue is the southernmost of five distinct tongues (see map, Pl. II) which extend eastward from the great central area of Huronian deposits in Wisconsin and Michigan, described in part in the Crystal Falls monograph. The five tongues, beginning with the northernmost, are the Marquette tongue, discussed in the Marquette monograph; the Sagola and the Felch Mountain tongues, treated in the Crystal Falls monograph; the Calumet tongue; and the Menominee tongue. Each is structurally a trough of Huronian sediments lying between rims of Archean granites, gneisses, and schists. To the west they all widen out into the broad expanse of Huronian sediments referred to above. To the east all except the Marquette tongue plunge beneath Paleozoic deposits. The Calumet tongue runs a little north of east and then east through the center of T. 41 N., R. 29 W., Michigan, as a narrow belt a mile or a mile and a half in width. At the east side of the township it widens rapidly, becoming broader and broader until, in T. 41 N., R. 27 W., where it disappears under Paleozoic deposits, its width measures 7½ miles.

Shape and size of the Menominee tongue.—In general the Menominee tongue is a spindle-shaped area about 17 miles long, trending about N. 55° W. Its narrowest portion is in the middle, in the vicinity of Vulcan, where it measures about 4 miles in width from its contact with the granite on the north to its contact with the green schists on the Menominee River on the south. To the east it widens gradually until, in the eastern portion of R. 28 W., its width is about 7 miles. To the west also it gradually becomes wider and finally loses its identity as a distinct trough at about the center line of R. 30 W., where it merges with the Calumet trough, and extends into the wide area of Huronian sediments to the west.

At its west end the south side of the Calumet tongue merges with the north side of the Menominee tongue. Farther east the two tongues are separated by an elliptical area of Archean rocks.

Economic importance of the district.—In 1902 the mines of the Menominee trough shipped 3,001,189 long tons of ore, and since the first shipment of ore from the Quinnesec mine in 1873 the aggregate shipments of all mines to the close of 1902 have amounted to the large total of very nearly 29,000,000 long tons. Of this
aggregate by far the larger proportion of ore has been of Bessemer grade. The total shipments from the Marquette district to the end of 1902 were 66,686,502 long tons; those from the Crystal Falls, Iron River, and Felch Mountain districts in Michigan, and the Florence district in Wisconsin, taken together, have amounted to about 13,400,000 long tons; those from the Gogebic range in Michigan and Wisconsin to 37,818,274 long tons; those from the Vermilion range in Minnesota to 19,061,506 long tons; and those from the Mesabi range in the same State to 53,747,807 long tons. It will thus be seen that in proportion to its area the Menominee trough has yielded as large a product as any other of the Lake Superior districts, with the exception of the Mesabi. Since the discovery and development of the Mesabi district the demand for low phosphorus and high silica ores to serve as mixtures for the Mesabi ores has so largely increased that many lean, low phosphorus ore deposits, formerly not marketable, now find a ready sale. The Menominee district can furnish an abundance of this grade of ore, so that it is probable that the importance of the district as a mining center will increase rather than diminish in the future.

Previous work in the district.—The only detailed geological maps of the Menominee trough that have heretofore been published are those of Brooks in the Geology of Wisconsin. Irving published a general map (Pl. V) of the district in his introduction to Dr. Williams’s bulletin on the origin of the Menominee green schists, but he made no claim that it exhibits more than the generalized structural features of the district. Wright’s map shows the distribution of the green schists, some of the iron-bearing belts, and the pre-Huronian rocks of the district, while that of Brooks exhibits, in addition, the location of all the ledges of dolomite, slate, quartzite, and other sedimentary rocks met with during this author’s explorations. Brooks also presents a structural sheet illustrating his views as to the sequence of the rock series and the character of the folding. This map was of great use to the field parties of the United States Geological Survey, since it enabled them to make systematic plans for the survey of the district and directed their attention to many rock ledges that might otherwise have been overlooked.

In addition to the works and reports referred to above, another valuable report on the district is that of Rominger. This report, like that of the same author on the geology of the Marquette district, consists mainly of a discussion of ledges and of detached statements concerning the relations to one another of the different ”rock groups” met with. It, nevertheless, was of great value in the prosecution of the field work on which the present volume is based, since it called attention to the most promising exposures in the district and in many instances afforded clues as to the places at which relations could best be studied.

The reports of Brooks, Wright, Irving, and Rominger are referred to more at length in the following chapter, and in this chapter also are given abstracts of all the other important papers in which the geology of the district has been discussed. A perusal of this chapter will show that many facts bearing on the subject have gradually been accumulated; but that in no other cases than those mentioned above did the facts known concerning the distribution of the different formations warrant the construction of geological maps of the district.

Method of work.—Most of the field work on which this monograph is based was done in the months of July, August, and a part of September, 1896. The entire area whose limits have been outlined above was cut by north-south traverses at intervals of one-tenth, one-fourth, one-half, or three-fourths of a mile, or 1 mile, according to the intricacy of the geology in different parts of the district and the character of the surface exposed to view. In those portions of the district from which the forest and undergrowth have been removed the traverses were at greater intervals than in those portions covered by dense thickets of young trees and brush. In the wide expanses of slate to the south of the Chicago and Northwestern Railroad the traverses were 1 mile apart. In those portions of the district where the different rock belts are closely folded traverses were made every quarter of a mile. The iron-bearing belt was examined thoroughly, every ledge, so far as is known, and every mining pit having been studied in detail. The same careful examination was made of the contact between the quartzite at the base of the sedimentary series and the crystalline rocks to the north, and an almost equally careful search was made for a contact of the slates with the greenstones to the south. In areas where exposures are small and scattered, north-south magnetic lines were run every half mile.

During the summers of 1899 and 1900 two other visits were made to the district, but the field work was limited to the study of relations, to the running of a few additional magnetic lines, and to the investigation of the structure of small complicated areas and the study of the mines. The work was supplementary to that of 1896, and was intended simply to fill the gaps left by the earlier survey.

Though the topography of the district is simple, much of the surface is covered with a thick mantle of glacial drift through which ledges of the softer rocks rarely penetrate. Other portions are covered by a sheet of sandstone which obscures some of the most interesting contacts.Moreover, thick growths of brush hide much of the surface, especially in the northern and eastern portions of the district. The detail maps show the character, the position, and the number of ledges.
investigated, and it is from the evidence afforded by these and by the mine plats that the structure of the district has been worked out.

Classification of formations.—The rocks of the Menominee district belong to the Archean, Algonkian, and Paleozoic systems. The oldest series of rocks bordering the Menominee tongue comprises various schists, gneisses, and granites. These are regarded as Archean. Resting unconformably upon the Archean rocks is a succession of Algonkian sediments, which are divisible into a Lower Menominee and an Upper Menominee series, separated from each other by an unconformity. The Paleozoic rocks comprise horizontal Cambrian sandstones and Ordovician limestones. These occur in patches on the tops of the hills, capping the closely folded and truncated Huronian rocks. Both of the Menominee series are divisible into a number of formations, each representing a time during which the conditions of deposition were approximately uniform. Each of the pre-Cambrian formations has been named and is represented on the general map of the district (Pl. IX) by a distinctive color. The following table gives a list of the formations, arranged in descending order according to age. The fractional formations, or members of the Vulcan formation, are represented on the detail maps and are separately characterized in the text, but they are not differentiated on the general map.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Ordovician</th>
<th>Cambrian</th>
<th>Unconform.</th>
<th>Unconform.</th>
<th>Unconform.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Cherty, Calcareous)</td>
<td>Potsdam</td>
<td>Lake Superior sandstone</td>
<td>Hermansville limestone</td>
<td>Hanbury slate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper Menominee</td>
<td>Vulcan formation, subdivided into the ore-bearing Curry member, Brier slate, and ore-bearing Trades member.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Menominee</td>
<td>Randville dolomite.</td>
<td>Sturgeon quartzite.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Archean</td>
<td>Granite and gneiss, cut by granite and diabase dikes.</td>
<td>Quartzite schists, cut by acid and basic dikes and veins.</td>
</tr>
</tbody>
</table>

Names of the formations.—The names of the Upper Menominee formations and of the Archean schists are taken from localities in the district. The names of the Lower Menominee formations are those of formations in adjacent districts already reported upon, with which the Menominee formations are believed to be continuous. Beginning at the bottom, the Quinnesec schists are so named since the iron formation occurs in typical development, with full succession and fine exposures, in the vicinity of West Vulcan. It is threefold, comprising a series of quartzites and fragmental ores at the base, called the Trades member; following these in upward succession, a series of slates known as the Brier slates; and above these, a set of ore beds, jaspilites, and quartzites, which has been called the Curry member, the names in each case being taken from the names of the mines near which the respective series is best exposed.

In the Menominee district, as will be seen, this formation has not yet been identified, although its presence is indicated by the character of the basal member of the Upper Menominee series.

In the Upper Menominee the Vulcan formation is so named since the iron formation occurs in typical development, with full succession and fine exposures, in the vicinity of West Vulcan. It is threefold, comprising a series of quartzites and fragmental ores at the base, called the Trades member; following these in upward succession, a series of slates known as the Brier slates; and above these, a set of ore beds, jaspilites, and quartzites, which has been called the Curry member, the names in each case being taken from the names of the mines near which the respective series is best exposed.


The Hanbury slates are thus named because in the vicinity of Lake Hanbury this formation is better exposed than anywhere else in the district.

References to Marquette monograph.—In the following pages references will be made repeatedly to the monograph on the Marquette district, especially in connection with the discussion of the Archean rocks. These are so nearly like the corresponding rocks in the Marquette district that a minute description of them would be little more than a repetition of what has already been recorded in the account of the Marquette Basement Complex. In order to avoid this unnecessary repetition, only brief descriptions of these rocks will be given. Those who may be interested in their petrography are referred to the chapter on the Basement Complex in the Marquette monograph, and to Dr. Williams’s bulletin on the greenstone-schist areas of the Menominee and Marquette regions of Michigan.


*Williams, G. H., The greenstone-schist areas of the Menominee and Marquette regions of Michigan; a contribution to the subject of dynamic metamorphism in eruptive rocks: Bull. U. S. Geol. Survey No. 62, 1890.

**CHAPTER II.**

**BIBLIOGRAPHY AND ABSTRACT OF LITERATURE.**

The geological literature relating to the Menominee district is much less voluminous than that relating to the Marquette district. Nearly all of it is concerned more particularly with the general problems presented by the district. Very little of the work done has been accomplished by geologists working privately. By far the greater portion of it, including all that is of the greatest value, is the result of public enterprise. The earliest, important publications are those of the United States geologists who were intrusted with the examination of
the geological features of the “Chippewa land district.” After these came the publications of the Michigan survey, followed by those of the Wisconsin survey, and, finally, by those of the U. S. Geological Survey. The authors who have done most toward familiarizing us with the broader features of the Menominee geology are J. W. Foster, J. D. Whitney, T. B. Brooks, C. Rominger, and R. D. Irving. Messrs. Foster and Whitney first recorded the existence of pre-Cambrian rocks within the limits of the district. Brooks separated these into the Laurentian and the Huronian groups, and published maps outlining the Huronian basin and the distribution of the principal formations represented in it. This author and Rominger both give a great many details with reference to the relations of these formations to each other, and both worked out a general theory of structure for the bedded rocks. Irving busied himself principally with a discussion of the relations of the iron-bearing formation to the overlying and the underlying series.

Brooks’s map (Pl. IV) is the only detailed one of the district. Others that have been issued are mainly copies of this, except the map of C. E. Wright, which was constructed primarily for economic purposes, and which shows merely the outline of the Huronian basin and the distribution of the iron-bearing and the green-schist formations within it.

In the present chapter reference is made to all the articles that are known to treat of the district under discussion. These are abstracted in each case, and the conclusions reached are outlined. A knowledge of the contents of many articles that treat of the relations of the pre-Cambrian formations to one another in the Lake Superior region, but which do not refer specifically to the Menominee district, is of importance to the correct understanding of the history of the discussion of the Menominee geology. In it, however, the author refers to various veins of spar met with in his travels.


1845.

The first known reference to the Menominee district is found in the report of George N. Sanders, who made an examination of the country along the Menominee River with a view to determine the feasibility of constructing a road from Green Bay on Lake Michigan to Copper Harbor on Lake Superior. In this report we find described the general features of the country traversed. The report is topographical rather than geological; nevertheless, the author refers to various veins of spar met with in his travels.


This report is a reprint of the preceding one.

1849.


In this article the author prints an abstract of his report to Dr. Jackson, published in full during the succeeding year. A brief description of Menominee geology is given, the reader being referred to the full report for details.

1850.


Dr. Jackson’s report is devoted mainly to the region immediately bordering Lake Superior. In it, however, the author mentions having received a specimen of slightly magnetic iron ore from the Menominee River. It was given him by Mr. Barbeau, of Sault Ste. Marie, who had received it from an Indian. The ore was reported as occurring in mountainous masses somewhere between the head of Keweenaw Bay and the Menominee River. An analysis of the ore yielded 89.70 per cent Fe₂O₃; 12.20 per cent siliceous matter.

FOSTER, J. W.  Notes on the geology and topography of portions of the country adjacent to Lakes Superior and Michigan in the Chippewa land district. This is shown in the excellent reports of the Michigan and Wisconsin...
Messrs. Foster and Hill were sent by Dr. Jackson to make a section from L’Anse to the Menominee River and to search for the iron mountain referred to in the preceding article. These geologists report that “alternating beds of hornblende and argillaceous slates” occur on the Menominee River about 1 mile below the junction of the Brule and the Michigamme. Near the south line of T. 41 N., R. 30 W., they also report the existence of a high ridge of “argillaceous slate containing amygdules of calc spar.” Between this point and the Upper Twin Falls the argillaceous slates and chloritic slates largely predominate. At these falls and at the Lower Twin Falls they present good sections. About 2 miles southeast of the lower falls, near sec. 30, T. 40 N., R. 30 W., large beds of specular ore are associated with talcose and argillaceous slates. The ore is similar to that of the “iron mountain,” which is now identified as Republic Mountain, in the Marquette range. Among the other rocks observed on what is now known as the Menominee range were great blocks of limestone in the Menominee River at the mouth of the Misskos (T. 40 N., R. 31 W.), ledges of “hornblende” exposed on the banks of the stream, beds of talcose slate at the foot of the Great Bekueneec Falls (now the Big Quinnesec Falls, in the northwest portion of T. 39 N., R. 30 W.), a similar bed at the foot of the Little Bekueneec Falls, and a third bed of the same character at the foot of the Sturgeon Falls. At the latter place the slates are “wedged out between walls of sienite.” At Chippewa Island the slates again occur. Here the authors constructed a section with drift on top, followed beneath by nearly horizontal sandstone, dark-colored basalt, and argillaceous and talcose slates. The sandstone rests upon the upturned edges of the slate. Since its deposition the former rock is said to have suffered no great alteration or disturbance, whereas the slates on which it rests are contorted and altered by the protrusion of igneous rocks.

The iron ores referred to are reported to “bear upon their surfaces strong marks of their mechanical origin.” The report continues:

They are regularly stratified, * * * so that a specimen, on its cross fracture, resembles ribbon-jasper. The lines of stratification can readily be distinguished from those of lamination. Like the slates, their are often found contorted and wrinkled, and the same facts could be advanced in both cases to prove their common origin [p. 779].

This statement sounds strange in view of the author’s later attempt, in conjunction with Whitney, to show that similar ores in the Marquette district are eruptive in origin.

In the systematic description of the rocks met with in the journey we find that a range of rock, supposed to be granite, was discovered running parallel to the Menominee River, in Tps. 39 and 40 N., Rs. 30 and 31 W., and crossing the river at Great Bekueneec Falls. On both sides of this range igneous hornblende rocks were found.

1851.


In the course of a general description of the Lake Superior sandstone the authors state that the belt of this rock is 14 miles wide where it crosses the Menominee, that it has a gentle dip to the southeast, not exceeding 3°, corresponding with the slope of the country, and that in the bed of the river it rests on vertical edges of slate rocks and of compact and igneous rocks intercalated with them.


In the general portion of this report the statements made to Dr. Jackson by the senior author with reference to his observations on the Menominee River are repeated. In addition it is stated that above the Big Quinnesec Falls and just above the lower falls the rocks consist of serpentine, and that at the head of the upper falls there is a protrusion of a rock like protogine, “composed of feldspar, talc, and quartz. * * * Occasionally hornblende replaces the talc, when it [the rock] passes into a well-characterized syenite” (p. 25). Slates are mentioned as occurring between the Little Quinnesec Falls and Sandy Portage, and serpentine between the latter place and Sturgeon Falls. On the portage a ridge was crossed in which the rock has the external character of granite, but the mineralogical composition of protogine. Slates and dark-green igneous rocks alternate as the Menominee is descended, the gradations between the igneous rocks being so numerous as to prevent their proper classification. At some distance below the portage are basaltic and other crystalline greenstones which at Chippewa Island are declared to be in contact with talcose slates. Near the south end of the island the slates are described as being porphyritic with red phenocrysts, and with them are said to be associated large masses of serpentine.

After describing the rocks occurring along the Menominee the authors give a general account of the topographical features of the Menominee Valley, and describe a geological section (see fig. 1) across the valley from sec. 35, T. 42 N., R 30 W., to a point near the Little Quinnesec Falls, in sec. 14, T. 39 K, R. 30 W. The description is taken from the notes of Charles Whittlesey. The quartz shown in the section is aid to pass into hornblende-slate, and to the north into gneissoid rocks.

A large number of observations were made on the rocks occurring north of the river, some of which are of interest. On the north side of Lake Fumée is a sharp and elevated ridge whose top consists of Potsdam and Calciferous sandstone resting undisturbed on the Azoic rocks beneath. In secs. 34 and 35, T. 40 N., R. 30 W., is a compact marble belonging with the Azoic, and in sec. 30 of the same town is a “conspicuous iron mountain.”

Monographs of the USGS Vol. XLVI – Chapters 1-5.1 – Page 15 of 111
Iron ores were also noted in a ridge south of Antoines Lake, in the southern portion of T. 40 N., R. 30 W. These are believed to be the southernmost ores in the district. They are specular in structure and are of a bluish-black color. Between secs. 28 and 29, in T. 40 N., R. 28 W., is a great deposit of ore containing from 63 to 68 per cent of iron.

The series to which the ores, schists, limestone, and quartz rocks belong occupies a belt whose broadest expansion is not less than 80 miles in width. The rocks comprising the series are supposed to be flexed and folded, as measurement across their upturned edges would give a thickness for the series, providing it is assumed to be unfolded, too great to be regarded for an instant as correct. The entire series is considered to be metamorphic, even to the compact "hornblende," which resembles an igneous rock. Between the granite that underlies them and the Silurian sandstones that overlie them the rocks of the series—

throughout their whole extent * * * are more or less metamorphosed, presenting a series of gradations represented at one extremely crystalline gneiss and compact hornblende and at the other by bedded limestone and ripple-marked quartz. To the presence of granitic and trappean rocks this transformation is, in a great degree, to be attributed. Much of the compact hornblende presents the external characters of an igneous product; but, since it is found to occupy an almost invariable relation to the granite axes—flanking their slopes—and to assume a fissile structure as it recedes from the lines of igneous outburst, we can not but regard it as the more highly metamorphosed portions of the dark-green chlorite-slates. This compact hornblende is not to be confounded with those lenticular-shaped masses observed in the slates which, we doubt not, are trappean in their nature.

We have seen that those igneous causes which produced numerous axes of elevation, and folded the strata into a series of flexures, had ceased to operate before the deposition of the Silurian groups, since they are found to repose in a nearly horizontal position upon the upturned edges of the strata, or to occupy the sinuosities in the granite, nowhere exhibiting traces of metamorphism or derangement of the strata.

* * From the local details above given, it will be seen that the igneous rocks of the Azoic period, though crystalline, compact, and occasionally porphyritic in their texture, are never amygdaloidal (like the traps on Keweenaw Point), and hence we infer that they were produced under widely different conditions. The latter may have been consolidated beneath the pressure of a great ocean, while from the former a greater part of this pressure may have been removed; or it may be that both were, in the first instance, equally vesicular, but that the latter assumed a crystalline or compact structure from long-continued exposure to heat, under immense pressure. All the phenomena would seem to indicate that the eruption of the trappean rocks of this period took place beneath an ocean of great depth; or, at least under conditions widely different from those which prevailed during the formation of the trappean belts of Keweenaw Point and Isle Royale [p. 32].

After making some general remarks upon the necessity of regarding the rocks below the base of the Silurian as composing a great system, which they call the Azoic, the authors proceed to describe each rock in detail and to note its occurrence in the region examined. They repeat many of the statements above referred to, and theorize as to the origin and the relative ages of the different rocks. Their conclusions with respect to the age of the Menominee rocks are not essentially different from those reached in the discussion of the Marquette rocks—results that have been freely described in the Marquette monograph. The most important of these conclusions relates to the igneous origin of the iron ore, which in the previous year the senior author had argued to be sedimentary. (Cf. p. 44.) Two other igneous rocks are especially noted; one is a compact, dark, hornblende rock, the other a light-colored rock resembling a member of the granite family, and designated a "feldstone."

The map which accompanies the report is intended to show approximately the distribution of the Azoic, the Paleozoic, and the igneous rocks. That portion of it which relates to the Menominee district is here reproduced without colors as fig. 2.

1855.

As its title indicates, this article is simply a catalogue of specimens.

1860.


In a somewhat general article on the “Azoic” rocks of the Upper Peninsula of Michigan, the author records the results of analyses of 15 rocks collected mainly from the Menominee drainage basin. By comparison of these analyses with those of the Laurentian rocks of Canada, the conclusion is reached that the Menominee “metamorphic rocks,” including the slates, etc., must be of a different age from the sediments which yielded the Laurentian rocks, if these are really metamorphic. The author, however, is inclined to doubt their metamorphic origin.

Igneous rocks are described as being in contact with Potsdam sandstone in the Menominee district, and the sandstone is said to have been metamorphosed at the contact. The agent producing the change is nevertheless thought not to be heat. It appears that the author would regard the “metamorphic rocks” associated with the iron ores as igneous.

1861.

WINCHELL, A. First biennial report of the progress of the geological survey of Michigan, etc. Lansing, 339 pages. 1861.

In this report the only allusion to the Menominee district is found in the statement that “On the State boundary the Azoic belt stretches from beyond Lac Vieux Desert to Chippewa Island, in the Menominee River” (p. 49). The rocks of the system are declared to be talcose, chloritic, and siliceous slates, quartz, and beds of marble.

1868.


In connection with a general discussion of the pre-Silurian rocks of North America, which are divided into the Laurentian and the Huronian systems, Credner describes briefly the geology of the Upper Peninsula of Michigan.

The Laurentian system of Michigan is made to consist of a series of gneissons, mica-schists, hornblende-schists, granites, and syenites, with a total thickness of over 20,000 feet. These rocks occur with many different variations of mineralogical composition, chloritic and talcose varieties being especially abundant. They all show their sedimentary origin in their present structure. Besides, at the Falls of the Sturgeon River there are typical conglomerates interbedded with micaceous and hornblende rocks. At this point the author observed, in the midst of the gneiss series, several hundred feet of a complex consisting of thin-bedded talcose and sandy ripple-marked schists, a thin layer of protogine-gneiss, and three beds of conglomerate, each 30 feet in thickness. These conglomerates contain pebbles of gneiss, granite, and quartzite, varying in size from that of a hazelnut to that of one’s fist, embedded in a talcose sandy groundmass. The conglomerate is described as conformably overlain by gneiss.

No eruptive rocks were discovered in the Laurentian of Michigan older than the coarse-grained and porphyritic granite that intrudes the gneiss.

The Huronian series surrounds the Laurentian rocks and lies upon them unconformably. It is characterized as a series of sediments intermediate in age between the Laurentian rocks below and the Silurian series above. It consists of a regular succession of quartzites, limestone, iron ores, chloritic and clay slates, and talc-schists, with a thickness of 18,000 feet, and, interlaminated with them, beds of diorite and aphanite. The series forms a major syncline, with a minor syncline extending into the embayments along the edge of the Laurentian areas.

In that portion of the Menominee district where the Huronian system is most regularly developed, this system comprises, in order, beginning with the oldest, 2,000 feet of quartzite; 2,000 feet of white or red limestone; 700 feet of schistose hematite, varying in composition from a ferruginous quartzite to a granular hematite; 1,200 feet of chlorite-schists; 8,000 feet of gray clay slates, interlaminated with layers of granular quartzite; 1,200 feet of chlorite-schists; 2,000 feet of coarse diorite; and a series of talcose clay slates and quartzose talc-schists.

The limestone contains thin layers of siliceous clay slate, bands of quartzite, and occasional inclusions of tremolite. On the south shore of Lake Antoine beds of coarse calcareous sandstone and of a conglomerate made up of limestone fragments in a quartzose groundmass are interlaminated with the limestone beds. In the upper horizon of the upper chlorite-schists are about 100 feet of diorites, and in certain places about 100 feet of talc-schists. The Huronian series, like the Laurentian, is devoid of eruptives.

1869.


In a fuller account of the pre-Silurian geology of the Upper Peninsula of Michigan Credner discusses the details upon which the conclusions expressed in his former paper (pp. 49-51) are based.

FIG. 3.—Geological section along the Falls of the Sturgeon River. After H. Credner, 1869.
The Laurentian gneisses and schists are reported to exist as islands projecting through the Huronian sediments. The most important Laurentian rocks are mica-gneisses, hornblende-gneisses, hornblende-schists, and granites, with a measured thickness of about 10,000 feet at the Falls of the Sturgeon River. Here the succession, beginning at the north, is as follows (see fig. 3):

(a) A great thickness of fine-grained, micaceous gray gneiss, interbanded with coarse-grained, feldspathic, red gneiss, and a few beds of hornblende-gneiss and hornblende-schist.

(b) Chlorite-gneiss, with streaks of chlorite-schist.

(c) Talc (protogine)-gneiss, through loss of talc passing into—

(d) Chlorite-gneiss containing bands of chlorite-schist.

(e) Fine-grained talc-gneiss, inclosing a mass of granular magnetite and hematite one-half foot in diameter.

(f) Fine-grained mottled schists ("Fleckschiefern"), composed of fine plates of talc and mica and very small grains of sand and of feldspar. In this are lenticular masses or thin bands of pure feldspar or of fine-grained talc-gneiss. The schist is thin bedded, and its bedding surfaces are marked by ripple marks. It occurs in four zones measuring from 8 feet to 40 feet in thickness. Between these are—

(g) Three beds of conglomerate, 15-30 feet thick, composed of a matrix similar to the "Fleckschiefern," filled with sharp-edged and rounded fragments of granite, gneiss, and quartz, varying in size between a hazelnut and a man's fist. Beds (f) and (g) dip vertically or steeply to the south.

Observations made a mile farther west show that these conglomerates are followed to the south by—

(h) Gneiss-granite, and—

(i) Fine-grained hornblende rock.

After comparing this section with several other sections observed farther north, the author summarizes concerning the Laurentian system as follows:

It consists of predominating mica-gneisses in all possible varieties that may be formed by the variations in structure and in the proportions of constituents present, of hornblende-gneisses and hornblende-schists interbedded with these, and of chlorite-gneisses and chlorite-schists associated with zones of granite, syenite, and chlorite-granite. These constitute the surface rocks over extensive areas, strike with great regularity east and west, usually dip vertically, are here and there contorted, and are intruded by younger granite.

Less broadly distributed are two series of talcose and chloritic forms. One series is composed of talc-gneiss, talcose mottled schists ("Fleckschiefern"), and conglomerates, with a sandy talcose groundmass. The other series consists of talc-chlorite-schists, with zones of crystalline, dolomitic limestone, chlorite-gneiss, chloritic hornblende rock, chlorite-schists with quartz pebbles, and foliated talc-gneiss. Between the equivalents of these as described in Canada are three limestone zones, of which the uppermost contains the *Eocyon canadense*. In the Laurentian limestones of the Upper Peninsula of Michigan I have not been so fortunate as to discover this fossil [pp. 525-526.]

The Laurentian areas are surrounded by a schist system composed of quartzite, limestones, iron-bearing rocks, and crystalline schists. Beginning at the bottom, the system consists of the following (see fig. 4):

(a) Dense, glassy, or sugary quartzite, thick bedded or thinly laminated, and possessing coatings of yellow mica in its foliation joints. Thickness, about 3,000 feet.

(b) Crystalline dolomitic limestone. Barely pure. Generally impure through admixture of silica. Its texture varies between coarse grained and very fine grained. Its color may be yellow, red, brown, or white. Its bedding is thick or thin, and the planes between the layers are sharply marked. Sometimes there are intercalated between them thin beds of argillaceous chlorite-schist and siliceous clay slate. Quartz veins penetrate the dolomite in thin and thick seams, which are more abundant in the upper portions than in the lower parts. The variation in the amount of quartz present is exhibited in the topographic differences noted. Occasionally the dolomite contains tremolite. Thickness, 3,500 feet.

(c) Hematite rock. This varies from a ferruginous quartzite or a ferruginous clay slate to a pure steel-gray dense or granular hematite (Rotheisenstein). It is thinly schistose to thick bedded, but usually occurs as a series of beds about an inch thick, in which siliceous and iron-rich bands alternate. In a few zones the jasper layers are entirely lacking and beds of iron ore 30 feet thick replace them. The ore is free from phosphorous and sulphur, but it contains everywhere traces of magnetite. Thickness of the group, 600 to 1,000 feet. The quartzite underlying the dolomite is also ferruginous in places in its upper horizons and is consequently colored red. At several points the ferruginous material is thought to be sufficiently concentrated to constitute ore bodies.

(d) Chlorite-schist, with spots and thin stains of red, ferruginous clay. Intermixed with the schist are layers of quartz 3-4 feet thick. Thickness, probably 1,000-1,500 feet.

(e) Clay slate, gray, thinly laminated and rusty brown on its schist planes; or blue, black, and very finely schistose. In the midst of the slate is a 150-foot bed of quartzite, which is very hard, granular, bluish gray, and is penetrated by veins of white glassy quartz and red orthoclase. Thickness, 8,500 feet.

(f) Dark-green chlorite-schist, often argillaceous. Thickness, 1,200-1,400 feet. In its upper horizons fine-grained and coarse-grained diores in beds varying from ten to several hundred feet are associated with the schist.

(g) Feldspathic talc-schist, light yellow or light brown in color. Thickness, 30 feet.

(h) Greenish-gray talc-schist, flecked with emerald-green spots and containing rounded quartz grains. Associated with the schist are very tenuously schistose. Thickness, 30 feet.

(i) Flesh-colored feldspathic talc-schist, containing lenticular grains of quartz. Thickness, 40 feet.

(k) Fine-grained rock consisting of a feldspathic groundmass, containing plates of talc, small reddish-brown orthoclase, and gray quartz grains. Thickness, 50 feet.

(l) Diorite rock series, 2,300 feet thick.

(m) Talcose clay slate and quartzose talc-schist, 1,500 feet thick. This series is the youngest in the Upper Peninsula of Michigan. Farther south in Wisconsin the same rock series occurs, but here it dips to the north, forming a basin with the northern schists.

The beds (g), (h), (i), and (k) seem to possess only a slight horizontal extension. They are local in their...
development. They are most fully developed at the Big Quinnesec Falls, but rapidly wedge out on both sides along their strike. At the Little Quinnesec Falls a portion of the talc-schist series is replaced by chlorite-schist and a diorite bed 12 feet thick.

The lowermost member of the Huronian, the quartzite, lies unconformably upon the gneisses. The other members of the iron-bearing series follow the quartzite conformably. In the neighborhood of Lake Antoine they are folded into two synclines, with limbs dipping very steeply toward the axes of the folds. South of the southern fold the entire iron-bearing series is repeated, with a steep southern dip, forming the north side of a third syncline with its south side in Wisconsin.

Over the Huronian rocks in many places lie patches of horizontal Potsdam sandstone and Calciferous sandstone. Two sections showing the relations of the Potsdam to the underlying rocks are given. The entire district is supposed to have been covered formerly with Paleozoic sediments, as is the district farther east at the present time, the patches on the tops of the hills being the remnants of this covering, which have thus far resisted the combined effect of weathering and the action of the ice.

In a few words, the iron-bearing series as developed in the southern part of the Upper Peninsula of Michigan is characterized as follows: A conformable series of quartzites, limestone, hematite, clay slates, chlorite-schists, and talc-schists, the last two associated with beds of diorite and having a total thickness of 20,000 feet, overlies unconformably a gneiss series, and is in turn unconformably overlain by Silurian beds. This schist complex occupies the entire distance between gneiss and granite rims in long narrow folds. Organic remains have not been discovered anywhere in the series [p. 534].

The map accompanying the article shows the general distribution of the Archean, the Huronian, and the Paleozoic formations in the Upper Peninsula. That portion covering the Menominee district is reproduced in fig. 5.


At the Big Quinnesec Falls of the Menominee River, in the upper portion of the Huronian series, as defined by Credner, is a belt of porphyroid schists, about 300 feet in thickness, lying between two beds of diabase (the diorite of former articles). The schists comprise 50 feet of slightly schistose orthoclase-porphyroid, 10 feet of feldspathic paragonite-schist, 30 feet of orthoclase-paragonite-schist, 15 feet of paragonite-schist, 15 feet of calcareous paragonite-schist, 30 feet of schistose porphyroid, 50 feet of calcareous chlorite-schist, and 100 feet of chlorite-schist. Above and below this schist series are diabase layers, which separate the porphyroids from an underlying series of chlorite-schists and an overlying series of siliceous talc-schists. The petrographical composition of the porphyroids is carefully discussed. All of the acid members consist essentially of quartz, orthoclase, and paragonite in varying proportions. Analyses of four varieties, the first two by Aarland, the third by Berghandler, and the fourth by Bornemann, resulted as follows:

After examining the theories proposed to account for these and similar rocks, the author concludes that they are not eruptives, nor are they metamorphosed sediments. On the other hand he regards them, together with all the other Huronian rocks and all the Laurentian series, as crystalline sediments, thrown down from the waters of the pre-Silurian ocean. Later they may have suffered some alteration through the influence of mineral waters.


At the time Major Brooks published his report on the Menominee district but two mines, the Breen and the Ingalls, had been opened, so that the author, in his study of the district, was compelled to rely for his data almost exclusively upon surface exposures. Many of the facts
The Menominee belt of ore-bearing rocks is separated from the more northerly belt of similar rocks by a wedge-shaped area of granite. The most easterly exposure of ore in the southern belt is at the Breen mine, in the north half of the northwest quarter, sec. 22, T. 39 N., R. 28 W. Traveling from this point toward the west, following a course running 16° north of west, several other exposures of ore are encountered before the last ore in Michigan is met with in the center of the southeast quarter, sec. 25, T. 40 N., R. 31 W. By magnetic observations the ore belt was traced across the Menominee River into Wisconsin, where its probable continuation is marked by outcrops between the Brule and the Pine rivers. Immediately north of this iron-bearing belt is a broad belt of impure marble, and north of this, in the vicinity of the Sturgeon River, are local magnetic attractions and a few iron-ore bowlders that are believed to mark the position of a second ore belt, which outcrops as a siliceous ore north of Lake Antoine. North of this second ore belt, and underlying it, is an immense bed of quartzite.

This quartzite, although believed to be geologically conformable with the ore formations, is not parallel with them, running more northerly, and dividing in T. 40 N., R. 30 W., into two and perhaps three ranges [p. 68]. In comparison with the Marquette district the Menominee district is simpler in its geological structure, and it possesses a correspondingly less varied topography. The elevations trend nearly east and west. The south iron range is the Menominee range proper—the one discussed in the present monograph. The north range is that now known as the Felch Mountain or Metropolitan range. Its geology was discussed in the Crystal Falls monograph. The southern range can be traced 15 miles in a WNW. direction through T. 39 N., R. 29 W., and T. 40 N., E. 30 W. (p. 72). Its structure is so simple that "whoever identifies the upper marble in the Menominee region has a sure key to the discovery of any ore which may exist in the vicinity" (p. 74). In Chapter IV of the report the general geology of the district is discussed, many localities of the different rock types occurring within it are mentioned, and three structural sections across the iron-bearing series are described.


The undoubted Huronian series includes, beginning with the lowermost, a light-gray, massive vitreous quartzite (I); a quartzose sandstone and conglomerate (II), that may be equivalent to the marble outcropping in secs 24 and 25 in T. 40 N., R. 30 W.; magnetic ore (III), whose existence is indicated by bowlders only; a great...
development of thin-bedded, usually light-gray marble (IV), whose upper portions contain seams of slate; the main ore-bearing formation (V), consisting of siliceous specular slate ores corresponding very nearly to the flag ores of the Marquette district; chlorite-schist (VI); a bluish and greenish slate (VII), showing indistinctly a distorted bedding with prevailing northerly dips; a bluish-gray quartzite (VIII), dipping north at 45°-75°; magnesitic schists (IX) near the Menominee River; granular diorite (X); and magnesian schists and protogine (XI). The quartzite may be simply a local bed in the clay-slate formation. Marked contortions in both the slate and the quartzite are observed, which point unmistakably to the presence of a great fold indicated in the section as a combination of an anticline with a syncline.

In the second section (fig. 7) the Huronian beds are arranged in the same sequence. First, to the north comes the quartzite (I) in a great synclinal fold; then marble (II), corresponding to the friable sandstone in the first section. Next follows a bed of siliceous red iron ore resembling the ore of formation V, but which is probably the western extension of formation III. Dr. Credner connects this bed with bed V, farther south, in a synclinal fold, but the author is inclined to regard it as an independent bed at a lower horizon than V. Above bed III is the great marble formation (IV), and then the great iron formation (V). Beds VI, VII, VIII of the first section (fig. 6) have no equivalents in the second section, their places being covered with drift. In the place where formation VI should occur, according to the author’s hypothesis of the structure, Pumpelly observed a large ledge of marble. The existence of this marble in this place leads Brooks to suppose that there may be folds in the rocks in this vicinity not revealed by his studies. Formations IX and X are the chloritic, hornblendic, and dioritic rocks exposed at the Big and Little Quinnesec Falls.

FIG. 7.—Geological section through Lake Antoine. After T. B. Brooks, 1872. Horizontal scale is approximate. Vertical scale is exaggerated. For significance of letter-symbols, etc., see Pl. III.

The description of the sections concludes the discussion of the general structure of the district. There are several further references to the ores, exposures of rocks, etc., but detailed studies of them are not recorded.

Pl. VII of the volume is a magnetic map of T. 40 N., R. 30 W., showing two lines of magnetic disturbance crossing the southern portion of the township and running in a NNW. direction. Pl. IV in the atlas accompanying the report is a geological map of the district, exhibiting the author’s theory of the structure. It is reproduced as Pl. III of this volume.

The author introduces his work on the Paleozoic rocks of the Upper Peninsula with a few preliminary remarks on the general geology of northern Michigan. Only a few of his statements refer to the Menominee district.

The existence of the upper beds of the Potsdam sandstone at the Breen mine is noted. The Menominee limestone is thought “to be connected with the slates and quartzite beds of the upper division of the Huronian series” (p. 100). The rock occurs in thick layers of a white, cream color or of a reddish tint. It is compact, subcrystalline, and very hard in composition the limestone is dolomitic, as is shown from the following analysis of a specimen from the Sturgeon River:

<table>
<thead>
<tr>
<th>Analysis of limestone from Sturgeon River.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃ ...........................................</td>
</tr>
<tr>
<td>MgCO₃ ..........................................</td>
</tr>
<tr>
<td>Hydrated oxide of Fe and Mn ..................</td>
</tr>
<tr>
<td>Silicous matter ................................</td>
</tr>
</tbody>
</table>

In many localities the limestone is cut by a dense network of coarse quartzose seams. On the Sturgeon River the seams are lacking, but the ledges are crossed in all directions by fine fissures.


In the description of this collection we find one of a pyritiferous talcose gneiss from the Falls of the Sturgeon River, one of a dolomite from sec. 11, T. 39 N., R. 29 W.; one of a hematite-schist from sec. 11, T. 39 N., R. 29 W.; one of an ochery hematite from the Breen mine; and one of a porphyritic speckled diorite from Sturgeon Falls on the Menominee.


This article contains the results of the determination of the quantity of the magnetic and of the nonmagnetic constituents in 10 specular ores from the Menominee district.

1876.


In the summer of 1874 the author and Professor Wright discovered a large granitic area south of the Menominee River. On its northern side it is bounded by micaceous and hornblende schists, the former of which are penetrated by a few small granite dikes. These schists are thought to correspond to the youngest member of the Huronian series discovered in the Marquette district, viz, bed XIX. The prevailing type of the granite is a medium-to coarse-grained gray hornblende rock that is more or less gneissic. The granite and its associated schists bear such a close resemblance to the Laurentian rocks exposed on the Sturgeon River that at first they were thought to be of the same age as these. A careful consideration of the facts, however, inclines the author to believe that the granites and schists are Huronian, and from observations made in the Penokee district, he is inclined to regard them as the youngest members of this system. He gives reasons for this conclusion, but they are based almost exclusively upon observations made in the Penokee district.

In a footnote the author calls attention to what he considers an error in Credner’s correlation of the entire Marquette series with the lower quartzite of the Menominee district. He thinks that Credner was led astray by his great overestimate of the thickness of the Menominee rocks, and by the fact that he founded his conclusions largely on a section of the Marquette series made in the neighborhood of Negaunee, where the upper members of the series are entirely lacking.

BROOKS, T. B. Classified list of the rocks observed in the Huronian series south of Lake Superior, with remarks on their abundance, transitions, and geographical distribution; also a tabular presentation of the sequence of the beds, with an hypothesis of equivalency: Am. Jour. Sci., 3d series, vol. 12, pp. 194-204. 1876.

The nomenclature of the rocks mentioned in this paper is based on the investigations of Wichmann, Wright, Rutley, Hunt, Törnebohm, and Wapler. The thickness of the Menominee beds is estimated at 12,000 feet or more. The estimate of 18,000 given by Credner is thought to be excessive. In one instance, it is stated, this geologist mistook cleavage for bedding and thus “overlooked at least one synclinal and one anticlinal fold, thus counting the same bed at least three times” (p. 195). In the scheme of sequence and frequency the beds of the Marquette and of the Menominee series are divided into 20 formations, whose approximate relative beds of the Marquette and of the Menominee series are.

195). In the scheme of sequence and frequency the beds of the Marquette and of the Menominee series are divided into 20 formations, whose approximate relative beds of the Marquette and of the Menominee series are.

In the description of the table the rocks are divided into (1) fragmental rocks, exclusive of limestone; (2)

metamorphic rocks not calcareous, subdivided into the mica-bearing series, the hornblende series, the felsitic, epidotic and garnet rocks, the hydrous magnesian series, the quartzite rocks, and the iron ore rocks; (3) calcareous rocks; and (4) igneous rocks, including a feldspathic series, a hornblende series, a pyroxenic series, and a schist magnesian series.

The fragmental rocks are conglomerates and sandstones. The metamorphic rocks are granites, gneiss, mica-schists, slates, syenites, diorites, diabasites (which Wichmann and Törnebohm regard as eruptives), hornblende-schist, anthophyllite-schist, protogine, talcose slate, chloritic argillite, serpentine, quartzite, jasper, magnetite, hematite, limonitic quartzite ores, and a number of other less important types. The calcareous rocks embrace only limestones and dolomites, and the igneous rocks only granites, a few doleritic, dioritic, and diabasic dikes, massive and schistose. The author states that “some geologists would include here a considerable portion of the bedded greenstones embraced under the metamorphic rocks” (p. 204).

1879.


In the introduction to his report the author sketches the geology of the Upper Peninsula. He divides the pre-Cambrian rocks into Laurentian and Huronian, placing all of the iron-bearing series in the lower portion of the Huronian. The outline of the geology given is not in any respect different from that given by Brooks.

The only mines opened on the Menominee range at this time were the Emmett, Breen, Vulcan, Norway, Cyclops, and Quinnesec. Each one of these is described. At the Emmett mine there are two kinds of ore—a soft specular variety, very low in phosphorus, and a brown one containing 1.29 per cent of this element. The latter lies beneath the former. At the Breen mine sandstone is found in some places underlying the ferruginous schists. This phenomenon is accounted for in the supposition that the schists formed an overhanging cliff in the Potsdam sea, in which the sands accumulated. From the structure of some of the ore in the mine the author is inclined to regard it as having been formed by the dissolving of silica from ferruginous jaspers.

1880.

Although primarily an account of the geology of the Menominee district on the west side of the Menominee River, this report includes also a description of the geology of that portion of this district which lies in Michigan.

The Menominee district in Michigan is divided, as in the author’s earlier reports, into a north and a south belt, of which only the latter concerns us. The south belt in turn is divided into a north and a south range, in the latter of which the principal mines are opened.

The rocks of the Menominee district are grouped as follows, beginning with the youngest:

<table>
<thead>
<tr>
<th>Age</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huronian</td>
<td>Sand and gravel (Champlain?), Bowdler clay (til), glacial.</td>
</tr>
<tr>
<td>Lower Silurian</td>
<td>Calcareous sand and limestone.</td>
</tr>
<tr>
<td>Keewenaw (copper series)</td>
<td>Wading.</td>
</tr>
<tr>
<td>Huronian (iron bearing)</td>
<td>Upper: Granite (eruptive?), gneiss, hornblende, actinolite, mica, chlorite, and quartz-schists, iron-ore, clay and carbonaceous slate, quartzite, and conglomerate. Middle: Clay slate and quartzite. Lower: Dolomite, iron ore, and quartzite.</td>
</tr>
<tr>
<td>Lower Laurentian (not subdivided)</td>
<td>Granite, gneiss, and crystalline schists.</td>
</tr>
</tbody>
</table>

In a second table (facing p. 437) the Huronian rocks are divided into two groups—an eruptive group, embracing diorite, gabbro, granite, and diabase, and a metamorphic group, including granite, greenstone, syenite, quartzite, limestone, and the various schists so abundant in the district. In the Menominee region the granite is declared to exist as dikes, which are said to be more frequent in the upper division of the series than in the lower divisions. The diorites and gabbros occur as conformable beds. Most of them are believed to be metamorphosed sediments. The Laurentian rocks are likewise separated into an eruptive group, which includes granite and greenstone, and a group composed of metamorphosed sediments. This latter group includes gray granites, gneisses, and schists, with the addition, probably, of granulite and quartzite.

In the first chapter of the report the author describes the Huronian and Laurentian series in some detail. The Lower Huronian includes beds I-VII. Of these, beds I, III, and IV are little known. Bed II is the great lower quartzite and bed V the great marble bed, which in the Sturgeon River district is almost as prominent as the quartzite. Overlying the marble is the great iron horizon. It is coextensive with the marble. This belt is best exposed along the line of the Chicago and Northwestern Railway. It is believed to be connected with a similar ore belt north of Lake Antoine by an anticline which pitches westward under Wisconsin.

The Middle Huronian members include beds VIII-XIII. They consist of quartzites, clay slates, and schists.

The Upper Huronian embraces mica-schists, gneisses, and granites. It comprises beds XIV-XX, represented best in the exposures on and near the Menominee River. The schists of the series dip at a high angle to the south, and apparently underlie the granite and gneiss observed south of the Big Quinnesec Falls.

In consequence of the sharply folded character of the Menominee rocks, the total thickness of the series cannot be estimated with a close degree of accuracy. Excluding the granite (bed XX), which the author is inclined to regard as eruptive, the thickness of the series is supposed to be from 10,000 to 15,000 feet. This estimate is from 4,000 to 9,000 feet less than that obtained by the measurement of the individual beds at different places within the limits of the district and the addition of the results thus obtained.

| Approximate thickness of the Huronian series in the Menominee region. |
|------------------------|------------------------|
| Bed       | Where observed          | Maximum thickness   |
| XIX       | Mississippi River       | 4,000                |
| XVIII     | Hulett River            | 1,900                |
| XVII      | Pine River              | 1,400                |
| XVI       | Sturgeon Falls          | 1,700                |
| XV        | Sturgeon Falls          | 300                  |
| XIV       | Pine River              | 800                  |
| XIII      | Fourfoot Falls          | 700                  |
| XII       | Fourfoot Falls          | 200                  |
| XI        | Fourfoot Falls          | 1,000                |
| X         | Fourfoot Falls          | 1,000                |
| IX        |                      | 300 (7)              |
| VIII-VII  | Lake Hiawatha, etc.     | 1,000 (7)            |
| VI        | South belt iron formation | 200                 |
| Y         | Marble, south belt      | 1,200                |
| IV-III    | Pine Creek              | 1,000 (7)            |
| II-I      | Secs. 7, 4, 30 N., 2B 42 W., Michigan | 1,000 (7) |
| I         | Falls of Sturgeon River | 1,000                |
|           |                         | 19,000               |

The character of the different formations met with in the Menominee district and their equivalency with the beds constituting the Marquette Huronian are exhibited in the following table. The correlation of the Menominee rocks with those of the Marquette, the Penokee, and the Sunday Lake series is so complete that the author thinks it points to the fact that the rocks of these different districts were all formed in one basin under essentially like conditions.

The Roman numerals affixed indicate to which beds of the Marquette series, as worked out by the author, the Menominee beds correspond.

<table>
<thead>
<tr>
<th>Table showing the character of the formations in the Menominee district and their equivalency with those of the Marquette district.</th>
</tr>
</thead>
<tbody>
<tr>
<td>XX. Granite, rarely gneiss, perhaps also including the rocks at Peninsee Falls.</td>
</tr>
<tr>
<td>XIX. Hornblende- and tremolite-schist, greenstone, gabbro, and diabase. The gabbros have the appearance of being eruptive.</td>
</tr>
<tr>
<td>XVII. Gneisses and schists.</td>
</tr>
<tr>
<td>XVI. Gabbros, diorite, diabase, and schistose greenstones.</td>
</tr>
<tr>
<td>XV-XVIII. Covered by drift in Menominee Valley, in vicinity of Quinnesec. At mouth of Sturgeon River covered with drift for a mile north of bed XVI. Lower portion of series consist of slates, greenstones, slates, quartzite, and mica-schist, and greenstone.</td>
</tr>
<tr>
<td>XVII. Hornblende-schist, gradating into chlorite slate.</td>
</tr>
<tr>
<td>XV. Iron ore.</td>
</tr>
<tr>
<td>IV-III. Covered.</td>
</tr>
<tr>
<td>II. Quartzite.</td>
</tr>
<tr>
<td>I. Chlorite gneiss, hornblende magnesium schists, slate conglomerates, quartzite, and perhaps diorite (may belong with Laurentian).</td>
</tr>
<tr>
<td>Xonolite with Xonolites.</td>
</tr>
</tbody>
</table>

Many details are given concerning the exposures of each of the formations, and a number of large-scale maps are published which exhibit well the distribution of these exposures in different portions of the district. The iron-ore rocks include magnetites, magnetic quartzose, and magnetic amphibole rocks; specular...
hematites and martites; siliceous, jaspery, and argillaceous hematites; and limonitic quartzose ore. Three beds have produced merchantable ore, viz, VI, XV, XIII. The magnetites and the specular hematites grade into each other through martite and the hematites into limonites, but the latter do not pass into magnetites.

The quartzites are sometimes conglomeratic and sometimes schistose.

The occurrence of conglomerates at the Falls of the Sturgeon is described in great detail. The author is now assured that they mark an unconformity between the Laurentian granites and gneisses and the Huronian beds.

The sequence of rocks beginning at the basin below the falls, i. e., between the quartzites and the granite-gneiss complex, is given as follows:

1. On the south side of this point, hence forming the north shore of the basin, is a considerable bed of a soft, fine-grained rock, apparently a chloro-argillaceous, arenaceous schist. * * * The strong cleavage planes strike N. 80° W., dip 60° S. A somewhat distinct banding had a strike N. 75° W., and vertical dip. As no rock is exposed for some distance south, this schist may have considerable thickness, and in part underlie the basin.

2. North of the schist is 8 feet in thickness of a reddish-gray quartzite.

3. A thin bed of a schistose conglomerate holding pebbles of what appear to be Laurentian granite and gneiss and white quartz, loosely bedded in a matrix resembling 1. * * *

4. Five feet of schist similar to 1.

5. Eight feet of conglomerate similar to 3.

6. Three feet of schist similar to 1, which brings us to a narrow part of the river and ends the series, for on the opposite side is Laurentian granitic gneiss. * * *

The bedding of the conglomerate and schistose beds 1 to 6, above described, was unmistakable, being N. 80° W., with vertical dip; hence essentially parallel with the great Huronian quartzite which overlies them on the south. * * *

The structural facts in connection with the strong lithological affinities which the schist-conglomerate series bear to the Huronian, and the still more important fact that the pebbles contained in the conglomerate are unmistakably Laurentian, leave no question in my own mind but that the rocks under consideration are Huronian, and form the base of the series at this point [pp. 467-468].

The dolomitic marble is quartzitic. It is associated with beds of novaculite and clay slates. The latter rocks are found also as beds inter-stratified with quartzites and actinolite-schists, as layers alternating with the ores and with magnesian schists, and as independent beds constituting a distinct formation.

The chloritic rocks are so closely related to the argillaceous ones that the author finds it difficult to draw the line between the two. On the one hand the schists appear to grade through argillo-chloritic schists into clay slates and iron ores, through quartzose varieties into quartzites and through micaceous varieties into mica-
Symbols indicate the character of rock as follows: b, hematite; e, quartzite; J, dolomite; q, greenstone; r, diorite; t, chloritic schist; u, clay slate and argillaceous schist; z, sericite-gneiss and schist; cc, gneiss, mostly biotitic; D, Laurentian.

Fig. 9.—Geological section through Sturgeon River. After T. B. Brooks, 1880. Vertical scale is approximately relative to horizontal. The Roman numerals indicate the groups or formations to which the beds are believed to belong. The letter symbols indicate the character of rock as follows: b, hematite; e, quartzite; h, sandstone; J, dolomite; q, greenstone; r, diorite; t, chloritic schist; u, clay slate and argillaceous schist; w, ferruginous clay slate; y, hydromicaceous schist; ee, conglomeratic gneiss.


Many of the rocks of the Marquette and the Menominee districts were submitted to Dr. Wichmann for microscopical study. His results are embodied in the paper which constitutes Chapter V of Brooks’s report. Among the rocks described from the Menominee district may be mentioned siliceous dolomite, quartzite, actinolite-magnetite-schist, serpentinite, diabase, quartz-diabase, mica-gneiss, sericite-gneiss, chlorite-mica-schist, calcareous mica-schist, sericite-schist, hornblende-schist, clay slates, and calcareous and ferruginous sandstones. The serpentine is said to occur in sec. 27, T. 39 N., R. 29 W.


Mica-gneiss, hornblende-gneiss, hornblende-schist, chloritic gneiss, granite, and hornblende granite are declared by Brooks to be the characteristic rocks of the Laurentian in Michigan. Hornblende-schists are said to be especially abundant in the Menominee district. By the alteration of the hornblende into chlorite, the hornblende-gneiss passes into chloritic gneiss, which also is abundant in the Menominee district. The granite is “that extreme massive variety of gneiss in which all interior evidence of bedding is obliterated by metamorphic action. I assume it to be an altered sedimentary rock, as it apparently must be from its structural relations with the other beds, the granite dikes and certain great irregular red masses not being included” (p. 662). Among the varieties of granite observed in the Menominee district, a red, massive granite, a fine-grained, white variety, and a porphyritic, gneissoid variety are most common. The hornblende granite is not found in the Menominee district.

The superposition of the beds in the Laurentian can not often be made out, owing to the complicated folding and the uniformity in the lithological character of the different rocks. Cutting these rocks are granite and greenstone, among the latter of which are some dolerites.

Fig. 10.—Structure section across the Menominee region through the west end of Lake Fumee. After T. B. Brooks, 1880.


In Brooks’s report the chief interest centers in the scientific problems presented by the Menominee iron region. In the present report Wright deals with the economic geology of the district. He describes the progress of the work at each of the mines in operation in 1879, gives analyses of their ores, and mentions some interesting details concerning the relation of the ore bodies to the surrounding rocks in some of the mines. At the Vulcan mine an ore lens occurs in the midst of jasper schists, into which the former passes without any break in the stratification. The author’s impression regarding the Menominee ore deposits is that they are of a secondary nature. He thinks that the ores “were originally the same as the jaspery specular schists in which they occur, and have been brought to their present condition by the dissolving out of the silica from the lean schists” (p. 671).

The author is inclined to the opinion that at the Saginaw mine, in the southwest quarter of sec. 4, T. 39 N., R. 29 W., there is a narrow syncline in the marble beds. If this is a fact, it points to the existence of a second ore belt to the south of the one on which the mine is situated, and it is on the eastward extension of this second belt that the Vulcan and Curry mines are opened. On the east side of the Norway property the formation is much disturbed and some of the beds are actually brecciated. At the Quinnesec mine the formation has a dip of 70° N. South of the ore belt the dip becomes steeper, then vertical, and then there is a southerly dip. From a consideration of other phenomena the author thinks there is here an indication of an anticline dipping west, and that this again indicates a second ore belt farther south.

Nearly all the ores are declared to be strictly first class. “Many of them contain quite a percentage of lime, magnesia, and alumina, all desirable elements as impurities. ** The sulphur in the majority of these ores is hardly worth considering, while the phosphorous is remarkably low” (p. 678).
In Chapter II the author describes the lithology of the beds constituting the Huronian series. He divides the rocks, on the basis of a microscopical examination, into calcareous rocks, quartzose rocks, including quartizes, mica-schists and various quartz-schists, hornblende-schists, and hornblende rocks; greenstones, including diorite and diabase; and schists and slates, including chloritic, talcose, and argillaceous varieties. The chloritic schists are closely allied to the greenstones. Their manner of association indicates that they may be metamorphic beds. The microscopical features of all the different varieties of all these rocks are briefly described. Among the greenstones one diabase is recognized, though it does not occur on the Michigan side of the river.

The map accompanying the report exhibits only the distribution of the iron formation and the greenstones. It contains no information not on Brooks's map.


This is a list of the specimens collected by the above-named authors from various portions of the Menominee district.

1881.


In his report on the geology of the Menominee district Rominger does not attempt to classify the rock beds into groups, as they were arranged in the report on the Marquette district, but describes in minute detail a large number of exposures in the district and makes a few general remarks on the succession of the beds, comparing them with the succession in the Marquette district. At the Breen and the Emmett mines, the most easterly ones on the range, the ore-bearing beds are seen to dip south, the highest beds being white and red mottled hydromica-schists. Below these is a large series of thin-bedded siliceous and argillaceous rocks impregnated with hematite and martite. Interlaminated between them are seams of nonstratified, reddish-brown ore, which "are evidently a secondary product of lixiviation of the strata by percolating water" (p. 158). In the pits of the Breen mine there is a contact of the Silurian sandstone with the nearly vertical strata. The lower ledges of the sand rock generally consist of a breccia containing angular fragments of ore and of the ore-bearing rocks. Cracks and cavities in the Huronian rocks are often filled with sandstone, so that in some places the younger sandstone appears to be beneath the older schists. After tracing the ore belt to the west, he concludes that the ore-bearing series amounts to more than 1,000 feet in thickness. North of it are ridges of limestone, and north of the limestone is a large series of "flaggy rock beds, richly impregnated with bright specular iron-oxide granules." The rocks are sandy quartzose beds that are often so richly bespangled with hematite as to resemble the specular ore of the Marquette range. North of this ore belt no rocks are met with for a quarter of a mile, when a belt of quartzite ledges is reached having a thickness of not less than 1,000 feet. The quartzite dips northerly, sometimes northwest, and sometimes northeast, and rests unconformably on the granite at the Falls of the Sturgeon River.

South of the East Vulcan mine, on the west line of sec. 13, T. 39 N., R. 29 W., crystalline diorites are apparently interbedded with slates and quartizes. They are regarded as intrusive.

The rocks west of the East Vulcan are the same in character as those east of the mine, and their relations to one another are the same. In the western of the Vulcan pits the ore beds dip only 20° to 30°, though in the eastern pits they are nearly vertical. The hills south of Lake Hanbury are formed of "a large succession of dark, blackish-colored clay slates, merging into various modifications of lighter gray-colored, pale silky-shining micaceous-quartzoze and feldspathic schists, which contain a considerable proportion of carbonate of lime, or of sparry carbonate of iron, and of numerous interlaminated belts of dark-colored granular quartizes" (p. 164).

The author agrees with Major Brooks in supposing a repetition of strata in this belt of exposures, one-fourth of a mile wide, due to plication, although he could observe "no synclinal and anticlinal position of the ledges." On the north side of the ledges the dip is clearly southward, in the center of the ledge it is vertical, and on the south side in many places a northern dip is observed, but no significance is attached to the phenomena.

North of the Curry mine it is noticed that the upper layers of the limestone formation are quartztic and sometimes brecciated. Occasionally beds of conglomerate are interbedded with the series, whose thickness here amounts to about 400 to 500 feet. In the pits of the Saginaw mine in the southwest quarter of sec. 4, T. 39 N., R. 29 W., the ore belt is inclosed in well-laminated, thin-bedded, partly siliceous, partly argilitic beds rich in iron oxides. At the Norway mine the limestone appears to be underlain by light-colored reddish, gray, or greenish slates, interbedded with which are arenaceous seams rich in mica scales.

At the Cyclops mine is another unconformable contact of the Silurian sandstone upon the Huronian schists. Here the latter rocks are hollowed out into a trough in which the sandstone is deposited.

The creek draining Lake Furmee passes through the limestone formation in sec. 35, T. 40 N., R. 30 W., exposing several successive synclinal and anticlinal arches, the measured thickness of the beds being 600 to 700 feet. The limestone here is dolomitic. It contains large belts of calcareous breccia, and is often full of quartzose seams parallel to the stratification. Certain ledges consist exclusively of flinty quartz.