CONTRIBUTIONS TO PRE-CAMBRIAN GEOLOGY

GEOLOGY OF LIMESTONE MOUNTAIN

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CONTRIBUTIONS TO THE PRE-CAMBRIAN GEOLOGY OF NORTHERN MICHIGAN AND WISCONSIN.

R. C. ALLEN AND L. P. BARRETT.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

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LETTER OF TRANSMITTAL.

To the Honorable, The Board of Geological and Biological Survey of the State of Michigan:

Gov. Woodbridge N. Ferris.
Hon. Fred L. Keeler.
Hon. Wm. J. McKone.

Gentlemen:—I have the honor to transmit herewith two manuscripts, viz., Contributions to the Pre-Cambrian Geology of Northern Michigan and Wisconsin, by R. C. Allen and L. P. Barrett, and The Geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan, by E. C. Case and W. I. Robinson, with the recommendation that they be printed and bound as Publication 18, Geological Series 15.

Very respectfully,
R. C. ALLEN,
Director.

Lansing, Michigan,
June 16, 1915.

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CONTRIBUTIONS TO THE PRE-CAMBRIAN GEOLOGY OF NORTHERN MICHIGAN AND WISCONSIN.

R. C. ALLEN AND L. P. BARRETT.

CHAPTER I.

INTRODUCTION AND ACKNOWLEDGMENTS.

R. C. ALLEN.

In 1909 the writer became interested through, studies in the Iron River district, in the problems of the pre-Cambrian terranes which occupy the great area west of the Crystal Falls and Iron River districts and south of the Marquette and Gogebic iron ranges to the state boundary line and beyond into Wisconsin. This region is a great Huronian interior into which the better known and structurally distinct "ranges" on its north and east borders coalesce and lose their identity. It is unattractive to the geologist because of the general scarcity of rock exposures, its apparent lack of structural individuality, its unimportance from the mining standpoint and the difficulty of access to many of its parts. Notwithstanding all of these it has seemed to the writer that a serious attempt should be made to acquire what information there is to be had of the geology of this region in order to reduce this geological "no man's land" to terms of general description even if nothing further could be expected to be accomplished. Although the conditions to be faced were discouraging, the labor great, and the results certain to be disproportionate to the cost in time and money in comparison with equal expenditures in more favored regions, it was finally determined to embrace the task of making a field examination of the entire area so far as it lies within the state of Michigan. Field work was prosecuted during the summers of 1910, 1911, 1912, and 1914. Fortunately for the progress of geologic knowledge of this district, a number of individuals became interested in 1911 in exploration for iron ore in northern Wisconsin adjacent to the Michigan boundary and a syndicate was formed under the direction of Dr. F. I. Carpenter to finance the geologic examination and reconnaisance exploration by drilling of a large territory extending westward from the vicinity of Lake Vieux Desert to near Butternut, Wisconsin, a distance of about 65 miles. The supervision of the geologic work, which fell to the writer, has enabled him to combine in this volume the results of private enterprise in Wisconsin with the work of the Michigan Geological Survey in Michigan.

The area which has been examined in the field contains not less than

2,000 square miles including 42 townships in Michigan and 32 townships in Wisconsin. (See Fig. 1.) Nearly all of the townships on the Michigan side were examined in the 80's by the Michigan Geological Survey but the information thus aquired was never used to any practical extent, if indeed it was understood. With the exception of the admirable notes of Prof. A. E. Seaman on certain townships none of this early work has been of much value in the present investigations beyond a saving in time in search of some of the exposures and in mapping parts of a few of the magnetic belts. These magnetic belts heretofore have not appeared on geologic maps but parts of some of them, more or less correctly located, appeared 20 to 30 years ago on commercial maps issued by land holding companies

A large area of Huronian rocks extending south of the Marquette iron range to about the line between townships 46 and 47 North, west to the Eastern sandstone and northeast in a great tongue fringing the Archean mass north of the Marquette district remains to be examined. It is planned to continue the work in this region in this and subsequent years.

In many townships in Wisconsin and in a number of those in Michigan rock outcrops are entirely wanting. The drift covered townships, and in fact the entire area, has been magnetically surveyed by the use of the dip compass and most of the magnetic belts thus located have been explored to some extent by diamond drilling, but the geology of the non-magnetic drift covered territory still remains and doubtless will remain for many years the subject of speculation and inference.

The geology of the area between the Gogebic and Iron River districts in Michigan and southward into Wisconsin is treated in the following chapters as a composite of several areas. Each of these has a well defined geologic individualism but is separated from adjacent ones by tracts in which this individualism is lost, through partial or complete lack of geologic data and disappearance of identifiable structures and stratigraphic horizons. Stated in clearer manner perhaps, there are (1) some areas in this composite in which the geologic data, while not so complete as to afford an entirely satisfactory view, are relatively ample, (2) some areas respecting which freedom of inference from meager facts alone renders possible any connected ideas of the geology, however hypothetical, and (3) some areas of which such ideas as may be advanced must rest solely upon inference.

For purposes of description it is necessary to consider these several areas separately. The discussion of each unit or separate area should, however, be approached with an understanding of its relations to adjacent areas and to those factors in the geology which have a general application to the entire region.

Let us refer for a moment to some earlier conceptions of the geology of this region. On early general geologic maps a line was drawn from the south end of Lake Gogebic southeasterly to the headwaters of the Brule river, separating the Algonkian rocks northeast of it from the supposedly Archean rocks to the southwest, forming what was then thought to be a part of the great Archean "Isle of Wisconsin." To this conception may be traced the idea, which was prevalent among explorers for iron ore as recently as 1909, that the Huronian series swing from the Iron River district northwesterly parallel to this hypothetical line and connect more or less directly with the Huronian of the Gogebic range. In 1911 Van Hise and Leith shifted this hypothetical line in general westward** and introduced an area of Archean "green schists and iron bearing formations" several miles broad extending from the south end of Gogebic lake eastward some 20 miles, bounded on the north by the South (Keweenawan) Trap Range and on the south by a narrow belt of Laurentian granite. The territory to the southwest was mapped as "undifferentiated pre-Cambrian." This classification of the rocks south and east of Gogebic Lake has not survived recent studies but the general mapping makes an advance over earlier attempts because it expresses doubt concerning the Archean age of all of the rocks included in the "undifferentiated pre-Cambrian," formerly mapped as Archean.

The assignment of an igneous complex or metamorphic schist series to the Archean in the absence of definite evidence of later age may be permissible for purposes of general mapping if qualified by an appropriate expression of doubt concerning its correlation. It sometimes happens that a correlation which was sufficiently qualified by the author as regards the points of doubt and uncertainty, through long standing and repetition in text books and other geological literature, becomes fixed in the minds of later workers as *fact* in distinction from *inference*, and to this extent acts as a bar to inquiry which otherwise would be directed toward a final solution of the uncertainties. So far as concerns the region under examination we are unable to say that rocks *older* than Huronian are present. On the other hand there is indisputable evidence that *most* of the area heretofore mapped as Archean and undifferentiated pre-Cambrian is in reality Huronian. The *granite* which has been considered as underlying most of the supposedly Archean area is intrusive into the Lower and Middle Huronian (Animikie) sediments. It constitutes a great batholith which seems to occupy many thousands of square miles in northern Wisconsin and is represented by outlying bosses in the east end of the Gogebic

**See "Geologic Map of the Lake Superior Region, with Sections," accompanying Monograph No. 52, U. S. Geological Survey, 1911.

range and southward and eastward in Michigan. There is clear evidence that this granite has displaced large masses of pre-Cambrian sediments. Nearly all of the sediments which remain have been rendered schistose, gneissose and thoroughly crystalline and in many areas they have lost all evidence of sedimentary origin. The profound exomorphic effect of granitic intrusion is apparent, particularly in the Manitowish range, in the Vieux Desert-Conover district and in the vicinity of the Wolf Lake granite north of Watersmeet. While there are other intrusives *it is apparent that this enormous intrusive granite mass when considered with its profound metamorphic effects on the pre-Cambrian sedimentaries is the great, significant, outstanding feature of the geology of this region.*

The region may be described in the most general terms as a series of highly folded belts of Huronian sedimentary rocks and, in some districts, associated contemporaneous igneous effusives, showing marked parallelism to the axis of the great Lake Superior geosyncline, and which are invaded, here and there terminated or interrupted, and in great part separated, one from another, by intrusive granite and schists of doubtful origin. The character of the folding is such as to support the inference that the Archean rocks were exposed by erosion on the anticlinal areas prior to the granitic intrusion of late Middle Huronian (Animikie) time and inasmuch as the sedimentary rocks were not entirely replaced or absorbed by the invading granite it must be presumed that the Archean also still remains in some of the territory not occupied by the sediments. That it has not been identified with certainty must be laid to total lack of exposures of contacts between the sediments of the Huronian group and the older terranes on which they were deposited, as well as a general scarcity of outcrops, and the fact that drilling and other exploratory operations have been confined to the vicinities of exposures of the sedimentaries and, in drift covered areas, the magnetic belts by which the positions of the sedimentary rocks are to considerable extent marked.

The geologic field investigations which are discussed in following chapters together with the data which has become available through exploratory drilling and underground mining have thrown much added light on the problems of correlation of the Huronian group and have furnished a body of evidence which, in our opinion, may be interpreted satisfactorily only through a revision of the present correlation of this group throughout the Lake Superior region in the United States. The following chapter is a discussion of this evidence and a revision of the correlation in the direction of a clearer and more adequate interpretation of present information. This chapter precedes the discussion of the various districts because it serves as an introduction to the general theme

and explains the correlations which have been applied throughout to the Huronian group in Michigan.

This volume is presented to the public under a full appreciation of its inadequacies. These, however, do not express lack of diligence on the part of the writer but rather the measure to which he has been able to surmount the difficulties imposed on him by the meagerness of the geologic data afforded by an exhaustion of available sources and present means. While he assumes full responsibility for the shortcomings of this presentation he desires to express his indebtedness to his assistants and to share with them any merit which it may possess. Messrs. R. E. Hore, R. W. Clark, R. E. Ascham, R. A. Smith, Geo. B. Corless, L. J. Youngs, and L. P. Barrett, geologists, have rendered valuable service in the Michigan field, Messrs. P. G. McKenna, H. J. Allen, L. P. Barrett, W. I. Robinson, J. P. Goldsberry, and Geo. B. Corliss, in Wisconsin. I am especially indebted to Messrs. McKenna and Allen who have had joint charge of both field work and drilling operations in Wisconsin, to Mr. R. W. Clark for petrographic descriptions of thin sections of the Paint slate series, and above all to Mr. L. P. Barrett who executed the field mapping of the eastern Gogebic range, made the greater part of the microscopic examinations of thin sections of the rocks in both Michigan and Wisconsin, and collaborated in the preparation of manuscript and illustrations. My indebtedness to Mr. Barrett is expressed in joint authorship of the chapters on the eastern Gogebic, Marenisco, Turtle, and Manitowish ranges, the Paint slate series and the Conover-Vieux Desert district. Thanks are due to the F. I. Carpenter syndicate for placing at our disposal all of its information relative to the geology of the area adjacent to Michigan in Northern Wisconsin without which it would be impossible to discuss the geology of that region and which has thrown much additional light on the geology of the contiguous area in Michigan.

For their bearing on the general subject of Huronian correlations I have introduced a description of the Gwinn and Little Lake areas in Marquette county and the east end of the Menominee range. The article by Dr. E. C. Case and W. I. Robinson on the geology of Limestone Mountain and vicinity has no bearing on the main theme of this volume but is appended, with apologies to the authors, for want of a better present means of publication.

Lansing, Michigan.
June 17, 1915.

CHAPTER II.

A REVISION OF THE CORRELATIONS OF THE HURONIAN GROUP OF MICHIGAN AND THE LAKE SUPERIOR REGION.

R. C. ALLEN.

The Huronian group comprises at least three unconformable series of pre-Cambrian sedimentary and associated igneous rocks separated from the younger Keweenawan series by a great unconformity and from the older Archean system by another more profound unconformity. The position of the group has been defined by the Uniied States Geological Survey and by a committee of Canadian and United States geologists* (1904) as follows:

Paleozoic			Unconformity.
	Keweenawan		
			Unconformity
		Upper	
			Unconformity
Algonkian	Huronian	Middle	
			Unconformity
		Lower	
			Unconformity
	Keewatin		
Archean			Eruptive contact
	Laurentian		

Former correlations of the Huronian group as well as the entire pre-Cambrian of the various districts of the Lake Superior region in the United States are mainly the results of detailed field study and mapping by the United States Geological Survey. These studies have been published in a series of monographs on the most important districts and a final summary covering the entire region.**

*Jour. Geol. Vol. 13, 1905, pp 89-104.

**The Penokee iron bearing series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise, Mono. 19, U. S. G. S., 1892.

The Marquette iron bearing series of Michigan, by C. R. Van Hise and W. S. Bayley, with a chapter on the Republic trough, by H. L. Smyth. Mono. 28, U. S. G. S., 1896.

The Crystal Falls iron bearing district of Michigan, by C. R. Van Hise, J. M. Clements, W. S. Bayley, and H. L. Smyth. Mono. 36, U. S. G. S., 1899.

The Mesaba iron bearing district of Minnesota, by C. K. Leith. Mono. 43, U. S. G. S., 1903.

The Vermilion iron bearing district of Minnesota, by J. M. Clements, Mono. 45, U. S. G. S., 1903.

The Menominee iron bearing district of Michigan, by W. S. Bayley, Mono. 46, U. S. G. S. 1904.

Geology of the Lake Superior region, by C. R. Van Hise and C. K. Leith, Mono. 52, U. S. G. S., 1911.

In 1892 Irving and Van Hise published their completed work on the Gogebic iron range. They believed that the Huronian group in the Gogebic district comprises *two* unconformable series, the *Upper* and the *Lower* Huronian, and that the Upper Huronian or iron bearing series is probably equivalent to the Animikie of the north shore of Lake Superior. In 1896 Van Hise, Bayley and Smyth issued a monograph on the Marquette iron range. There were found here *two* unconformable Huronian series, the *Upper* and the *Lower* Huronian, which were correlated with the *Upper* and the *Lower* Huronian of the Gogebic range, the Negaunee iron-bearing series of the Marquette range falling in the *Lower* Huronian. This is the *dual classification* which was gradually extended to cover all of the other districts of the Lake Superior region until A. E. Seaman discovered about 1902 that the "lower" Huronian of the Marquette range is divisible by a great unconformity at the base of the Ajibik quartzite. In 1904 Seaman's discovery was formally recognized by an international committee of Canadian and United States geologists which adopted the tripartite classification of the Huronian group. The Negaunee iron-bearing series was separated from the Lower Huronian to form the new Middle Huronian but the old correlations outside the Marquette range were preserved. Nine years later (1913) Allen accounted for a tripartite division of the Huronian in the Gwinn synclinorium south of the Marquette range and correlated the Gwinn iron-bearing series with the Negaunee iron-bearing series of the Marquette district*. In 1914 Allen and Barrett found that the Upper Huronian as described by Van Hise and Irving on the east end of the Gogebic range includes *two* unconformable series. This discovery, in their opinion, has finally opened the way for a revision of the correlation of the Huronian group of the Lake Superior region on the tripartite basis in which most of the difficulties and inconsistencies in the old dual classification largely disappear.

The new correlations place the Animikie series in the Middle Huronian, rather than in the Upper Huronian as in former correlations. Briefly stated, the steps in the argument are these:

(1). The Animikie (iron-bearing) series of the Gogebic range is the equivalent of the Negaunee (iron-bearing) series which constitutes the Middle Huronian of the Marquette range; therefore, the Animikie series of the other Michigan districts, Minnesota and the north shore of Lake Superior is also the equivalent of the Negaunee series, i. e., Middle Huronian.

(2). The Negaunee series of the Marquette range is unconformably overlain by the Upper Huronian. The Ironwood (Animikie) series of the Gogebic range is also overlain unconformably by a series which is

*Jour. Geol., Vol. XXII, No. 6, 1914.

unconformably beneath the Keweenawan. This series is equivalent to the Upper Huronian of the Marquette range. Therefore the Animikie series is Middle Huronian.

CORRELATION OF THE ANIMIKIE SERIES AS MIDDLE HURONIAN.

Correlation of the Ironwood series with the Negaunee series: The Ironwood (Animikie) iron-bearing series of the Gogebic range is correlated with the Negaunee (Middle Huronian) iron-bearing series of the Marquette range because (1) these series occupy identical positions in the Huronian succession of these districts, (2) are essentially similar, (3) are underlain and overlain by essentially similar series, (4) are in practically adjacent territory, (5) there is substantial evidence of their equivalence through direct connection of the Negaunee series with the Vulcan (iron-bearing) series of the Crystal Falls-Iron River district which bears the same relation to a great granite batholith and its outliers as does the Ironwood series of the Gogebic range and its correlatives in the Marenisco and Turtle ranges, and (6) there is no direct *evidence* in favor of any other correlation.

The similarity of the successions in the Gogebic and Marquette districts is striking and coupled with proximity would ordinarily determine a direct correlation of the similar series occupying identical positions in the group even were there no further evidence of identity.

CORRELATION OF THE HURONIAN GROUP IN THE GOGEBIC AND MARQUETTE DISTRICTS.

	Marquette District.	Gogebic District.
Upper Huronian	Greenstone intrusives and extrusives.	
	Clarksburg volcanics partly replacing Michigamme slate.	Graywacke and slate.
	Michigamme slate carrying iron-bearing lenses (Bijiki schist).	Ferruginous and cherty slates and jasper.
	Goodrich conglomerate-quartzite.	Conglomerate.
	—unconformity—	—unconformity—
Middle Huronian. (Animikie)		Presque Isle granite.
	(Deep erosion)	Tyler slate.
	Negaunee (iron-bearing) formation and extrusive greenstone.	Ironwood (iron-bearing) formation and extrusive greenstone.
	Siamo slate.	Palms quartzite and quartz slate.
	Ajibik quartzite.	

——unconformity——		——unconformity——
Lower Huronian.	Wewe slate.	(Deep erosion)
	Kona dolomite.	Bad River dolomite.
	Mesnard quartzite.	Sunday quartzite.
——unconformity——		——unconformity——
Archean		

The absence of slate above the Bad River dolomite should be considered with the evidence of deep erosion in middle-lower Huronian time in the Gogebic district which not only removed the slate if it was ever present there but also the entire Lower Huronian over the greater part of the range. In respect to the Middle Huronian (Animikie) of these districts the situation is reversed, i. e. the thick Tyler slate formation above the Ironwood series is to be considered with the evidence of deep erosion of the Negaunee series and the development of iron ores on the exposed surface of the iron formation (now represented by the hard ores of the upper part of the Negaunne formation) prior to the deposition of the Upper Huronian. If the correlative of the Tyler slate was ever deposited on the Negaunee formation it had been removed prior to the deposition of the Goodrich quartzite. The Middle Huronian (Animikie) of both districts is characterized by volcanic activity which continued on into and culminated in the Upper Huronian in the Marquette range but apparently terminated prior to the deposition of the Copps formation in the Gogebic range.

There is a strong resemblance of the Copps formation of the Gogebic to the Upper Huronian of the Marquette range in respect to lithology and order of succession. At the base of these series is a great conglomerate which is overlain by slate and graywacke. Neither series carries a great productive iron bearing member but both contain jasper and ferruginous beds near the base, which in the Marquette district are locally iron ore bearing.

It can not be easily doubted that if Van Hise and Irving had disovered in 1892 the great unconformity at the base of the Copps formation on the Gogebic range and Van Hise, Bayley and Smyth in 1896 the great unconformity at the base of the Ajibik quartzite on the Marquette range, the correlation of the Huronian group of the Lake Superior region would have been *tripartite* from the beginning and not *dual* for the correlations have been built up on these two type districts which were earliest studied by the U. S. Geological Survey. The Ironwood (middle) series would *then* have been correlated with the Negaunee (middle) series because, as above stated, they occupy identical positions in the Huronian succession, are essentially similar, are overlain and underlain by essentially similar series, and are in practically adjacent territory. The character of the reasoning which was employed in separating the Negaunee and Ironwood series in the correlations would have united them had present information been available. There could *then* have been little, if any, reason for assigning these two iron bearing series to different positions in the Huronian group; certainly there is no reason for such assignment today particularly as there is additional substantial evidence for the correlation of the Ironwood and the Negaunee series which will be discussed below.

CORRELATION OF THE VULCAN (IRON BEARING) SERIES WITH THE NEGAUNEE (IRON BEARING) SERIES.

Marquette and Crystal Falls Districts: The basis of correlation of the formations of the Marquette and Crystal Falls districts is afforded by an indicated actual continuity of the Negaunee and Vulcan iron bearing formations. In 1903 H. L. Smyth traced the Negaunee iron formation from the Republic trough southwest around two major anticlines to the northeast side of the great oval anticline in the northern part of the Crystal Falls district*. The relation of the Negaunee formation in this area to a persistent magnetic line may be seen on Fig. 1. From the vicinity of Michigamme Mountain, T 44 N, R 31 W, where the Negaunee formation is exposed, a magnetic line extends north through the Sholdice and Doan explorations, where the Negaunee is again exposed, and thence north, northwest, west, and southwest around the great oval anticline into section 27, T 46 N, R 33 W, where it still coincides with the position of the iron formation. A short distance beyond the latter locality the line is broken but it reappears after an interval of about two miles and passes through the Red Rock and Hemlock mines at Amasa and beyond connecting with the iron formation which has been mapped as Vulcan or Upper Huronian.

The U. S. Geological Survey in 1911[1] accepts the conclusion that the magnetic line, exposures, explorations, and drift boulders prove the practical continuity of the Negaunee formation from Michigamme Mountain for a distance of 25 miles around the great anticline to a point about a mile south of section 27, T 46 N, R 33 W, but from a point about two miles further on, through the Red Rock mine and southward, the iron formation is correlated with the Vulcan or Upper Huronian despite the facts (1) of similar position with reference to the underlying Hemlock volcanics, (2) that the strike of the magnetic line north of the Red Rock mine indicates a continuity of the "Vulcan" iron formation there with the Negaunee a little farther north, (3) and that there is no evidence whatever beyond some differ-

*See Smyth's discussion in Mono. 36, U. S. G. S., pp. 452-5.
[1]Mono. 52.

ence in degree of metamorphism to show that the iron formations in section 27, T 46 N, R 33 W, and at the Red Rock mine are not one and the same.

The reason why the iron bearing series (Vulcan) of the Crystal Falls-Iron River-Florence district was not correlated with the Negaunee by the U. S. Geological Survey is a simple one. In the Menominee range Van Hise and Bayley found that the iron bearing series is unconformably above a quartzite-dolomite succession similar to the Lower Huronian of the Marquette range and, under the dual classification, therefore Upper Huronian. Since the Negaunee formation had been correlated prior to 1904 with the *Lower* Huronian the question arose as to the position of the iron bearing series in the intervening districts. It was reasoned that (1) because the iron bearing series of the Crystal Falls district was at that time inseparable from the great Upper Huronian slate area opening out south and west from the Marquette district, and (2) because the Hanbury slate of the iron bearing series of the Menominee range seemed to have areal connections with the slates of the Florence-Crystal Falls district, therefore the iron bearing series in the latter district must be considered Upper Huronian. This conclusion was preferred notwithstanding the evidence of continuity of the Vulcan and Negaunee formations in the northern part of the Crystal Falls district and as we shall see became a source of considerable difficulty in applying the dual classification to the facts of succession in the Felch Mountain and Florence districts.

Recent developments in the Hemlock and Michigan mines at Amasa fortunately determines conclusively that the Vulcan iron formation there which has been correlated as Upper Huronian is in reality Negaunee or Middle Huronian. On the thirteenth level of the Hemlock and Michigan mines the folds in the iron formation are truncated by a heavy conglomerate and quartzite carrying fragments of the Negaunee formation of all sizes up to several feet in diameter, including small angular hard jasper fragments, rounded pebbles of chert and ore and great boulders of the iron formation. It is reported that this same conglomerate was found by drilling in similar relations to the iron formation about three miles south of Amasa and in section 36, T 44 N, R 33 W, about four miles further southward. There can be no reasonable doubt that this conglomerate-quartzite is the Goodrich formation of the Marquette range where exactly similar relations are observed.

The productive iron formation at the Hemlock mine extends with only a few unexplored breaks in drift covered country southeastward around the great anticline of Hemlock volcanics and other rocks and is believed to be almost if not quite continuous with the iron formation passing through the Hollister, Armenia, and other mines in the vicinity

of Crystal Falls. Such continuity is indicated, so far as definite information is available, by drilling, underground openings and magnetic surveys. Furthermore, the iron formation on the west and southwest sides of the great Crystal Falls oval anticline maintains the same position with reference to the underlying Hemlock volcanics that it does on the north and east sides. Therefore if the iron formation at the Red Rock and Hemlock mines is Negaunee the burden of proof rests on those who would assert in the absence of any supporting facts that the Upper-Middle Huronian unconformity cuts out the Negaunee iron formation and occupies an inferior position with reference to the Vulcan iron formation at any or all points southward. As a matter of fact this practical continuity was accepted by Clements in 1899 and by Leith and Van Hise in 1911 as shown on the maps issued in Monographs 36 and 52 of the United States Geological Survey. In fact Leith and Van Hise argue in this work that the iron formation at the Hemlock mine is *not* Negaunee *on the assumption of practical continuity with the Vulcan formation of the Crystal Falls district to the south and lack of continuity with the Negaunee formation a few miles northward.*

CORRELATION OF THE NEGAUNEE (IRON BEARING) SERIES WITH THE VULCAN (IRON BEARING) SERIES OF THE STURGEON TROUGH, FELCH MOUNTAIN DISTRICT, CALUMET TROUGH, AND MENOMINEE RANGE.

These ranges lie south of the Marquette district and east of the Iron River-Crystal Falls-Florence district and form eastward projecting tongues of the Huronian series of this great area. (See fig. 1.)

1. *Sturgeon River Syncline.* The Negaunee formation has been traced by outcrops, exploration and magnetic surveys from the Marquette Range into the north limb of the Sturgeon River syncline. From near Witch Lake, about eight miles south of Republic, the Negaunee formation is shown by the mapping of the U. S. Geological Survey to rest directly on the Archean. In the Sturgeon syncline, however, the Archean is overlain by the Randville dolomite and Sturgeon quartzite equivalent to the Kona and Mesnard of the Lower Huronian in the Marquette range. On the south limb of this syncline the iron formation reappears above the Randville dolomite and has naturally been correlated with the Negaunee of the north limb.

2. *Felch Mountain District.* The Felch Mountain district is a narrow syncline of Huronian rocks downfolded in the Archean, from one to two miles wide, trending east-west and, like the Sturgeon trough, opening out westward into the great slate area of the Crystal Falls district wherein the structure is obscured. It is separated from the

Sturgeon trough north of it by an anticline on which the Archean appears as a belt of granite about 2½ to 3 miles wide. In the Felch syncline there is an iron formation (Groveland) similar to that in the Sturgeon trough, separated from the quartzite-dolomite below by conformably underlying sedimentary schist (Felch schist) which has not been observed in the Sturgeon trough although it may be present there also. Bayley makes no mention of the Negaunee formation of the Sturgeon trough in 1899* although it was subsequently discovered through exploration and is shown on the maps of the U. S. Geological Survey published in 1911**. On these maps the iron formation in the Sturgeon trough is called Negaunee (Middle Huronian) and, in the Felch syncline, Vulcan (Upper Huronian). This seems to be a purely arbitrary classification but it fulfils the necessity under the old correlation of making the jump *somewhere* from the Negaunee of the Sturgeon trough to the Vulcan of the Menominee range. The Felch schists were regarded by the U. S. Geological Survey as Upper Huronian because they open out and seem to connect with sediments to the west which had been correlated as Upper Huronian although the area in which the connection is indicated is deeply drift covered and wholly devoid of rock exposures. But even if this connection were a fact, as it may well be, it appears *now* that it constitutes merely an added reason why the Groveland iron formation should be correlated with the Negaunee since the Crystal Falls slate-iron formation series has been shown to be more probably *Middle* rather than Upper Huronian.

As a matter of fact Smyth *did* correlate the Groveland with the Negaunee formation in 1899 but after Seaman's discovery of the unconformity at the base of the Ajibik quartzite necessitated the correlation of the Negaunee series with the *Middle* Huronian (1904) Van Hise and Leith in 1911 took the Groveland out of the *Lower* Huronian and placed it in the *Upper* Huronian. In order to make this change it was necessary to assign a highly metamorphic quartzite-mica schist series which is unconformably *above* the Groveland to the Keweenawan or Paleozoic for the reason that no place was then left for it in the Huronian group. Smyth was obviously right in correlating the Groveland with the Negaunee formation. The quartzite-mica schist series above the Groveland bears no resemblance to the Keweenawan or Paleozoic. It is Huronian and we believe, should be correlated with the Copps, part of the Michigamme and the Princeton series. The quartzite which is unconformably above the slate-iron formation series (Animikie) of the Florence district is similarly correlated.

3. *Calumet Trough.* In the Calumet trough, about four miles south

*Monograph 36, U. S. Geological Survey.
**Monograph 52.

of the Felch syncline, the situation is practically identical with that in the Felch Mountain district, and the same arguments for revision of the correlation apply here as in the Felch district. In other words, the iron formation now assigned to the Upper Huronian is believed to be really an equivalent to the Negaunee of the Middle Huronian. Rocks similar to the quartzite-mica schist series of the Felch syncline are exposed at the old Hancock exploration in T 41 N, R 27 W, and in at least one or two places near the southern edge of the Calumet trough. Each of the three Huronian series seems to be represented here exactly as in the Felch syncline a few miles north.

4. *Menominee Range.* The general similarity of the iron bearing series of the Menominee district with that in the Sturgeon, Felch, and Calumet troughs and in turn with certain phases of the Negaunee formation of the Marquette district, its similarity in relation to the underlying Lower Huronian and its areal connections with the great slate-iron formation series of the Florence-Crystal Falls district determine that the Vulcan of the Menominee range is probably of Negaunee age, that if the iron formation in the districts intermediate between the Menominee and the Marquette ranges is Negaunee, there is no basis on lithological, structural, or other grounds for assigning the iron formation of the Menominee range to any horizon other than Negaunee, i. e., Middle Huronian.

Leith has described a remnant of cherty quartzite, of a maximum thickness of 70 feet, lying apparently unconformably between the Randville dolomite below and the Traders member of the Upper Menominee series above in the vicinity of Norway* but he places no emphasis on it so far as concerns its significance in the correlations. This formation according to the more recent opinion of Dr. Leith** is a remnant of regolith unremoved by erosion in Lower-Middle Huronian time.

CORRELATION OF THE IRONWOOD SERIES (ANIMIKIE) OF THE GOGEBIC RANGE WITH THE VULCAN (MIDDLE HURONIAN) SERIES OF THE CRYSTAL FALLS-IRON RIVER-FLORENCE-MENOMINEE DISTRICT ON THE BASIS OF SIMILAR RELATIONS TO INTRUSIVE GRANITE.

Area southeast of the Gogebic range including Marenisco, Turtle, Manitowish, Vieux Desert, Conover, Iron River, Crystal Falls, and Menominee Districts. Probably the most striking feature of the Middle Huronian (Animikie) of these districts is the general prevalence of intrusive granite. Heretofore these granites have been variously correlated, from

*Monograph 52, U. S. Geological Survey, pp. 234-5.
**As expressed in conversation with the writer.

Laurentian in the Gogebic, northern Wisconsin, and Menominee districts, through the Upper Huronian in the Crystal Falls district to Keweenawan in the Florence-Menominee and northeastern Wisconsin areas.

In the Menominee district Bayley found that the granite south of the Menominee River intrudes a series of basic volcanics called the Quinnesec schist which he correlated erroneously with the Keewatin. Although it was realized that the correlation of the Quinnesec schist as Keewatin introduced a conception of structure quite out of accord with natural inferences on the basis of the facts, it remained for Corey and Bowen, working under the direction of Van Hise and Leith, in 1905* and Hotchkiss in 1910** to show conclusively that the Quinnesec schist is partly intrusive into but in greater part interbedded with the upper part of the Upper Huronian†, i.e. Animikie†.

Inasmuch as the granite was thus proven to be the youngest rock in these districts, and the youngest pre-Cambrian sediments had been correlated with the *Upper* Huronian, Leith and Van Hise in 1911†† correlated the granite with the Keweenawan and extended the boundaries south and east to include several thousand square miles of acid intrusives in north central Wisconsin which had been mapped and described by Weidman in 1905†††.

It is interesting to note here that Brooks and Wright had correctly interpreted these relations as early as 1876, although they did not, at that time at least, comprehend the great mass of the intrusive granite. To quote from Brooks:"In the summer of 1874 Chas. E. Wright and myself exploring the country west and south of the Menominee River about 90 miles from its mouth, under the auspices of the Wisconsin Geological Survey, observed a large granite area, the north edge of which was bounded by dark colored hornblendic and micaceous schists of Huronian age, which I have since concluded are equivalents of the youngest member of that series yet observed in the Marquette iron region . . . . . The lithologic character of this wide granite belt bore so much resemblance to the Laurentian rocks, which are extensively developed on the waters of the Sturgeon River in Michigan, 10 to 20 miles to the northeast, that we were disposed at the time to believe that some phenomena of folding or faulting had brought rocks belonging to that system to the surface in an unexpected quarter. Professor Pumpelly and myself, several years previously had observed, farther to the north and west, similar granite rocks crossing the Michigamme and Paint rivers (branches of the

*Unpublished notes of field work done in 1905 by G. W. Corey and C. F. Bowen.
**Unpublished field notes of W. O. Hotchkiss.
†Middle Huronian of this article.
††Mono. 52, U. S. G. S.
†††The Geology of North Central Wisconsin, by S. Weidman, Bull. Wis. Geol. & Nat. Hist. Survey No. 16, 1907.

Menominee) presenting similar puzzling relations with beds known to be Huronian, and younger as well as lithologically different from any rock then known to be of that period.

"A careful consideration of all of the facts to be observed in the Menominee region confirms me in this hypothesis, ..."*. The conclusion of Brooks is confirmed by the work of Hotchkiss in the Florence district of Wisconsin in 1910†.

In 1911-14 the writer and assistants, through field mapping and diamond drilling, traced what appears to be this same granite from the Iron River district westward through the Animikie series of the Vieux Desert-Conover district and Manitowish, Turtle, and Marenisco ranges, in all of which it is in intrusive relation with the sediments, and connected it with the "eastern Laurentian area" of Van Hise and Irving on the eastern Gogebic range which was considered by these geologists to form a part of the Archean basement complex whereas it actually intrudes the Lower and Middle Huronian (Animikie) series and is unconformably overlain only by the Upper Huronian (Copps) series. *Thus the great granite batholith of Northern Wisconsin has been fairly demonstrated to be not only in intrusive relations with the Animikie sediments over several thousands of square miles but also to be overlain unconformably by a pre-Cambrian series which is unconformably below the Keweenawan.*

Inasmuch as the Vulcan (Animikie) series of the Crystal Falls, Iron River, Menominee, Florence and other Michigan districts has been shown to be very probably equivalent to the Negaunee series of the Marquette range and the Ironwood series of the Gogebic range, the age of this great granite batholith and its outliers may be considered as late Middle Huronian.

GENERAL REMARKS ON THE CORRELATION OF THE ANIMIKIE SERIES WITH THE MIDDLE HURONIAN.

The correlation of the Animikie series with the Middle Huronian eliminates what would otherwise be the necessity of assuming a *fourth* Huronian series of which the Copps formation of the Gogebic range would be the sole representative. The practical identity of the Huronian succession of the Gogebic and Marquette ranges together with the marked similarity of the Copps formation and the Upper Huronian of the Marquette and Gwinn districts is an adequate basis for moving the Animikie of the Michigan and other Huronian districts downward into the Middle Huronian, particularly as this correlation, as we have seen, eliminates what would otherwise be a further necessity of including the uppermost series of metamorphic sediments in the Felch, Cal-

*On the youngest Huronian rocks south of Lake Superior and the age of the copper bearing series, by T. B. Brooks. Am. Jour. Sci. Vol. II, 1876, pp. 206-7.

†Unpublished manuscript.

umet, and Florence districts in the Keweenawan or the Paleozoic where they obviously do not belong.

The anomalous position in the correlations of the great Negaunee iron bearing series has been unsatisfactory to a great many students of the pre-Cambrian for many years.[1] We now have a firm basis for the correlation of the Negaunee series with the great productive iron bearing series of the Animikie of all of the other districts of the Lake Superior region and are able to recognize the consideration that the unique conditions which resulted in the deposition of the great Huronian iron formations were regional rather than local and should be correlated in time. While it is true that the names now used have come to have well understood significance because of long usage, it can not be held that this is a valid argument for the retention of a classification which no longer correctly interprets the facts of present knowledge.

[1]See Geological section of Michigan, A. C. Lane and A. E. Seaman, Mich. Geol. Survey, Annual Report, 1908, pp. 23-30. Lane and Seaman correlate the Animikie iron-bearing series of Michigan throughout with the Negaunee iron-bearing series (Middle Huronian) of the Marquette range.

CHAPTER III.

A REVISION OF THE SEQUENCE AND STRUCTURE OF THE PRE-KEWEENAWAN FORMATIONS OF THE EASTERN GOGEBIC IRON RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTORY STATEMENT.

In this chapter there is presented the results of recent studies of the geology of the Gogebic iron range from T 47 N, R 45 W, east to Gogebic lake, a distance of 15 miles.

Former interpretations of the geology of the Gogebic iron range are based almost entirely on early investigations of the United States Geological Survey*. Prior to 1914 four years of study of the pre-Cambrian of the region south and east of Gogebic Lake to the Iron River district, including 38 townships adjacent in northern Wisconsin, by the senior writer and his assistants had failed to establish a satisfactory basis of correlation with the rocks of the Gogebic range. (Fig. 1.) Inasmuch as recent drilling for iron ore has supplied important information, unavailable to earlier workers in this field, it was thought that a field study of the eastern Gogebic iron range would probably alter former interpretations of the geology and furnish a better basis of correlation with the pre-Cambrian terranes of adjacent territory and the Lake Superior region. The results of our studies are more satisfactory than we had anticipated and we believe are of considerable importance to the progress of pre-Cambrian geology.

We acknowledge our indebtedness to Dr. C. R. Van Hise for placing in our hands his early field notes and plats, to Dr. C. K. Leith for helpful suggestions in field conference, to Mr. Robert Selden Rose of Marquette, Messrs. Luther Brewer and George Rupp of Ironwood, and the Presque Isle Mining Company for records of drilling and underground exploration.

SUMMARY OF THE GEOLOGY BASED ON EARLIER WORK.

Van Hise and Leith have recently presented the views of the United States Geological Survey† which may be briefly summarized.

*Monograph 19, United States Geological Survey, C. R. Van Hise and R. D. Irving.
†Monograph 52, United States Geological Survey.

The Huronian rests on the Archean with profound unconformity and is represented by two unconformable sedimentary series, the Upper and the Lower Huronian, which are in approximate structural parallelism and dip steeply northward beneath the Keweenawan.

The Archean comprises a green schist series (Keewatin) intruded by granite (Laurentian).

The Lower Huronian has two members, a basal quartzite (Sunday) and an upper cherty dolomite (Bad River).

The geology of the "Upper Huronian (Animikie) Group of the Eastern Area" is summarized in the following words:

"In the eastern part of the district—that is, from about 6 miles east of Sunday Lake to Lake Gogebic, the Upper Huronian rocks have an exceptional character. In the larger part of the district the conditions were those of quiet sedimentation but in the eastern area throughout the greater part of the Upper Huronian there was continuous volcanic action. In consequence the rocks are lava flows, volcanic tuffs, conglomerates, agglomerates, and slates, with all sorts of gradations, just such as one would expect if a volcano rose in a sea and volcanic action continued for a great period. Naturally in this area it is not possible to map any continuous sedimentary belts. The dominant rocks are greenstone conglomerates and lavas and massive eruptives. The uppermost formation for the extreme eastern part of the area is ferruginous slate. This ferruginous slate, though dominantly clastic, contains narrow bands of non-clastic sediments such as chert, cherty ferro-dolomite, ferro-dolomitic chert. *It is believed that the ferruginous slate is probably at the same horizon as the Ironwood formation to the west and that its dominant fragmental character is due to the presence in this area of one or more volcanic mountains which arose above the water and upon which the waves were at work after the close of the period of active volcanic outbreaks.*"†

SUMMARY OF THE WRITERS' CONCLUSIONS.

The writers' most important conclusions, insofar as they differ from those of the earlier writers as summarized above, may be stated briefly as follows:

1. Huronian. *There are three unconformable sedimentary groups in the Huronian series.* The formations heretofore included in the Upper Huronian group are divisible into two groups separated by an unconformity of the first magnitude. For the superior group we propose the name Copps in recognition of the important exposures of its basal horizons near the old Copps mine.

2. Archean. *The granite heretofore described as Laurentian not only intrudes the Keewatin but also cuts across two great unconformities into the Animikie group* (Middle Huronian).

3. *The unconformity between the Copps formation and the Middle Huronian (Animikie) group is one of great angular and erosional magnitude* and is of greater importance to this district, measured by the usual criteria for evaluation of breaks in pre-Cambrian sedimentary successions, than either the unconformity separating the Keweenawan and Huronian or the one separating the Animikie and Lower Huronian.

For convenience of reference and greater clearness in the discussions which follow we introduce the successions of the United States Geological Survey and the writers' in parallel columns.

†Writers' italics.

CORRELATION TABLES. GOGEBIC IRON RANGE.

	By U. S. Geological Survey, 1911.		By Michigan Geological Survey, 1914	
	West of center of T 47 N, R 44 W.	East of T 47 N, R 45 W.		East of T 47 N, R 45 W.
Quaternary System Pleistocene series	Glacial deposits	Glacial deposits		Glacial deposits
Cambrian System		Unconformity Lake Superior sandstones		Unconformity Lake Superior sandstone (doubtful)
Algonkian System Keweenawan series	Unconformity Gabbro, diabase, basic lavas, conglomerate, etc.	Unconformity Gabbro, diabase, basic lavas, and interbedded sandstone and conglomerate		Unconformity Gabbro, diabase, basic lavas, interbedded sandstone and conglomerate, and basal conglomerate.
Huronian Series Upper Huronian (Animikie)	Unconformity Greenstone intrusives and extrusives. Tyler slate Ironwood formation (iron bearing) Palms formation	Unconformity Extrusive and intrusive greenstone. Palms and Ironwood formations represented by ferruginous slate, graywacke and quartzite	Upper Huronian	Unconformity Copps formation. Ferruginous slate, graywacke, chert, and basal conglomerate.
Middle Huronian			Middle Huronian (Animikie)	Unconformity Granite Extrusive and intrusive greenstones Ironwood formation (iron bearing) Palms formation
Lower Huronian	Unconformity Bad River limestone Sunday quartzite	Unconformity Bad River limestone Sunday quartzite		Unconformity Bad River limestone Sunday quartzite
Archean System Laurentian series	Unconformity Granite & granitoid gneiss	Unconformity Granite and granitoid gneiss		Unconformity
Keewatin series	Greenstone and greenschist	Greenstone and greenschist		Greenschist

ARCHEAN SYSTEM.

The rocks of Archean age include only the fine grained chlorite schists in the west half of T 47 N, R 44 W, which are unconformably beneath the Sunday quartzite of the Lower Huronian. In the reports of the U. S. Geological Survey* the hornblende-mica schists and gneisses lying south of the Huronian sediments in T 47 N, R 43 W, (Fig. 2) are included in the Keewatin and the extensive area of acid intrusives, to which the name Presque Isle granite is here given, is placed in the Laurentian. It will be shown later that the Presque Isle granite intrudes the Middle Huronian (Animikie) and that the schists in T 47 N, R 43 W, heretofore correlated with the Keewatin, are metamorphic phases of the Palms formation. The Presque Isle granite may include Laurentian rocks but it seems clear that the greater part of it is of late Animikie age. Farther west, however, the base of the Huronian series rests unconformably upon Laurentian granite.

ALGONKIAN SYSTEM.

HURONIAN GROUP.

Lower Huronian Series.

The Lower Huronian comprises two formations, viz, the Sunday quartzite and the Bad River limestone, exposures of which are confined to a prominent hill in the south half of sections 17 and 18, T 47 N, R 44 W. The persistence of the Lower Huronian east of section 17 is problematical (See map, Fig. 2 A and Fig. 2 B).

SUNDAY QUARTZITE.

Lithology. The Sunday quartzite is made up of a basal conglomerate from a few inches to ten feet thick overlain by about 150 feet of quartzite. The conglomerate contains pebbles of vein quartz, greenstone, and granite, fragments of red feldspar, and occasional pebbles of gray cherty siliceous material. The vein quartz pebbles are the most abundant. The matrix of the conglomerate is composed mainly of particles of chlorite, feldspar and quartz.

The Sunday quartzite is a rather coarse grained aggregate of rounded grains of quartz and feldspar, the latter very subordinate in quantity. Near the base it has a greenish tinge on fresh fracture but grades rapidly up into a grayish white or slightly pinkish rock. The formation dips north at angles of 30° to 40°.

Relations to Adjacent Rocks. The Sunday Quartzite is separated

*Monographs Nos. 19 and 52.

from the underlying Keewatin greenschists by a great unconformity. The actual contact between the two formations (see Fig. 2) is exposed for a distance of 50 paces at the base of the prominent bluff near the north line of the SW$\frac{1}{4}$ of SE$\frac{1}{4}$ of section 18. The green schist at this locality has a nearly N-S strike and a vertical dip. It is abruptly overlain by the southeasterly striking and northerly dipping quartzite. It is apparent from these relations that the greenstone had been folded, metamorphosed, uplifted, eroded and base leveled prior to the deposition of the Lower Huronian.

The Sunday quartzite grades upward into the Bad River limestone.

BAD RIVER LIMESTONE.

Lithology. This formation is described by Van Hise and Leith as follows:** "The formation is called a limestone because that is the predominant rock. The limestone is heavily magnesian and in places approaches a dolomite. It commonly bears silicates of which tremolite is the most abundant, but chlorite and sericite are not uncommon. The rock is very siliceous. The coarsest varieties are quartz but chert is more common. In many places the silica is closely intermingled with the dolomite. In other places it occurs in bands varying from a fraction of an inch to much greater width, and in one place a band of siliceous material 45 or 50 feet wide was observed. Thus the chert and limestone are intermingled and interstratified. The cherty limestone is a water deposited sediment. Whether the original carbonate was of chemical or organic origin we have no definite evidence, but there is no more reason to suppose that life was not concerned in the deposition of this cherty limestone than of those of later age.

"The Bad River limestone has been much metamorphosed since its deposition. During its metamorphism the silica recrystalized. It was concentrated into bands. It was arranged into veinlike forms. During these changes a part of the silica may have been introduced from extraneous sources or at least from parts of the formation now removed by erosion. The abundant tremolite is evidence that the metamorphism took place under deep seated conditions when the silica united with the calcium and magnesium to form silicates, the carbon dioxide being released at the same time. This is an anamorphic change that took place with a decrease of volume."

Middle Huronian (Animikie).

Introductory statement. The Upper Huronian is represented on the east end of the range by the Palms quartzite and the Ironwood iron

**Monograph 52, U. S. Geological Survey.

BASAL CONGLOMERATE OF THE SUNDAY QUARTZITE IN CONTACT WITH KEEWATIN GREEN SCHIST IN THE SW¼ OF THE SE¼ OF SECTION 18, T. 47 N., R. 44 W.

bearing formations, volcanic agglomerates, breccias and flows and intrusive granite (Presque Isle) and greenstone.

The Palms formation is composed mainly of quartzite, quartz slate and graywacke; the Ironwood formation is mainly non-clastic and is composed of ferruginous chert, cherty iron carbonate, iron ore and locally amphibole-magnetite rocks. Slate becomes increasingly important in the Ironwood formation east of Sunday Lake.

Throughout the central part of the Gogebic range the Middle Huronian includes a third formation, the Tyler slate, a pelite or mud formation of immense thickness. It is cut out east of Sunday Lake by erosion and the great Wakefield thrust fault and apparently does not appear on the east end of the range.

In the maps accompanying the reports of the U. S. Geological Survey the Palms and Ironwood formations are carried as cartographic units eastward to section 22, T 47 N, R 44 W, where, with the exception of isolated patches of iron formation which are correlated with the Ironwood, a new unit representing ferruginous slates is introduced to carry their combined stratigraphic horizons to the east extremity of the range. As a result of the field work of the Michigan Geological Survey the Palms and Ironwood formations have been traced in typical development as far east as section 23, T 47 N, R 43 W, where they disappear, *not through lithologic gradation* into ferruginous slate but by *abrupt truncation by a superior unconformable series.* The major portion of the ferruginous slate belt of the U. S. Geological Survey is unconformably above the Palms and Ironwood formations of the Animikie group and has been separated in mapping and named Copps formation in recognition of the important exposures in the vicinity of the old Copps mine. The essential changes in mapping and interpretation may be seen by a comparison of the map accompanying this report with those found in the reports of the U. S. Geological Survey*.

Relations to adjacent formations. The Lower Huronian is overlain unconformably by the Palms formation of the Middle Huronian. The evidence of this relationship does not refer to any one locality but is based largely on general field relations, and particularly upon a lack of continuity of the Lower Huronian formations which is believed to be due to erosion preceding the deposition of the Upper Huronian. Van Hise and Leith** summarize the evidence as follows: "The fact that where the belt of conglomerate at the base of the Palms lies above the Bad River limestone it bears much detritus from that limestone shows that the limestone after deposition became indurated and was eroded before Palms time. In general, the strikes and dips of the two

*Monographs 19 and 52.
**Monograph 52, U. S. G. S., page 230.

formations are approximately parallel, as are those of correlated formations in the Menominee district, but it is plain that the erosion was sufficient to remove the major portion of the Bad River limestone and also any later formations that may have been deposited in the Lower Huronian. The lack of marked discordance in the bedding of the Bad River limestone and the Palms formation is no evidence that the time gap between the two was not long enough to have produced a pronounced discordance elsewhere, for the Penokee district at this time may have been distant from areas of important folding and thrusting which elsewhere may have occurred."

PALMS FORMATION.

Distribution and exposures. The Palms formation is exposed in a few outcrops and many test pits south of the iron formation in sections 17, 18 and 21, T 47 N, R 44 W. East of section 21 for a distance of about three and one-half miles there are no exposures. Near the center of section 30, T 47 N, R 43 W, and thence northeast to the NE$\frac{1}{4}$ of NW$\frac{1}{4}$ of section 23, exposures in outcrops and test pits are fairly plentiful. The outcrops and test pits along the N-S quarter-line through the south half of section 21 and the north half of section 28 afford an excellent cross section for study, especially of the progressive metamorphism of this formation toward the contact with the Presque Isle granite. Near the center of the NE $\frac{1}{4}$ of section 21 the upper quartzite horizon is exposed in outcrops and test pits adjacent to the iron formation. Recent drilling in sections 21 and 22 has served to define more accurately the position of the Palms formation and in addition has furnished data without which it would be impossible to obtain a clear idea of its structure in that vicinity.

Lithology. Throughout the Gogebic range the Palms formation maintains a characteristic succession of members.

The base is nearly everywhere marked by a thin conglomerate one to three feet thick. Where the formation is in contact with the Archean the pebbles are granite, gneiss, and greenschist, but where the underlying formation is the Bad River limestone the conglomerate also include fragments of chert and limestone. In a few localities the conglomerate contains scattered jasper fragments.

The central part of the formation is a graywacke quartz slate member from 350 to 500 feet thick. This member comprises many facies, including fine grained slate, novaculite, graywacke, and quartz slate. In the upper horizons thin layers of quartzite become increasingly important and mark the change in conditions of sedimentation leading to the deposition of the upper quartzite member.

The upper part of the Palms formation is a massive, light colored vitreous quartzite from 50 to 150 feet thick, of very uniform texture and composition. Near the contact with the overlying iron formation the quartzite is stained brownish red with hematite.

From the west line of T 47 N, R 44 W, east to section 22 the Palms formation maintains its general character and merits no special description. The test pits and outcrops indicate graywacke and quartz slate overlain by quartzite. Its thickness in this locality is probably in the neighborhood of 500 to 600 feet.

Metamorphic Phases of the Palms Formation. In T 47 N, R 43 W, the Palms formation possesses an exceptional character and merits detailed treatment. The upper quartzite is persistent and easily recognized but the base of the formation grades irregularly into micaceous and hornblendic schists toward the contact with the Presque Isle granite.

In the south half of section 21 and the north half of section 28 the upper quartzite member is exposed in numerous outcrops, especially near the center of section 21 immediately south of pits in iron formation. The upper horizon is massive, grayish white to pink and even grained but near the contact with the Ironwood formation it is dark red. Beneath the massive upper horizon thin beds of slate become increasingly important. About 250 paces south of the center of section 21 there are abundant exposures consisting of alternate layers of quartzite and slate averaging from one to four inches thick. The rock is highly contorted, the axial planes of the minor folds dipping southward. The slate bands exhibit well developed schistosity also dipping south. The formation as a whole appears to be inclined steeply northward. The quartzite bands are microscopically very similar to those from the upper member although there is a slight increase in the content of feldspathic material. Quartz in stringers and veins is a conspicuous feature of the rock in these exposures.

Southward for a distance of about 500 paces outcrops are lacking, but the rocks are well exposed in exploration pits. The dumps of these pits contain purple and gray slate and graywacke. In some of them thin seams of quartzite are indicated. The coarser layers are composed of grains of quartz, feldspar, and lesser amounts of chert and biotite imbedded in a fine grained matrix of smaller fragments of the same materials and a large amount of sericite and chlorite. The more slaty phases are composed of a felty mass of chlorite, sericite and fine grained limpid material, probably quartz and feldspar. A clastic texture is indicated only by the presence of widely scattered large rounded grains of quartz or feldspar. The accessory minerals are ferrite, epidote, rutile, and rarely magnetite and tourmaline. Quartz is the most abundant mineral but feldspar is common, including orthoclase, plagioclase, and microcline. The clastic biotite is more often visible

macroscopically than microscopically. It occurs as flat rounded flakes on the cleavage surfaces of the slate to which it imparts a characteristic shimmer. In general it may be stated that these rocks do not differ in mineral composition or texture from similar exposures of the Palms formation in other parts of the range. Their composition indicates derivation predominantly from acid granite. The fragmental chert is probably derived from the Bad River formation.

Southward from about 250 paces north of the south $\frac{1}{4}$ post of section 21 the rocks gradually lose their sedimentary textures and become hornblendic and micaceous. This change is accompanied by an increasing abundance of secondary quartz, the occurrence of pegmatite veins and sudden change of strike and dip. Near the Presque Isle granite the rock becomes a hornblende gneiss or mica schist cut by numerous veins of pegmatitic and granitic material. Many of these veins are parallel to the gneissosity while others cut across it indifferently.

Under the microscope the change is first manifest by the appearance of secondary biotite, small scattered needles of hornblende, or both, and by the increase in importance of the epidote and titanium minerals. The finer grained bands are recrystalline but the coarser bands retain in part their sedimentary appearance in the rounded outlines of the larger grains. A short distance farther south the hornblende becomes increasingly more important and is easily visible in hand specimen while the quartz and feldspar interlock in a crystalline aggregate in which all suggestion of sedimentary texture is obliterated. The number of secondary minerals increases and finally includes epidote, leucoxine, ferrite, sericite, chlorite, pyrite, tourmaline, apatite and rutile.

On maps of the U. S. Geological Survey these hornblende and mica schists and gneisses are included in the Keewatin. It has been shown, however, that there are all possible gradations between them and the graywackes and slates readily recognizable as belonging to the Palms. On the N-S quarterline at the locality just described exposures are exceptionally numerous and the gradational change from graywacke to hornblende gneiss is unmistakable. This exceptional metamorphism of the Palms formation is believed to be the result of intrusion by the Presque Isle granite. Further evidence of granitic intrusion will be presented later.

Exposures of the Palms formation occur at a number of other localities in T 47 N, R 43 W, but nowhere else is the section so complete nor can the progressive metamorphism of the Palms formation in approaching the contact with the Presque Isle granite be so well observed. The rocks at these localities are similar to those in the typical section just described.

It is not possible to determine accurately the thickness of the Palms

formation in T 47 N, R 43 W, on account of intense folding and intrusion. It may be thicker here than elsewhere, but the apparent increase in thickness is probably to be accounted for by repetition of beds by folding.

Relations to adjacent formations. The relations between the Palms formation and the Bad River limestone of the Lower Huronian have already been discussed.

The Presque Isle granite, formerly considered as Laurentian, intrudes the Palms. A discussion of this relationship will be given in connection with a description of the Animikie intrusives.

The Palms formation is conformably overlain by the Ironwood formation. In places the base of the latter is marked by a thin conglomerate which, however, is not believed to mark a break in sedimentation of any great significance. The change from fragmental sedimentation of Palms time to the non-fragmental deposition of Ironwood time was relatively sudden although there appears to be some evidence of the approach of this change in the cherty matrix of portions of the upper horizons of the Palms quartzite.

IRONWOOD FORMATION.

Distribution and exposures. In the latest maps of the U. S. Geological Survey* the Ironwood formation is carried as a continuous formation as far east as the northwest corner of section 22, T 47 N, R 44 W. East of this locality small patches of iron formation are indicated in the NW$\frac{1}{4}$ of section 15, near the W$\frac{1}{4}$ post of section 14, near the W$\frac{1}{4}$ post of section 23, and in the SW$\frac{1}{4}$ of section 25, T 47 N, R 44 W. In T 47 N, R 43 W, iron formation is noted in the east portion of section 30, S half of section 20, NE$\frac{1}{4}$ of section 21, and in the NE$\frac{1}{4}$ of section 22.

The recent work of the Michigan Geological Survey warrants a number of important changes in the mapping of this formation. On the accompanying map (fig. 2) we have shown the areas known to be underlain by iron formation and have indicated probabilities of extension in territory devoid of conclusive evidence.

With regard to the patches of iron formation located on the U. S. Geological Survey maps in sections 14 and 15, T 47 N, R 44 W, it may be stated that the evidence in section 15 consists of a group of pits ledged in black slate. The dumps of these pits contain also a small amount of magnetic slate and ferruginous chert. The exact age of these rocks is problematical but on the basis of their position and lithologic character it is probable that they belong to the Copps (post-Animikie) formation rather than to Ironwood. We were unable to

*Monograph 52, U. S. Geological Survey.

find any field evidence of the existence of iron formation in the east half of section 14, and careful search in the original field books of the U. S. Geological Survey failed to find any evidence of the existence of pits or outcrops of iron formation or associated rocks. It is therefore probable that the patch of iron formation in this section is to be attributed to an error in printing the map.

The Ironwood formation does not appear east of the NE$\frac{1}{4}$ of section 23, T 47 N, R 43 W, where it was truncated by erosion preceding the deposition of the Copps formation.

Lithology. The Ironwood formation carries the iron ore bodies of the Gogebic range. In the central and western parts of the district it is made up of the following main varieties of rocks: (1) ferruginous chert, (2) ferruginous slate, (3) slaty and commonly cherty iron carbonate, (4) actinolitic and magnetitic schists, (5) black and gray slate, and (6) iron ore. Concerning the distribution of the above rocks in the formation Van Hise and Leith* summarize as follows: "The iron bearing carbonates are usually found only near the upper part of the formation where they have been protected by the Tyler slate. The ferruginous slates and ferruginous cherts are characteristic of the central iron-producing part of the district, and the actinolitic and magnetitic slates are characteristic of the eastern and western parts of the district. The latter also form a belt 20 to 300 feet wide bordering the Keweenawan rocks on the north. In the intermediate areas there are of course gradations between the ferruginous slates and ferruginous cherts and the actinolitic and magnetitic slates, as there are also gradations between the cherty iron carbonates and the ferruginous slates and ferruginous cherts. Black slates form thin intercalated layers in the iron bearing formations. Quartzite is also found in layers up to 100 feet thick well up from the base of the formation near Sunday Lake."

Interbedded slate and graywacke. With the exception of the increasing importance of interbedded clastic sediments the Ironwood formation east of T 47 N, R 45 W, maintains its general lithologic characteristics. In sections 16, 17, 18, and 21, T 47 N, R 44 W, it is split 200 feet up from the base by a great graywacke-slate member 500 feet thick. This slate is probably continuous with the so-called "secondary slate foot wall" of the Brotherton, Sunday Lake, and Castile mines at Wakefield. The Meteor shaft in section 11 is sunk in this slate and recent diamond drilling in section 12 has encountered the same rock. At the Brotherton and Sunday Lake mines the thickness of this member varies from 40 to 140 feet. At the Castile and Meteor locations and the exploration in section 12, T 47 N, R 45 W, its thickness is unknown. In sections 16 and 17, T 47 N, R 44 W, the

*Monograph 52, U. S. Geological Survey, page 231.

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slate has been cross sectioned in two places by drilling and the thickness is in the neighborhood of 500 feet. This member of the Ironwood formation is not exposed at the surface.

The extensive explorations made by the Presque Isle Mining Co. has disclosed the character of the Ironwood formation in sections 20, 21, and 22, T 47 N, R 43 W. The formation in this township contains, especially in the upper horizon, lenses and layers of slate, some of whcih are of considerable thickness. Although the problem of the correlation of these members is complicated by folding it is believed that the slates are not continuous. It seems more probable from the available data that they are lenses and are not continuous over any great distance. The slates are not exposed and consequently knowledge of their character is based almost entirely on drill cores. For the most part they are fine grained, gray, green or red and commonly soft but occasionally harder and more quartzose phases are encountered. A noticeable feature is the almost total absence of black slate. No attempt has been made to differentiate on the accompanying map the slate in T 47 N, R 43 W, from the nonclastic portion of the Ironwood formation.

Lithology of the Ironwood formation in T 47 N, R 44 W. The total thickness of the Ironwood formation in sections 16, 17, 18, and 21, T 47 N, R 44 W, is in the neighborhood of 1400 or 1500 feet. This great thickness is due largely to the presence of the 500 feet of graywacke-slate above described. For the purposes of this description the iron bearing rocks below the graywacke-slate will be referred to as the lower member and the iron bearing rocks above the slate as the upper member.

Exposures of the lower member are not plentiful, being limited to three test pits in section 17 and a few outcrops on a low north facing ridge in section 21. All of the exposures are in the horizon immediately above the foot wall quartzite. The rocks on the dump of the pits in section 17 are soft, rich, ferruginous chert and the peculiar semi-detrital material characteristic of the basal horizon of the Ironwood. This detrital rock consists of thin layers in which red and white rounded grains of quartz are embedded in a chert matrix. The detrital grains average about one-sixtieth of an inch in diameter as a rule but occasional pebbles of quartz up to one-half inch in diameter are present. Detrital material is in general subordinate to the nonclastic chert matrix. It may be added that this peculiar basal horizon is characteristic of the Ironwood formation throughout the range.

In section 21 the contact between the Ironwood and Palms formations is marked by a narrow, strongly magnetic field in which the exposures are actinolite-magnetite schists. It is evident from the narrowness of the magnetic field that these rocks are confined to a thin

horizon lying directly upon the Palms. According to Van Hise and Irving* these rocks are identical with the actinolite-magnetite schists at Penokee Gap. The explanation of the occurrence of these schists in this locality is in doubt but it is probable that they have been formed through local shearing at the contact between the Palms and Ironwood formations.

The thickness of the lower member is probably in the neighborhood of 200 to 300 feet.

The upper iron bearing member is made up of ferruginous chert, hard jaspilite and amphibole-magnetite slate. An average of 150 analyses of drill cores shows an iron content of 33.48 per cent. Ferruginous cherts are characteristic of the lower-middle horizon. The jasper and amphibole-magnetite slates are characteristic of the upper horizon in contact with intrusive gabbro and associated greenstone sills. Exposures and test pits in the upper horizon are plentiful along the south slope of the high ridge marking the position of the main gabbro mass. The amphibole-magnetite slates at this horizon are characterized by strong to violent magnetism.

The Ironwood formation is in contact with the gabbro on the north for about four miles from the SW$\frac{1}{4}$ of the SE$\frac{1}{4}$ of section 1, T 47 N, R 45 W, east to the SW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 15, T 47 N, R 44 W. From this locality southeast to the great fault in section 25 the overlying rocks are effusive greenstone, agglomerates, and associated basic lavas. It is apparent from magnetic observations that the upper horizon of the Ironwood along the contact with the greenstone effusives carries considerable magnetite although the magnetism is not nearly so strong as that marking the contact of the Ironwood formation and the gabbro. Only two exposures of the Ironwood formation are known from the NE corner of section 22, SE to the NW$\frac{1}{4}$ of section 25, but it is presumed to extend southwest from section 21 to section 25 mainly on the basis of magnetic attraction. There is a group of test pits in hard jasper and amphibole-magnetite chert near the W$\frac{1}{4}$ post of section 23, and a small outcrop of cherty iron carbonate in the southeastern part of the NW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 25.

The Ironwood formation in T 47 N, R 43 W. For the most part the Ironwood formation in this township is made up of ferruginous chert and slate and interbedded lenses of soft gray and green sericitic and chloritic slate. The exposures in section 30, T 47 N, R 43 W, and near the S$\frac{1}{4}$ post in section 25, T 47 N, R 44 W, are amphibole-magnetite chert and schist.

In sections 20, 21, and 22 the iron bearing rocks are ferruginous chert with a subordinate amount of ferruginous slate. An average of 130

*Monograph 19, U. S. Geological Survey, page 243.

analyses from the drill holes in section 20 gives an iron content of 36.87 per cent. This figure is not representative of the formation as a whole as only the richer beds were analyzed.

A noticeable feature of the iron formation in T 47 N, R 43 W, is an abundance of white quartz veins, some of which are large. The unusual number of these veins is in sharp contrast to their general absence in the mines to the west. They were encountered with great frequency in the diamond drilling in adjacent territory and in the Presque Isle mine have rendered worthless in some instances concentrations of hematite that would otherwise be valuable iron ore. It is, therefore, apparent that these quartz veins must be taken into consideration in connection with the ore bearing possibilities of the iron formation in this territory.

On account of the folding and post-Animikie erosion in T 47 N, R 43 W, no accurate estimate of the thickness of the Ironwood formation is possible. There is no reason to believe, however, that, as originally deposited, it is thinner here than elsewhere on the Gogebic range.

Relations of the Ironwood formation to adjacent formations. The Ironwood formation rests conformably upon the Palms quartzite. It is possible that the detrital horizon at its base represents a break in sedimentation. On the other hand it is not inconceivable that this horizon represents merely an abrupt change in conditions from clastic to nonclastic sedimentation. In restricted localities this horizon is conglomeratic. In a test shaft dump near the center of section 21, T 47 N, R 43 W, quartz pebbles up to an inch in diameter may be observed.

The greenstone volcanics in sections 15, 22, 23, and 25, T 47 N, R 44 W, are believed to lie conformably above the Ironwood formation. No contacts are exposed but the field relations are not indicative of any structural break. The exact relationship of the greenstone agglomerates to the iron formation in sections 20 and 21, T 47 N, R 43 W, is unknown. It is probable, however, that they occupy the same stratigraphic position as the greenstones adjacent on the west.

The Copps formation rests unconformably upon the Ironwood formation.

MIDDLE HURONIAN (ANIMIKIE) EXTRUSIVES.

Greenstone Agglomerates and Associated Rocks. Effusive greenstones are found in three localities on the east end of the range, (1) in an area of about 4 sq. miles in the vicinity of sections 23 and 24, T 47 N, R 44 W, (2) in a narrow strip of territory extending east from the center of section 20, T 47 N, R 43 W, to in the vicinity of the E$\frac{1}{4}$ post and, (3) in a small area in the NE$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 22, and the NW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 23, T 47 N, R 43 W.

For a detailed treatment of the lithology of the effusives in these areas the reader is referred to section 3, chapter 8, Monograph 19, U. S. Geological Survey. The description to which we have referred is based on careful microscopic and field study. The effusives are mainly basic volcanic agglomerates and breccias with associated amygdaloidal lavas, tuffs, and some slate and conglomerate. The main area of the greenstone includes, near the base, coarser grained rocks largely of the character of diabase and diorite. These may be intrusive equivalents of some of the flows or they may be later intrusives with no genetic relation to the greenstone effusives. Certain small diabase dikes are without doubt later intrusives, probably Keweenawan. Amygdaloidal lavas are characteristic of the upper horizon of the greenstone immediately underlying the Copps formation, although an occasional bed is found near the center of the greenstone area.

The effusives in section 20, T 47 N, R 43 W, are agglomeratic in all of the exposures. In sections 22 and 23 the greenstone includes both agglomeratic and fine grained basic flows.

The greenstones at locality (1) are apparently superimposed upon the Ironwood formation, perhaps in part interbedded in the upper horizons. At locality (2) the relationship, as previously stated, is not clear. If the greenstone occupies the same stratigraphic position with reference to the Ironwood formation as it appears to occupy farther west, it is probable that they are in the center of a syncline overturned to the south, the north limb of which has been truncated by post-Animikie erosion. With regard to the position of the greenstone in locality (3) nothing definite is known, but the general field relations indicate that these rocks are interbedded with the lower horizons of the Ironwood fromation.

The Copps series is believed to rest unconformably on the greenstone agglomerates. The inference is based on general field relations and the presence of pebbles of the greenstone in the Copps conglomerate. No actual contacts are exposed. Wherever the Copps formation is in juxtaposition to the volcanic greenstone it invariably dips away from it. Volcanic rocks have not been found in the Copps formation.

BASIC INTRUSIVES.

Basic intrusives occur in two main areas, viz, (1) massive diabase in sections 22, 26, and 27, T 47 N, R 44 W, and (2) fine grained greenstone in sections 20, 29, and 30, T 47 N, R 43 W. Aside from these two localities there are many small dikes of diabase which intrude the entire Huronian succession.

We have not examined these greenstones microscopically and shall

therefore rely wholly upon the petrographic studies of Van Hise and Irving to which the reader is referred for a detailed discussion*.

Diabase in Sections 22, 26 and 27, T 47 N, R 44 W. Exposures in this locality occupy two high ridges trending north and south. The more prominent one extends from the center of section 27 to about one-quarter of a mile north of the S¼ post of section 22; the other is located in the north central part of section 26. Both hills are characterized by a steep to precipitous west face and a more gentle eastern slope. A noticeable major jointing strikes approximately N-S and dips east. The greater number of exposures exhibited are typical diabase but in places they grade into coarse textured gabbro.

In the west side of the hill in section 26 a narrow belt of banded amphibole-magnetite chert 50 feet thick is exposed. It strikes N 7° W and dips 55° E. The iron formation is underlain by diabase and overlain by fine grained massive greenstone grading upward into diabase but neither the upper nor the lower contact is exposed.

A mile west of this locality a few feet of magnetic slate striking N 20° W and dipping 32° NE is exposed at the base of a prominent westward facing bluff of diabase. The relations indicate clearly that the overlying diabase is an intrusive sill. For the most part the contact between the slate and diabase is parallel to the banding of the formation but at one point a dike of diabase 4 feet wide cuts directly across the bedding. Small fragments of slate up to one foot in diameter are imbedded in the diabase close to the contact. Faulting normal to the plane of the contact has effected small displacements in both rocks. The thickness of the slate is unknown. It is noticeable that the most prominent set of joints in the diabase is parallel in strike and dip to the banding in the slates in section 27 and the amphibole-magnetite chert in section 26. It seems not unlikely in view of the above facts and the general topographic expression of the hills that the diabase is in the form of sills of great thickness intruded in the Huronian series.

In describing this greenstone Van Hise correlated the fine grained amygdaloidal greenstones in the northern half of section 15 with the diabase to the south, but we would favor including the amygdaloidal greenstones in the overlying greenstone effusives. Their position seems to warrant direct correlation with the upper horizon of amygdaloidal lava.

Greenstone in Sections 20, 29, 30, T 47 N, R 43 W. Greenstone is exposed in a high ridge south of the iron formation in the southeast half of section 20, in a hill in the northwest part of section 29, and in a low ridge extending about east and west through the center of the

*Monograph 19, U. S. Geological Survey.

NW¼ of section 30. Van Hise* describes these rocks as follows: "Petrographically this rock has all the characteristics of a surface flow. It is a much altered augite-porphyrite. It varies a good deal in coarseness of grain and degree of alteration, but the original minerals are found with sufficient frequency and the secondary minerals are so uniformly the same that there is every reason to believe that detached exposures are parts of a continuous belt. The original minerals are menaccanite, plagioclase, and augite, this being the order of crystallization. The secondary ones are kaolin, chlorite, epidote, leucoxine, and smaragdite." Van Hise also noted a mineralogical similarity between the augite porphyrite and the diabase in sections 26 and 27, T 47 N, R 44 W. "In original minerals contained in secondary products the augite-porphyrites are almost precisely like the diabases of the first division. The similarity is so remarkable as to make it probable that the rocks of the two divisions are, or once were, connected. The likeness is further reinforced by the correspondence of the double angles of the feldspar as measured by Pumpelly's method." Macroscopically they differ. The augite-porphyrites are usually fine grained while the diabase is characterized by coarse crystallization.

Van Hise regards the augite-porphyrites as probably interbedded surface flows. The workings of the Presque Isle mine together with the diamond drilling show conclusively that the greenstone is intrusive in the iron formation at that locality. The iron formation dips south and the greenstone cuts directly across the bedding. The plane of contact between the greenstone and iron formation is nearly vertical.

Rocks very similar in appearance to those just described occur on a small knoll just west of the group of old test pits and trenches in the S½ of the NE¼ of section 21. The relations of this greenstone with adjacent iron formation and quartzite are unknown but are not presumed to be different from the relations exhibited at the Presque Isle mine.

PRESQUE ISLE GRANITE.

Location and Extent. The Presque Isle granite is so named because of its typical exposures along the Presque Isle River in the south half of T 47 N, R 43 W. It includes the rocks described by Van Hise and Irving as constituting the "Eastern Laurentian Granite area."† It is probable that the Presque Isle granite is to be correlated directly with the great granitic intrusives that cover a large area southward in Michigan and Northern Wisconsin, possibly including the granite of the Florence and Menominee districts heretofore doubtfully correlated

*Monograph 19, U. S. Geological Survey, pp. 414-15.
†Monograph 19, U. S. Geological Survey.

with the Keweenawan. (See discussion of the Marenisco, Turtle, and Manitowish ranges and the Vieux Desert-Conover district).

Lithology. The term granite is here used in a loose sense to cover rocks that are predominantly acid granites, but which include here and there rocks of more basic types not excluding syenite and diorite. The basic varieties are possibly differentiation products of a normally acid magma although their predominance near the contact with the Huronian sediments may perhaps be accounted for on the theory that the marginal tendency towards basicity is an endomorphic effect of the intrusion of granite into the Animikie series.

Van Hise summarizes the description of the Eastern granite as follows: "In all essential respects the massive rocks here contained are like those found in the granite areas to the westward. The phases here included run from typical syenites to typical quartzose granites. Usually in them, as in the previous areas, an alkaline feldspar, occurring largely in idiomorphic forms, is the chief constituent. In a few of the exposures quartz is as abundant as the feldspar. In some cases in this area the decomposition of the feldspar has gone far. Aside from the quartz and feldspar, hornblende and chlorite, as in the Central granite, are the only important minerals, and very frequently the chlorite, as in it, has resulted from the alteration of the hornblende or the decomposition of the feldspar. The typical syenite exposures are more common than in the other two granite areas." The Presque Isle granite is mainly massive but marked gneissosity is not an uncommon feature. In general the rocks are light gray to white in color and acid in composition. They are very uneven grained and cut by innumerable pegmatite dikes. Along the road leading from Marenisco to the Presque Isle mine predominant white varieties give the rock the appearance of massive white quartz or dolomite when seen from a distance. In T 47 N, R 42 W, there are limited areas of red granite.

Relation of Presque Isle Granite to Middle Huronian (Animikie) Formations. The inference that the Presque Isle granite is intrusive into the Animikie formations rests on the following evidence:

1. The exposures of the Palms formation show a gradual transition, in proportion as they approach the granite, to micaceous and hornblendic schists and gneisses with accompanying obliteration of clastic textures.

2. The Palms and Ironwood formations are characterized by abundant quartz veins and the Palms formation by veins of aplite and pegmatite which become increasingly prominent toward the granite.

3. The Ironwood formation becomes amphibolitic, magnetitic and schistose in section 25, T 47 N, R 44 W and section 30, T 47 N, R 43

W, where closely approached by diorite and hornblende syenite which is correlated with the Presque Isle intrusives.

4. At this latter locality the Palms formation is absent and the amphibole-magnetite slate of the Ironwood is separated by only a short distance from exposures of diorite and hornblende syenite believed to belong to the Presque Isle granite.

The above remarks may be illustrated by reference to certain localities. The exposures showing the metamorphism of the Palms to best advantage are in sections 21 and 28, T 47 N, R 43 W, earlier described. In no other locality are exposures sufficiently abundant to permit observation of the gradual change from graywacke and slate to crystalline schists. Mention will be made here of a few other localities where the same phenomenon may be less satisfactorily observed.

Exposures of slightly altered phases of the Palms are found near the center, and at the E$\frac{1}{4}$ post of section 29, and at the bridge where the township road crosses the Presque Isle River in section 28. The clastic texture is usually present in some of the coarser grained bands, but in the finer grained layers no sedimentary textures remain. In the exposures in section 29 small needles and fibres of green hornblende are visible under the microscope although not usually determinable in hand specimen. The outcrop near the east $\frac{1}{4}$ post of section 29 is cut by quartz veins, some of which are feldspathic. A short distance south the rocks are fine grained hornblende-mica gneisses cut by bands and dikes of granite and pegmatite. From this point south to the granite exposures are numerous; the hornblende gneisses become gradually coarser grained and the granitic material increases in amount until finally the rock is contorted and banded gneiss made up of alternate layers of granite and hornblende schist, cut indifferently by dikes of aplite and pegmatite. Nowhere is it possible to draw a sharp boundary between the granite and the Palms formation. The base of the latter is doubtless involved in the former and can only be represented on the map by a transitional zone.

The unusual abundance of quartz veins in the Ironwood formation in T 47 N, R 43 W, has already been referred to and merely need be recalled at this point. Although no trace of feldspathic material was noted in the quartz veins in the Presque Isle mine the presence of these veins in unusual numbers in this particular part of the range is significant. If correctly interpreted as originating from hot magmatic waters derived from the Presque Isle intrusive, the quartz veins are the only direct metamorphic effect of this granite on the iron formation in sections 20, 21 and 22. The explanation of the absence of marked metamorphism of the iron formation here probably lies in the competency of the massive upper quartzite member of the Palms through which the granite magma was not able to penetrate.

Farther west in the SE$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 30, and in the SW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 25, there are exposures of amphibole-magnetite slate and chert. In section 25 the iron formation is overlain by greenstone agglomerate and is only about 50 feet north of exposures of diorite and hornblende syenite. The total thickness of iron formation cannot be more than 150 to 200 feet. The outcrops of amphibole-magnetite schist and chert in section 30 lie south of a low ridge of augite-porphyrite. They are larger and more extensive than the outcrops in section 25. Four hundred paces south of the iron formation, diorite similar to the exposure in the south part of section 23 is encountered. An intervening test pit is ledged in fine grained hornblende schist similar macroscopically and microscopically to metamorphic phases of the Palms.

It should be stated that there is no absolute proof that the iron formation in section 30 is continuous as a part of the main belt in section 20, although such connection is plainly indicated. The apparent discontinuity is the result of folding and displacement which will be discussed later.

The same statement applies to the outcrops in section 25, and in fact it seems possible from consideration of the magnetic observations in the intervening territory that igneous intrusives may have eaten their way up through the entire iron bearing series between the exposures in section 25 and those in section 30.

There can be little doubt that the diorite and hornblende syenite are the rocks responsible for the metamorphism of the iron formation at both localities. As to whether they should be correlated with the Presque Isle intrusives is not so clear. Macroscopically the diroite and syenite differ from the other basic rocks in the east end of the range in being lighter colored and in many places banded or gneissose. The exposures are uneven grained and vary rapidly in composition, becoming in places gradationally more acid and including phases of hornblende syenite. Some of the hornblende syenite is porphyritic in texture; phenocrysts of light pinkish and gray orthoclase up to one-half inch in diameter are imbedded in a fine grained matrix of hornblende and feldspar. The more basic varieties are commonly badly altered and when examined microscopically are found to be made up of ragged green hornblende and a badly altered basic feldspar. The alteration products are gray saussurite, epidote, zoisite, and sericite. Leucoxine and pyrite are found in small quantities. A noticeable feature is the general absence of magnetite which is found in all the other basic rocks in sufficient quantity to affect the dip needle.

It is not possible to establish a direct areal connection of these basic rocks with the main mass of granite to the south but in view of their similarity in structural features and sudden compositional and textural changes it is regarded as likely that these rocks are a part of the main intrusive granite. The basic types may be well interpreted as a product of differentiation or if, as seems possible, the Presque Isle intrusives have in this vicinity eaten their way up through the underlying Palms and in section 25 through the greater portion of the Ironwood, the basicity of the adjacent rocks may be a direct result of the absorption and assimilation of the Animikie sediments.

Relation of the Presque Isle Granite to the Copps Formation. The Copps formation rests unconformably upon the Presque Isle granite. The contact is marked by a great conglomerate carrying boulders and pebbles of the granite.

Upper Huronian Series.

COPPS FORMATION.

Location. The Copps formation is the name proposed for the rocks which occupy most of the area which is mapped and described in Monograph 19, U. S. Geological Survey as "Ferruginous Slates of the Eastern Area."

The most westerly of the exposures which can be correlated with the Copps formation with certainty are those of ferruginous graywacke in section 14, T 47 N, R 44 W. A mile and a half farther west in the SW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 15, there is a small group of test pits ledged in black slate and graywacke. The dumps of these pits include also a small amount of ferruginous chert and jasper. If these rocks are referable to the Copps, and this seems not unlikely in view of their position and lithologic character, this formation extends as far east as section 18, T 47 N, R 44 W, where it occupies the valley lying between the Keweenawan lavas on the north and the high gabbro ridge on the south. This valley gradually narrows toward the west and disappears in section 6, T 47 N, R 45 W, where the gabbro is apparently in direct contact with the Keweenawan amygdaloidal trap. The only evidence of the character of the rocks occupying this depression is afforded by the pits in section 15 and the occurrence of a strong magnetic belt at the north base of the gabbro hill in section 8, T 47 N, R 44 W.

The east limit of the Copps formation is in section 28. T 47 N, R 42 W, where it is unconformably overlapped by flat lying red sandstones of Cambrian (?) age.

Lithology. The Copps formation is essentially graywacke slate, highly ferruginous in its western and central parts but becoming decreasingly ferriferous eastward from section 22, T 47 N, R 43 W. Bands of chert and jasper are characteristic of the lower horizons. The base of the series wherever exposed is marked by a well defined conglomerate.

The iron bearing minerals form a cement in which the fragmental grains are imbedded. In the westerly exposures iron oxide, largely hematite but including considerable magnetite, is predominant. In sections 16, 17 and 20 the oxide and carbonate of iron are both present and east of section 16 the iron mineral is largely siderite. According to Van Hise* the relations between the iron oxide and iron carbonate indicate that the former is derived from the latter. Microscopic study reveals the presence of iron carbonate in all stages of alteration to iron oxide.

The lower horizon of the Copps is a well defined basal conglomerate. From section 23, T 47 N, R 43 W, east to the extremity of the range the Copps conglomerate is in contact with the Presque Isle granite. It is here composed of granite boulders and pebbles, ranging up to four or five feet in diameter, imbedded in a matrix of arkose which includes also a considerable quantity of iron carbonate. In addition to the granite boulders are a few pebbles of greenstone, quartz, chert, and more rarely quartzite and jasper. Exposures of the granite conglomerate are found in section 28, T 47 N, R 42 W, and in sections 23 and 24, T 47 N, R 43 W.

North of the old Copps mine near the southeast corner of section 15, T 47 N, R 43 W, the Copps formation truncates the Animikie formation. Here the granite pebbles have entirely disappeared giving place to small fragments of chert, quartz, and occasionally quartzite imbedded in a matrix consisting of smaller grains of quartz, chert, feldspar, and a large amount of iron carbonate.

The conglomerate horizon was cut by a drill hole in the northeast part of section 21 and is also exposed in test pits a short distance north of the center of this section. In these localities the conglomerate contains pebbles of quartz, jasper, quartzite, and chert imbedded in a graywacke matrix which includes a small amount of iron oxide.

West of section 21 conglomerates are found in test pits in section 19, T 47 N, R 43 W, in section 14, T 47 N, R 44 W, and in fact, according to J. M. Longyear, Jr., "all along the north and east edges of the greenstone area" in sections 13, 14, 19 and 24, T 47 N, R 44 W[1].

It is not possible to work out in any detail from available data a definite succession of dissimilar members for the Copps formation but the following probably expresses in a very general way the succession in the territory from section 13 to section 17, T 47 N, R 43 W. East

*Monograph 19, U. S. Geological Survey, pp. 392-3.

[1]A thesis on the geology of part of the Gogebic range, Harvard University, 1915, (unpublished).

of section 13 and west of section 17 information is too meager to justify even general statements.

The base of the formation is conglomerate which grades up into hard graywacke carrying layers of chert and, in the western part of the formation, narrow seams of jasper. The cherty bands near the base of the formation are persistent everywhere. An interesting feature is the presence in the chert bands of considerable detrital material and even in the associated clastic bands there is a subordinate amount of interstitial chert.

In the eastern part of section 15 and the western part of section 14 the ferruginous graywacke and chert are sharply overlain by a thin belt of black slate. Whether this member is persistent or is merely a local feature can not be determined. The black slate grades upward into coarser grained graywacke characterized by a considerable content of magnetite. This member can be traced magnetically and by outcrops from section 19, T 47 N, R 42 W, to section 20, T 47 N, R 43 W. Associated with the graywacke are slates and a few beds of lighter colored feldspathic quartzites. The magnetic graywacke is composed mainly of rounded grains of quartz and feldspar, the latter including orthoclase, plagioclase, and microcline. The interstitial material comprises magnetite, hematite, carbonate, sericite, and chlorite. Magnetite occurs also in a later second generation of large well formed crystals which contain inclusions of the other minerals.

Above the magnetic graywacke are graywacke and slate, more or less ferruginous, containing locally considerable magnetite. In this connection it may be said that the entire Copps formation west of T 47 N, R 42 W, is weakly magnetic. The rocks termed here magnetic graywacke contain important quantities of magnetite. The other graywackes and associated rocks present no unusual petrographic features.

In the central part of the Copps formation the highest member is a soft slate. Its color is dark gray or grayish green excepting only a red phase at the top which grades downward irregularly into the darker colored facies.

In T 47 N, R 42 W, exposures of the Copps formation are confined to the lower horizons. The cherty bands characteristic of the member immediately above the basal conglomerate are present and the overlying rocks, insofar as it is possible to determine, are largely soft gray and green choloritic and sericitic slates. Iron carbonate, and to a limited extent iron oxide, are present but the relative importance of these minerals in the general make up of the rock has diminished when compared with their abundance farther west.

In the western exposures in T 47 N, R 44 W, the rocks are rather coarse grained and highly ferruginous carrying bands and layers of red chert, jaspilite and slate. The iron is almost entirely in the form of hematite with subordinate magnetite. The clastic grains include quartz, feldspar, red chert, and rarely jasper.

The width of the Copps formation lessens rapidly going west from section 19, T 47 N, R 43 W, and in section 14, T 47 N, R 44 W, has narrowed to about 300 paces. This is believed to be due to erosion prior to the deposition of the Keweenawan series. This conclusion is strengthened by the fact that the ferruginous graywackes and associated cherty material characteristic of the lower horizons farther east are in section 14 in contact with the overlying Keweenawan lavas.

The outcrops of ferruginous graywacke in the southeast part of section 19 and the north half of section 30, T 47 N, R 43 W, are almost identical with the exposures in section 14, T 47 N, R 44 W, and require no special description.

Thickness of the Copps Formation. The Copps formation is one of considerable thickness. Throughout the greater part of its extent it has a surface width averaging well over a half mile. Assuming a northerly dip of 65° in sections 13, 14 and 15, T 47 N, R 43 W, the thickness is not less than 2300 feet. It is possible that some of the beds are repeated by close folding but the figure given is believed to be slightly if any in excess of the actual thickness of the formation.

Relations to Adjacent Formations. The Copps formation rests unconformably above the Presque Isle granite. The relationship is clearly indicated by the prominent granite conglomerate marking their contact. It is separated from the underlying Animikie formations by an unconformity of great structural and erosional magnitude. This conclusion rests on the following evidence:

1. The bottom horizon of the Copps formation is a true basal conglomerate containing fragments of the underlying Palms and Ironwood formations.
2. The Presque Isle granite intrudes the Palms and Ironwood formations but yields boulders and matrix to the basal conglomerate of the Copps formation.
3. The Copps formation is in great structural discordance with the Animikie group.
4. The areal relationships are those of unconformity.
5. Volcanic rocks are characteristic of the Animikie but are apparently entirely absent in the overlying Copps formation.

The structural and areal relationships are shown on the accompanying map and structure sections, (fig. 2) and are discussed in another place.

Keweenawan Series.

It is not intended to discuss the Keweenawan series except with regard to its relations to the subjacent Huronian group. The great Keweenawan series of lavas, sandstone and conglomerate limits the Huronian series on the north throughout the entire length of the Gogebic iron range. In addition to the overlying lavas and associated sandstones and conglomerates the Keweenawan series also includes the diabase dikes which cut the Huronian rocks and have played such an important part in the localization of the iron ore bodies. The Keweenawan is also believed to include the gabbro intrusive in the east part of T 47 N, R 44 W.

Relation of the Keweenawan to Adjacent Formations. In the east end of the range the Keweenawan series is in contact only with the Copps formation which it overlies unconformably. This relationship is clearly indicated in the exposures and test pits 450 paces west of the E$\frac{1}{4}$ post of section 15. The base of the Keweenawan in this vicinity is a partially indurated sandstone 50 to 75 feet thick marked by a strong basal conglomerate. The subjacent rocks of the Copps series are soft red slate and the conglomerate immediately above them contains abundant pebbles of this red slate and in addition pebbles of vein quartz, quartzite, graywacke, jasper, chert and iron ore derived from the various formations of the Huronian group.

Keweenawan (?) Gabbro in T 47 N, R 44 W. Reference has been made in connection with the discussion of the Ironwood formation in T 47 N, R 44 W, to the high ridge of gabbro extending from section 1, T 47 N, R 45 W, southeast to section 15, T 47 N, R 44 W. This ridge lies north of the Ironwood formation and is parallel to it. The rock varies from a coarse grained gabbro to fine grained diabase. Close to the contact with the iron formation the greenstone is aphanitic. The gabbro is best exposed in the southwest part of section 8 and the northwest part of section 17, although outcrops are plentiful in all parts of the ridge. The outcrops in sections 8 and 17 furnish the most favorable locality for observation of a well developed system of joints. The most prominent set strikes about east and west and dips south. A less marked set of joints, normal to the first, dips east.

The gabbro is in contact with the Ironwood formation on the south; on the east it is limited by the greenstone agglomerates and effusive lavas. North of section 15 the gabbro is separated from the Keweenawan by a valley about one-half mile wide. This valley narrows toward the west and in section 1, T 47 N, R 45 W, the gabbro is apparently in direct contact with the trap. The gabbro thins rapidly westward and does not appear west of the NE$\frac{1}{4}$ of the SE$\frac{1}{4}$ of section 1. From section 1, T 47 N, R 45 W, to Sunday Lake the Keweenawan overlies the Ironwood formation.

The exact relationship of the gabbro to adjacent rocks is not clear except in the case of the iron formation; actual contacts are nowhere exposed. The Ironwood formation adjacent to the gabbro is everywhere characterized by highly metamorphic facies including amphibole-magnetite schist and slate and hard jaspilite, and this fact together with the occurrence of intrusive sills of fine grained dolorite in its upper horizon is strong evidence that the gabbro intrudes the Ironwood formation. The exact form of intrusion of the gabbro is not known. It may be either an immense dike or a sill. A prominent jointing or sheeting dipping southward at 65° in a plane approximately parallel to the northern and southern bases of the ridge suggest that this plane is also probably parallel to the opposite surfaces of the intrusives, in which case the intrusive is in the form of a dike dipping southward and inclined about 55° to the plane of the bedding in the iron formation.

In section 1, T 47 N, R 45 W, outcrops of gabbro are found only 75 paces south of the Keweenawan lavas. There is no evidence in the trap outcrops of contact metamorphic action and it is not possible to determine the relationship between them and the gabbro.

To summarize,—the gabbro intrudes the Ironwood formation. There is indirect evidence that it intrudes the rocks (Copps formation?) occupying the valley separating the gabbro from the Keweenawan in sections 7, 8, 15 and 16, T 47 N, R 44 W. There is no evidence that gabbro intrudes the Keweenawan.

Van Hise makes only slight reference to the gabbro intrusive but apparently correlates it with the Keweenawan.

Structure of the Gogebic Range east of Wakefield.

From T 44 N, R 6 W, Wisconsin, eastward to the center of T 47 N, R 46 W, Michigan, the Gogebic range is a steeply northward dipping monocline, but east of the Black River the structure is locally complicated.

From the vicinity of the Eureka mine east to the Castile mine the Lower Huronian and Animikie (Middle Huronian) formations are folded, faulted, and intruded by dikes and irregular masses of greenstones. The most noticeable feature is the great thrust fault at Wakefield. With the exception of the general northward tilting the folding and faulting of the Huronian rocks took place prior to Keweenawan time and after the deposition and induration of the Animikie (Middle Huronian) series.

From the Castile mine eastward to section 22, T 47 N, R 44 W, the structure of the range is, so far as known, a simple northward dipping

monocline similar to that west of the Black River. The Lower Huronian and Animikie (Middle Huronian) series dip north at angles varying from 35° to 65°. The structure is illustrated by section AA accompanying the general map. In section 22, T 47 N, R 44 W, and eastward the structure again becomes complicated and except where diamond drill holes have supplied the data it is not possible to work it out in detail. The structural problem is complicated by great intrusions of granite and greenstone and by immense masses of basic volcanic material. In fact the igneous activity of Animikie time in the east end of the range is probably closely related to the exceptional local deformation of the pre-Copps rocks.

From section 22, T 47 N, R 44 W, eastward to section 20, T 47 N, R 43 W, little is known of the details of the structure. Exposures of igneous rocks are plentiful but the sedimentary rocks are mainly drift covered. The iron formation can be traced magnetically wherever the magnetism has developed in sufficient strength so that the iron formation can be clearly differentiated from the associated greenstones which are nearly everywhere weakly magnetic. In sections 20, 21, and 22 it is possible to work out the structure in some detail.

Geologic structural sections have been drawn only in localities where surface data is supplemented by diamond drilling or underground exploration.

Structure of the Keweenawan series. The Keweenawan series has an approximate eastward strike and uniform northward dip. Superimposed on the northward dipping monocline are gentle cross folds which are indicated by the gently sinuous character of the Copps-Keweenawan line of contact in sections 13 to 17, T 47 N, R 43 W. A cross anticline in the vicinity of sections 14 and 15, T 47 N, R 44 W, is particularly well marked. It is possible that the Keweenawan is cut by the cross fault in section 14, T 47 N, R 44 W, which has apparently produced a horizontal misplacement of about 1500 feet in the underlying Copps formation and Animikie volcanics.

Structure of the Copps Formation. The trend of the Copps formation is about parallel to the Keweenawan and its dip is northward. Southward dips are confined, so far as known, to the secondary structure, i. e. schistosity or slaty cleavage, while the bedding invariably dips northward so far as observed. The bands of chert and jasper near the base of the formation dip north and northward dips are exhibited wherever bedding is recognizable in the slates and graywackes. In the slate exposures in the SE$\frac{1}{4}$ of the SE$\frac{1}{4}$ of section 15, T 47 N, R 43 W, the cleavage dips south at angles varying from 45° to 80°, but the bedding is nearly vertical or steeply inclined to the north. This is the only locality where the dips of bedding and shistosity are opposed

in the same exposure. An exception to the general northward dip of the Copps occurs in the exposures of ferruginous graywacke in the southwest part of section 19 and the NW$\frac{1}{4}$ of section 30, T 47 N, R 43 W. These rocks are mainly massive and exhibit neither bedding nor schistosity except in an outcrop near the southwest corner of section 19 which contains narrow bands of chert striking northeast and dipping southeast. The occurrence of the Copps formation in this locality is of considerable structural significance. The Animikie rocks are here believed to be compressed into an overturned syncline with axial plane striking NE-SW and dipping northwest. It is probable that this fold has passed into a thrust fault, the plane of which is approximately parallel to the axial plane of the syncline. While the position of the ferruginous graywacke here indicates that the graywacke is younger than the Animikie volcanics and iron formation it may be equivalent to the upper horizon of the Ironwood or the lower part of the Tyler formation. If any part of the Tyler formation is preserved on the east end of the range the remnant should be looked for in synclines such as this. There is considerable lithologic dissimilarity between the ferruginous graywacke at this locality and the Tyler sediments, while on the other hand it is identical in appearance and composition with phases of the Copps rocks. It is of course possible that the exceptional conditions which prevail in this part of the range may account for the deposition of material entirely dissimilar to that elsewhere simultaneously laid down.

The determination of the time at which the deformation and folding in this locality took place is directly related to the problem of the age of the ferruginous graywacke. There are three possibilities. (1) If the ferruginous graywacke is equivalent in time to the Tyler or to the Ironwood formation the deformation is probably post-Animikie and pre-Copps because there is no evidence elsewhere of any pre-Keweenawan folding in the Copps. (2) Assuming that these rocks are part of the Copps formation it is possible that the folding may have taken place prior to the deposition of the Copps and to have resulted in the formation of a basin or depression which was later filled by the post-Animikie sediments. (3) Finally, if the ferruginous graywacke belongs to the Copps and has been itself affected by the folding, the age of the disturbance is post-Copps and probably Keweenawan.

Structure of the Middle Huronian Series (Animikie). It is impossible to obtain sufficient information on which to work out the detailed structure of the Animikie rocks except in the vicinity of sections 21 and 22, T 47 N, R 43 W. From the west line of section 21 east to section 22, T 47 N, R 44 W, the available data warrants nothing beyond a general idea of the gross structure.

The structural conditions in the east part of T 47 N, R 43 W, are exhibited by the geologic sections (Fig. 2) which are based to a great extent upon the drill records of the Presque Isle Mining Company. The data for structural sections here are unusually ample because of the large amount of drilling and test pitting which has been executed, fortunately in a most critical area from the structural point of view.

The chief fact brought out by the structure is the pre-Copps folding of the Middle Huronian (Animikie) and the truncation of these folds by the Copps formation. East of the center of the NW$\frac{1}{4}$ of section 21 the Copps formation is first in contact with the iron formation, then the Palms quartzite and finally, in the northeast part of the section, again with the Ironwood formation. In the NE$\frac{1}{4}$ of the section a drill hole pointed south entered the Copps formation, passed through its basal conglomerate and penetrated the Palms quartzite without encountering the Ironwood formation. These relations indicate that the Middle Huronian (Animikie) sediments were deposited, indurated, folded, uplifted, eroded, and depressed prior to the deposition of the Copps rocks.

The Middle Huronian (Animikie) series in sections 20, 21, and 22 forms two major synclines, one pitching east and the other west from the crest of an anticline near the center of section 21. The eastward pitching trough is divided by a secondary anticline into two sub-troughs so that the iron formation in the west half of section 21 occurs in two parallel belts which, however, merge into the main single belt in the major syncline in the adjoining section to the east. Details of the structure of the west syncline are not so well known nor does the drilling define the limits or depth of the trough except on the east side of the Presque Isle river. There is some evidence that this trough is broken by cross faulting at the approximate location of the Presque Isle river. The drilling just east of the river indicates a relatively shallow syncline but a short distance west at the Presque Isle mine drill holes to a depth of 850 feet have failed to reach the bottom of the trough. The sudden termination of the greenstone belts north and south of the iron formation is also suggestive of faulting. If there is a fault at this locality it is evident that the rocks west of the river are on the down thrown side.

Nothing is known concerning the attitude of the wide belt of iron formation continuing east through section 20 except that the rocks along the north border dip south. The iron formation in the Presque Isle mine and in the old exploration in the NW$\frac{1}{4}$ of the SW$\frac{1}{4}$ of section 20 dips south.

The stratigraphic position of the greenstone agglomerate in section 20 with reference to the Ironwood formation is uncertain. The plane of schistosity in the greenstone dips south parallel to the bedding in the adjacent iron bearing rocks. If the greenstone is stratigraphically above the Ironwood formation as in T 47 N, R 44 W, the volcanics probably occupy the center of an overturned syncline whose axial plane dips south.

It has been said that little is known regarding the structure of section 20 westward to section 22, T 47 N, R 44 W. The following is merely a statement of known facts of structure with such interpretations as seem best fitted to the facts.

The prominent feature of this territory is the great belt of greenstone agglomerate and other extrusives in the east part of T 47 N, R 44 W, and the occurrence of thick diabase sills in sections 26 and 27 of the same township. The relations and structure of the diabase sills have already been discussed. The greenstone agglomerates are in general massive in structure, less commonly schistose. Structural problems in a volcanic formation such as this are hopeless of solution because it is not possible to identify everywhere any of the flows or ash beds which might, if continuous, serve as horizon markers. Detailed petrographic and field study of the greenstones might throw some light on structure, but the chances are that even this would be of slight assistance.

Information regarding the Animikie sediments is also meager. There are no rocks susceptible of correlation with the Palms east of section 22 in T 47 N, R 44 W, and the iron formation is exposed only at wide intervals.

The definite magnetic line immediately south of the greenstone volcanics indicates that the Ironwood formation is continuous from section 22, T 47 N, R 44 W, southeast to the exposure of cherty iron carbonate in the northwest part of section 25, although actual exposures in the intervening territory are found only near the W$\frac{1}{4}$ post of section 23.

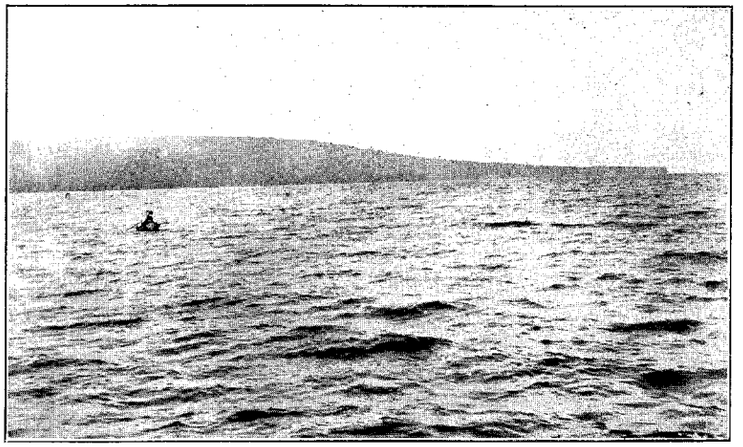
Reference has been made to the amphibole magnetite chert and slate associated with the diabase in sections 26 and 27. If these rocks are part of the Ironwood it is evident that this formation is distributed here over a surface width of about a mile, this being accounted for by the occurrence within the formation of the great diabase sills possibly combined with a flattenting of the dip.

The general strike of the iron formation west of the agglomeratic greenstone is southeast. An exception is the exposure in the northwest part of section 25 in which the strike is slightly east of north. The strike of the iron formation belt east of the greenstone in this territory is NE. The most westerly outcrop of iron formation is in the south part of section 25, T 47 N, R 44 W. The magnetic attractions in the south half of section 26 are probably caused by iron formation directly connected with the exposure in section 25.

The difference in strike of the iron formation east and west of the greenstone extrusives is one of the chief structural features in this part of the range. The question at once arises, (1) are the two belts of iron formation one and the same formation or (2) if not now actually connected were they originally deposited as a continuous formation? The evidence on this point seems conclusive. It has been shown that the iron formation in section 21 overlies rocks which are identical in succession and lithologic features with the type exposures of the Palms formation in the central part of the range. The structure in sections 25 and 26 is an overturned fold, the western limb of which has been faulted and thrust eastward and northward above the lower or western limb. There is considerable field evidence in favor of this interpretation (1) in the attitude of the iron formation and greenstone in section 25, (2) the absence of diabase south of the fault line, (3) the location of the magnetic attractions in section 25 and (4) finally in the fact that the indicated fault line follows low ground in both sections. For the most part the above facts show clearly on the map.

A. CHARACTERISTIC EXPOSURES OF PRESQUE ISLE GRANITE IN T. 47 N., R. 43 W.

B. CHARACTERISTIC TOPOGRAPHY OF THE GREENSTONES IN T. 47 N, R. 44 W.



A. ALLIGATOR POINT. LOOKING NORTH FROM SOUTH END OF LAKE GOGEBIC.

B. FALLS ON THE MIDDLE BRANCH OF THE ONTONAGON RIVER, SECTION 32, T. 46 N., R. 41 W., SHOWING JOINTING IN AMYGDALOIDAL GREENSTONE.

CHAPTER IV.

GEOLOGY OF THE MARENISCO RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTORY STATEMENT.

The Marenisco Range extends from the northwest corner of T 46 N, R 41 W, Michigan, where it is overlapped by the Keweenawan Series of the South Trap Range, southwestward through Marenisco to T 44 N, R 2 E, Wisconsin, and an unknown distance beyond. It was prospected for iron ore in the 80's near Gogebic Lake in Michigan and in the vicinity of Long and Pine lakes in Wisconsin. At the latter locality the village of Magnetic Center was laid out at the north end of Pine Lake but all traces of it have long since disappeared. Among the early explorers this range was known as the South Range but few today recall its existence.

Only about a half dozen outcrops are known on this range from the vicinity of Marenisco southwestward. In the opposite direction there are a considerable number of exposures but these alone furnish an insufficient basis for geologic mapping. The range is characterized by a strong to violent magnetism which furnishes a ready means and, for the greater part of its extent, the only means of determining its position. That this strong magnetism attracted the early explorers is evidenced by traces of their prospects in the most violently magnetic localities. Fragments of diamond drill cores properly arranged in core trays, were found on the site of the Magnetic Center exploration in a dense forest of hardwood and hemlock in the SW$\frac{1}{4}$ of NE$\frac{1}{4}$, section 28, T 44 N, R 3 E, Wisconsin. These cores furnish the only direct evidence of the nature of the magnetic rock southwest of Marenisco. Although there are many pits and an old shaft in this vicinity there is no evidence that bed rock was opened in any of them. In T 46 N, R 42 W, Michigan, outcrops are more abundant, and in this locality only is it possible to work out a definite succession. Whether the succession here is representative of the range as a whole can not be determined.

Succession on the Marenisco Range. In T 46 N, R 42 W, Michigan.

Keweenawan ?		Diabase.
	Igneous contact	
Huronian	Middle Huronian (Animikie)	Intrusive granite (Presque Isle) Intrusive greenstone Slate Extrusive lavas Iron formation Quartzite and graywacke
	Unconformity	
Archean	Northern area.	Granite and greenstone.
	Southern area. amphibolite.	Mica schist, greenschist and (May be Huronian)

ARCHEAN SYSTEM.

NORTHERN AREA.

The Marenisco range is separated from the Gogebic range to the north by a territory from three to twelve miles wide, underlain for the most part by granitic rocks but including subordinate areas of greenschist. The granite in this area was formerly considered as entirely Laurentian but, as has been shown in the discussion of the east end of the Gogebic range, there is ample evidence that, in part at least, it is intrusive into the Middle Huronian. On the other hand, the relations between the Huronian rocks and the granites and greenschists throughout the major part of the Gogebic range clearly indicate the Archean age of the latter.

On the basis of present knowledge it is not possible to differentiate the granites representing the two or more different periods of intrusion except in limited localities where the relations to adjacent Huronian rocks are exhibited. The facts, however, seem to warrant the general statement that the granite from about the vicinity of the Little Presque Isle river east to Lake Gogebic is preponderantly Middle Huronian.

In section 4, T 46 N, R 42 W, the northern granite intrudes the Middle Huronian slates. Elsewhere the relations between the northern granite and the Huronian sediments may only be inferred.

SOUTHERN AREA.

Location and General Statement. The Marenisco range is separated from the Turtle range by a non-magnetic area two to seven miles wide. In this territory, in sections 4 and 9, T 43 N, R 3 E Wisconsin, there

are several outcrops of granite gneiss and hornblende schist. Northeast for a distance of approximately 24 miles there are no rock exposures. In T 46 N, Rs. 41 and 42 W, Michigan, the territory between the Marenisco and Turtle ranges is occupied by a complex of mica and hornblende schist and coarse grained amphibolite with a large amount of intrusive granite, greenstone and fresh diabase.

There is no certain evidence that any of these rocks are Archean and it is probable that the intrusives are Algonkian. The schists and gneisses are placed tentatively in the Archean because they appear on what seems to be an anticline separating the Marenisco and Turtle ranges and are plainly older than the other rocks which are igneous and intrusive in them. The Huronian rocks are also extremely metamorphic and therefore correlation on the basis of metamorphism or lithologic similarity with the Archean of other localities is not warranted.

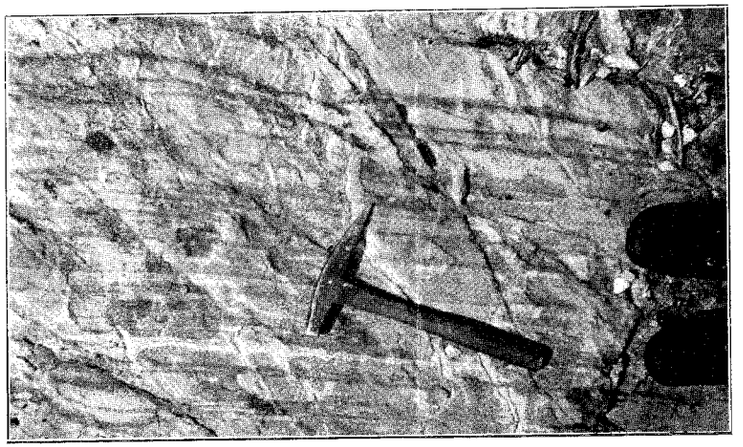
Mica Schist. The most interesting rocks in the southern area are the mica schists. In T 46 N, R 41 W, particularly in sections 13, 14, 15, 18, 29 and 30, outcrops of mica schist are associated with massive greenstone. Mica schist also occurs in association with greenstone in one exposure in section 30, T 46 N, R 42 W. Near the south quarter post of section 8, T 46 N, R 41 W, there is a small exposure of biotite schist intruded by granite. This is the only exposure known where granite is in contact with mica schist.

The mica schists are generally of light gray color; some are coarse and others are fine grained. A common feature of all of the exposures is the occurrence of an abundance of milky white quartz in blebs and stringers parallel to the schistosity. Here and there these stringers are minutely folded. Other quartz veins cut across the schistosity indifferently, apparently filling joint planes. At two localities in the south part of section 29 the mica schist shows a banding in addition to the ever present schistose structure. In many cases the plane of schistosity is inclined to the banding, but in general the two structures are parallel. At one locality the banding has a strike of N 25° E, the schistosity N 62° E. The dip of banding and schistosity is about vertical.

The mica schists are composed principally of quartz, biotite and limpid feldspar, with subordinate muscovite magnetite, sericite, garnet, epidote and apatite. The quartz, biotite and feldspar, which make up the mass of the rock, constitute an interlocking crystalline mosaic Locally the mica is muscovite but in general, biotite prevails. The biotite is definitely oriented, but the interlocking grains of quartz and feldspar do not, in the coarser grained rocks, partake of the schistose structure. In the finer grained varieties there is a tendency for elongation of many of the quartz and feldspar grains parallel to the biotiet

flakes. Quartz, the most abundant mineral, exhibits strain effects and inclusions in the coarse grained schists, but the absence of these features is characteristic of the finer grained facies. The feldspar, except in case of the biotite schists associated with the granite in section 8, T 46 N, R 41 W, occurs in small, limpid, unstriated grains and is very difficult to distinguish from the quartz. However, certain of the weak doubly refracting grains show brightly polarizing alteration specks, presumably sericite, and grains of this type have a uniformly lower index of refraction than the other grains which are clear and free from all alteration products. In addition, biaxial interference figures may be observed in some of the larger grains. The schist where intruded by granite shows considerable striated plagioclase feldspar, and is also fresher in appearance and rather coarse grained. Biotite alone exhibits parallel orientation; the quartz and plagioclase (about albite-oligoclase) form an allotrimorphic crystalline mosaic. Accessory minerals in the granitized schist are zircon, pyrite partly altered to red ferric oxide, a few grains of magnetite, epidote and apatite. The zircon, pyrite and magnetite are included in the biotite.

Origin of the mica schist. While we incline strongly to the view that the feldspathic mica schist is an altered sediment, the evidence is inconclusive. Rounded grains of quartz and feldspar are not uncommon, but in all cases they fit perfectly into the crystalline mosaic and can not be regarded as detrital with any degree of certainty. One or two doubtful indications of secondary enlargment were noted, but little reliance is placed on them. In the field, the schist is associated in almost every exposure with either diabase or massive greenstone. This association lead early to consideration of the idea that the schist might be a sheared phase of the massive rocks. Microscopic study of the greenstone and diabase shows, however, that these rocks are much more basic in composition than the schists. They are composed, dominantly, of green hornblende and basic plagioclase. Some specimens of the fresher diabase show traces of original pyroxene and the characteristic ophitic or lath shaped development of feldspar is in every instance preserved. The metamorphism of a rock of this type under conditions which would induce schistose structure would produce an amphibolite or hornblende schist rather than a typical quartz-mica schist. Furthermore it is possible to say with certainty that the massive greenstone intrudes the schist. The schist in fact seldom occurs except in association with massive greenstone. As a whole the schist is soft and easily eroded and therefore is more apt to be exposed in those places where it is partially protected by intrusive masses of greenstone of much greater erosive resistance. Consequently, it is probable that observation is confined to the most severely metamorphosed parts of



BANDED MICA SCHIST. SECTION 30, T. 46 N., R. 42 W.

the schist wherein evidences of sedimentary textures and structures have been obliterated. It is well known that contact metamorphism, even without addition or subtraction of material from extraneous sources, can change a pelite or psammite formation into a crystalline mica schist. Mention was made earlier in the discussion of the presence in certain outcrops of a banding at variance with the prevailing regional schistosity.

Intrusives. In addition to the mica schist the rocks of the southern area comprise amphibolite, hornblende schist, and intrusive greenstone, granite and diabase. These are certainly younger than the mica schist, and are probably to be correlated with similar intrusives in the Huronian sediments in T 46 N, R 42 W. The amphibolite and hornblende schist are in part derivatives of massive intrusive greenstone. Certain isolated outcrops may, however, be older and have no connection with the massive greenstone. The intrusives will be described later. For the present it should be borne in mind that intrusives are extremely abundant in the southern complex.

RELATIONS TO ADJACENT ROCKS.

Relations to Keweenawan. In section 13, T 46 N, R 41 W, Michigan, the steeply dipping and highly metamorphosed micaceous schists are overlain by the almost flat lying unaltered basal sandstone and conglomerate of the South Trap range. The conglomerate contains pebbles derived from the underlying schists.

Relations to Huronian. The relation of the southern schists to the Huronian rocks of the Marenisco range may only be inferred. The schist series lying south of the range is referred to the Archean for the following reason. These rocks lie at the eastern extremity of the territory between the Marenisco and Turtle ranges. The magnetic belts of these ranges mark the location of folded sedimentaries and lavas, a conclusion amply sustained by their linear character and the nature of the underlying rocks wherever exposed or opened in exploration. The gross structure between the Marenisco and Turtle ranges is believed to be anticlinal with the Huronian series exposed on either flank of the major fold.

The exposures along the Turtle range in T 46 N, R 41 W, Michigan, are effusive lavas with subordinate intrusive greenstone and diabase. At no place are these rocks in contact with the mica schist.

MIDDLE HURONIAN SERIES (ANIMIKIE).

The full succession of the Middle Huronian is exposed only in T 46 N, R 42 W, Michigan. The succession here includes basal graywacke-quartzite, iron formation and a vast thickness of slate occupying a

belt not less than two miles wide between the iron formation on the south and the Presque Isle granite of the Gogebic range on the north. The entire succession with the exception of the central part of the slate is highly metamorphosed.

GRAYWACKE-QUARTZITE.

The base of the Middle Huronian series is highly metamorphosed quartzite and graywacke. The quartzite is exposed in a large outcrop in the NW$\frac{1}{4}$ of SE$\frac{1}{4}$ of section 7, T 46 N, R 41 W, and also occurs on the dump of a pit in section 12, T 46 N, R 42 W, where it is apparently in association with the iron formation. The quartzite is a hard gray, vitreous, fine grained aggregate of interlocking, crystalline, quartz grains, containing rounded grains of orthoclase and plagioclase, abundant chlorite, and a small amount of sericite as an alteration product of feldspar. In thin section, in ordinary light the outlines of original clastic quartz grains are made conspicuous by fringing shreds of chlorite, but under crossed nicols a crystalline mosaic appears in which the only indication of sedimentary origin are the rounded grains of feldspar.

In sections 22 and 23, T 46 N, R 42 W, are a number of outcrops of fine grained, banded graywacke associated with intrusive diorite and diabase. The bands vary from mere laminae up to an inch or more in width. In places differential weathering of the bands has given the rock a ribbed appearance. Near the contact with the intrusives the graywacke is usually greatly contorted. Under the microscope the graywacke reveals a crystalline aggregate of quartz, epidote and zoisite, with some secondary feldspar and a few shreds of green hornblende. The rock is thoroughly recrystalline and in some cases a schistose structure is produced by parallel alignment of the hornblende crystals. The banding is caused by alteration of zones of finer and coarser grained material. The least altered of these rocks are made up of finely crystalline quartz, secondary feldspar, badly altered to sericite, scattered needles of green hornblende, and a few specks of magnetite, epidote and chlorite. In general, the texture is that of a recrystalline rock, but there are many rounded grains of quartz which seem to be caught in a feldspathic cement.

The occurrence of the graywacke immediately south of the iron formation in sections 22 and 23, as well as its position on the strike of the quartzite exposed in section 12, T 46 N, R 42 W, and section 7, T 42 N, R 41 W, its mineral composition, and its structure are the basis of our belief that this formation is part of the basal detritus of the Middle Huronian series. The exposures are in all cases intruded by greenstone and diabase, or located a short distance from outcrops of igneous rocks. To the presence of these igneous intrusives must be

ascribed the recrystalline character and the obliteration of the clastic texture of the graywacke when viewed under the microscope.

Neither the quartzite nor the altered graywacke were observed in contact with the Archean or any formation of the Huronian, but that both are stratigraphically below the iron formation is apparent from the field relations.

IRON FORMATION.

The iron formation of the Marenisco range is exposed in a number of pits and outcrops in sections 12 and 13, and in a few pits in section 22, T 46 N, R 42 W. The formation is also exposed in section 21, T 46 N, R 43 W, along the C. & N. W. R. R. track one half mile south of the station of Marenisco. From Marenisco southwest along the strike of the range there are no exposures, but diamond drill cores of iron formation were found at the Magnetic Center exploration in section 28, T 44 N, R 3 E, Wisconsin.

Lithology. The drill cores from the Magnetic Center exploration are a banded quartz-amphibole-magnetite rock. The banding is conspicuous on the polished sides of the core but on fractured surfaces close examination is necessary to distinguish the structure except where a wide band of light colored chert or quartz is present.

Proceeding from this locality northeast, exposures are first encountered on the C. & N. W. R. R. in section 21, T 46 N, R 43 W, Michigan, one half mile south of Marenisco station. The most striking characteristic of these outcrops is a conspicuous fine banding of various shades of gray, green and brown alternating across the face of the exposure in the plane of a well developed schistosity which is vertical and strikes in the general direction of the magnetic belt, N 55° E. Here and there are bands of dull gray to white chert, less persistent than the others, and broken into lenticular shaped masses resembling flattened fragments in an exceedingly schistose conglomerate. Blebs and stringers of quartz are abundant. Some of the bands are highly ferruginous, weathering to a rusty brown color.

The microscope reveals the presence of rounded clastic grains of quartz and feldspar embedded in a groundmass of finely crystalline chert, dirty greenish brown biotite, magnetite, carbonate (probably siderite) with subordinate amphibole and chlorite. The fine bands, so conspicuous on exposures, are caused by the alteration of bands of amphibole and biotite with bands of chert, magnetite and carbonate. Fragmental grains of quartz and feldspar are for the most part oriented with the long dimension of the particles parallel to the banding, but some of them show no tendency toward orientation. This rock is evi-

dently a highly metamorphosed lean iron formation intermixed with clastic material.

The best localities for observation of the iron formation are the pits in section 22 and the pits and outcrops in sections 12 and 13, T 46 N, R 42 W, Michigan. A careful examination of the rocks at these localities has been combined with the study of a large number of thin sections. In general, the rock is a lean iron formation, intensely metamorphosed and, for the most part, typically banded, the bands varying in width from mere laminae up to one to two inches. The wider bands are mainly light colored, crystalline quartz. The darker and narrower bands contain quartz and iron bearing silicates and oxides. These bands are not uniformly continuous, the smaller ones often pinching out and dovetailing with the larger ones in an intricate manner. Thin veins of pyrite and carbonate cement innumerable fractures across the banding. Pyrite and perhaps pyrrhotite have been concentrated along some of the darker bands. Certain of the dump specimens are not banded, and as a rule iron amphiboles are abundant in this type. The rocks may be classified as follows: (1) Chloritic-sideritic-magnetitic schist, (2) manetitic-sideritic-quartz rock, (3) actinolitic-magnetitic schist, (4) grüneritic-magnetitic schist, and (5) chloritic-biotitic-magnetitic schist.

The prevalent type in the pits of this township is the *magnetitic-sideritic-quartz rock.* In hand specimens the most pronounced feature is the alternate gray and white banding mentioned before. It is made up of quartz and magnetite with subordinate siderite and considerable chlorite in occasional bands and small flakes. Hematite and pyrite are present but not abundant. The banded structure, which is such a marked macroscopic feature, is due to alternate zones of fine and coarse grained quartz. The banding is heightened by the concentration of magnetite in the zones of finer grained quartz. This mineral occurs in two forms; (1) as small grains with a tendency towards crystal development, and (2) in large irregular patches that commonly show considerable fracturing with development of hematite and siderite in the fracture planes. The siderite and hematite in these situations appear to be alteration products of the magnetite. In general, the siderite occurs in small patches and occasionally in bands or zones not directly associated with the large irregular patches of magnetite although the carbonate, with the exception of an occasional small crystal, is confined to the bands in which magnetite is concentrated. It is probable that the siderite is original except in the cases noted above, where it appears to be formed along the cleavage cracks of magnetite. In by far the larger number of cases the tendency is for the development of magnetite along the cleavage cracks and around

the edges of the carbonate. Where the chlorite occurs in sufficient quantity to be a marked feature of the rocks as a whole it may be defined as a *chloritic-magnetitic-sideritic schist.*

The *actinolite-magnetite-schists* are usually dark gray and may or may not show banding. The bands vary from one inch to one eighth of an inch or less in width. The wider bands are predominantly finely crystalline quartz, magnetite and fibrous amphibole being concentrated in the narrower bands. Where the rock is not banded it is dark gray and shows the metallic luster of innumerable minute crystal faces of magnetite. In this rock the greenish yellow actinolite crystals seem to be collected in masses and rosettes. The banded types are made up of zones of finely crystalline quartz, alternating with zones of actinolite, magnetite and siderite. The quartz grains exhibit no trace of detrital origin such as rounded outlines or zones of secondary growth. While quartz is the most abundant mineral in the so-called quartz bands they contain a considerable amount of scattered siderite associated with the minute crystals of magnetite and occasional needles of actinolite. Alternating with the quartz are bands of magnetite, actinolite and siderite. The latter mineral occurs in every stage of alteration to actinolite, from pure crystals surrounded by needles of amphibole, through early stages of alteration in which actinolite occurs in the centers of the siderite grains along cleavage cracks, until, finally, the crystals of siderite can barely be discerned through the mass of actinolite fibres. In general, the center of these bands is occupied by unaltered iron carbonate, although in some of the narrower bands the alteration to actinolite has been complete. The amphibole is in its customary fibrous development. There is no alignment of the fibres. In the center of the bands and on the edges near the contact with the quartz zones the fibres lie at right angles to the banding and penetrate into the adjacent quartz grains. The magnetite is in well developed octahedra and is most abundant in the siderite-amphibole bands although it is present in much smaller quantities and smaller crystals in the quartz bands where it is closely associated with scattered grains of carbonate.

Thin sections of the *non-banded actinolite rocks* present a much different appearance. Siderite is not observed in rocks of this type. Upon a dull gray mosaic of small interlocking quartz grains there appear, as if painted, rosettes of actinolite through which are scattered idiomorphic crystals of magnetite. In the spaces between the rosettes of actinolite the finely crystalline mass of interlocking quartz grains appears. The actinolite occurs in rosettes of long, faintly green, almost colorless needles and in minute bundles between the quartz grains, the needles penetrating the adjacent quartz mosaic. Small individual

needles are also included in single individuals of quartz. Crystals of magnetite are scattered haphazardly through the rosettes of actinolite although there is sometimes a tendency towards concentration at the center and at the junction of two rosettes. In areas where the quartz predominates, the magnetite, while not entirely absent, is represented only by occasional and usually small crystals.

Grunerite-magnetite-schist occurs in a small outcrop near the pits in section 12. The variety cummingtonite has not been identified but as this mineral is rather common in the metamorphic iron formations of the Lake Superior country it is probable that a more careful search would result in its identification.

So far as it is possible to determine from the very limited data available, the iron bearing rocks of the Marenisco range do not differ from the metamorphic phases of the iron formation on the other Lake Superior ranges and there is no reason to believe that the Marenisco iron formation differs from them in origin. The abundance of carbonate and its apparent close genetic relationship with the magnetite and iron amphibole together with the bands of finely crystalline chert point to the primary deposition of cherty iron carbonate. There is evidence that locally, at least, the deposition of non-clastic ferruginous material was accompanied by clastic sedimentation.

Ore bearing possibilities of the iron formation. With regard to the ore bearing possibilities of the iron formation of the Marenisco range attention should be once more directed to a statement made earlier in this discussion, viz., that the range is everywhere characterized by strong to violent magnetism. The iron bearing rocks throughout the entire range are highly metamorphosed. The possibilities for discovery of valuable ore bodies are not promising. It is of course possible that some portions of the iron formation may have escaped the general intense metamorphism, and that in such places, ore bodies may have been concentrated.

Igneous intrusives in the iron formation. The iron formation exposed in the pits and outcrops in T 46 N, R 42 W, is closely associated with massive igneous intrusives. Considerable igneous material occurs on the dumps of some of the pits in iron formation. Many outcrops of altered diorite and diabase are in close proximity to the pits and a short distance southeast of the pit in section 22 is an area of granite, probably intrusive. Intrusives were nowhere observed in contact with the iron formation, but there can be no doubt that the latter has been severely altered by igneous intrusion. The presence of iron silicates, the completely crystalline character of the quartz, abundant magnetite, almost total lack of hematite, and igneous injection, described

below, all point to contact action as the cause of the extreme metamorphism of the iron bearing rocks.

Specimens from the dump of a pit near the center of section 22 are of special significance inasmuch as they show intimate injection of igneous material. These rocks are typically quartz-magnetite schists, dark gray to black and strongly magnetic. The noticeable feature is the presence of thin veins and streaks of red feldspar which cut across the banding of the rock in some places and in others are parallel to it. A slide made from one of these specimens cut one of the red veins and served to confirm the field determination of its mineral composition. The rock is made up of bands of finely crystalline quartz and magnetite alternating with bands composed of small interlocking grains of altered feldspar with subordinate quartz and considerable chlorite. The feldspar is filled with fine red dust and shows considerable alteration to sericite. The contrast between the clear, fresh quartz and the cloudy feldspar is marked. The feldspar in the bands is in a crystalline aggregate and the individual grains are small and unstriated. The uniformly lower index of refraction of the feldspar compared with the quartz, the observation of biaxial interference figures, and the character of the alteration product, leaves no doubt that these small grains were correctly determined. There is a tendency for chlorite to concentrate between the quartz-magnetite and the feldspathic bands, although it is scattered in flakes throughout the slide. Magnetite is present throughout the rock in well developed octahedra but is concentrated for the most part in the feldspar free bands.

No intrusive igneous material was found in or near the exposure of iron formation at Marenisco or at the Magnetic Center locality at the western extremity of the range, but the character of the rocks in these localities points toward metamorphism through igneous intrusion. In section 4, T 45 N, R 44 W, Michigan, there is a knob of granite projecting above the drift. This outcrop is a short distance north of the line of maximum attraction in the south magnetic belt and there can be little doubt that it is intrusive into the adjacent magnetic rocks.

THE SLATE FORMATION.

The slate formation in T 46 N, R 42 W occupies a belt about two miles wide north of the iron formation. Outcrops are not plentiful but their distribution together with the character of the topography and the absence of exposures of other rocks warrant the assumption that the slate underlies practically the entire area. The formation strikes northeast and the secondary cleavage is, on the whole, inclined steeply southward. The slate is probably as thick as the Tyler formation of the Gogebic range with which it is apparently lithologically

identical, but as in the case of the Tyler, its apparent thickness of about 9,000 feet may be in considerable measure accounted for by close folding.

Lithology. The main types are gray, grayish green and black slate and fine grained graywacke. Exceptional phases of local importance are chlorite, mica, and hornblende schists. The hornblende schists are confined to the borders of the slate belt near the contacts with the southern intrusives and the northern Presque Isle granite. In the central portion of the belt the rocks show no evidence of extreme metamorphism. Microscopic examination shows that the slate and graywacke are composed mainly of fine fragments of orthoclase, plagioclase and quartz. The central part of the formation is cut by veins of quartz which become increasingly important near the borders of the belt. In the neighborhood of the intrusives these veins are often noticeably feldspathic.

The most favorable localities for study of the unaltered slate of the central part of the belt are the exposures near the quarter post between sections 8 and 17 at the locality known as Nelson canyon, the extensive outcrops at Judson Falls on the slate river and the exposure at the outlet of the Slate river into Lake Gogebic. At Nelson canyon, a tributary of the Slate river has cut a gorge 375 feet long, 20 feet wide, and from 5 to 25 feet deep, parallel to the strike of the slate. At Judson Falls the river tumbles in a series of low cascades over the upturned edges of the slate for a distance of 500 feet. The rock at both localities is gray slate, very uniform in appearance, with here and there coarser graywacke phases. At Nelson canyon the slate contains reddish stained breccias which apparently caught the eye of the early explorer for iron ore and led to the sinking of a few shallow pits in the vicinity. At the mouth of the Slate river the rock is predominantly a fine grained graywacke with subordinate slaty phases. A peculiar feature of the coarser varieties are ellipsoidal cavities from one to three inches long, one half inch wide and from one half to one inch in depth. The cavities are in all cases oriented in the direction of schistosity.

The southern exposures of the slate series are more or less metamorphosed although their clastic character is commonly recognizable in the field. In the north half of section 20 there are two small outcrops of fine grained granitic material injected parallel to the schistosity. The schistosity is pronounced but the cleavage is less perfect than that of the northern exposures. As determined in thin sections this rock is composed of quartz, biotite, orthoclase, plagioclase and chlorite with scattered small crystals of apatite and tourmaline. The original clastic structure is plainly apparent in the rounded character of the larger grains of feldspar. The biotite is plentiful in small grayish brown

flakes with parallel alignment. The space between the larger fragments is filled with an interlocking mosaic of quartz, secondary limpid feldspar and biotite.

About 650 paces north of the south quarter post of section 15 is an outcrop of dense massive graywacke, the clastic structure of which is still plainly evident under the microscope, although a partial recrystallization has taken place. In the same section there is a small outcrop of the slate series in contact with diabase. Near the contact all traces of sedimentary textures in the slate has been obliterated by recrystallization.

Relations of the slate to adjacent formations. So far as known the contact between the slate and the underlying iron formation is not exposed but the relations are believed to be those of conformity.

The slate formation is intruded by the Presque Isle granite. The actual contact is exposed in two localities in section 4. Sheared chloritic schist occurs adjacent to the contact, but a short distance away the slate differs but little in appearance from the typical exposures in the center of the belt. The schist adjacent to the contact is cut by abundant stringers and veins of granitic material. In one place blocks of the schist are imbedded in the granite.

Dark colored fine grained quartz-biotite schists occur along the *east border* of the great granite ridge that forms the west shore of Lake Gogebic in section 33, T 47 N, R 42 W. The biotite schists, some of which are hornblendic, are intimately injected by granite and pegmatite and present the appearance of banded and contorted gneiss. Whether these biotite schists are a part of the slate series along the *south border* of the Presque Isle granite is entirely conjectural but their occurrence east of the granite is of some interest and furnishes the only clue to the nature of the rocks occupying the low ground in the southeast part of T 47 N, R 42 W.

IGNEOUS ROCKS.

The entire Huronian succession is intruded by both acid and basic rocks and the iron formation and basal quartzite are associated with extrusive flows and possibly tuffs.

Extrusives.

Altered Porphyrites. In section 7, T 46 N, R 41 W, about 200 paces north of an outcrop of the basal quartzite and in the strike of the iron formation in T 46 N, R 42 W, there is an exposure of schistose porphyritic lava. The outcrops occur for a distance of 30 paces in a narrow gorge on the west branch of Trout Creek. The lavas present some pe-

culiar and interesting features and will, therefore, be described in some detail. They are highly metamorphosed and schistose parallel to the prevailing strike. The dip of the schistosity is nearly vertical or inclined at a steep angle southward. The least altered rocks are plainly porphyritic but those that have suffered the greatest deformation are beautifully crenulated schists in which the phenocrysts may be detected only by careful search. The crenulated structure is caused by minute folding of the fibrous amphibole of the ground mass which has produced perfect false cleavage*. In the schistose specimens phenocrysts of red feldspar, showing in may cases good crystal form and attaining the size of one fourth inch in the longer dimension, are embedded in an aphanitic dull gray ground mass. At one place for a space of a few feet the rock has been brecciated and recemented by calcite which gives it the appearance of dolomite or limestone containing scattered nodules of chert. Under the microscope, however, these fine grained gray cherty appearing fragments are seen to be porphyrite differing in no respect from other porphyries in this locality. The porphyrites are cut out by a narrow dike of fresh diabase.

Microscopic examination of the porphyrites discloses badly altered and mashed phenocrysts of feldspar and quartz, feldspar predominating, embedded in a ground mass, which, in the schistose type, is composed of a fine grained fibrous mass of green hornblende or actinolite with abundant minute grains of epidote. Lesser quantities of magnetite, biotite, chlorite, quartz, limpid feldspar and calcite are present. Where the small fibers of amphibole are thrown into a series of close minute folds the slide shows beautifully the crenulated or helicoidal structure, while the rock as a whole has a well developed false cleavage. Where the rock is more massive in character the ground mass is made up of a very fine grained interlocking mosaic of unstriated feldspar, subordinate quartz, grains of epidote, a few scattered flakes of biotite, green hornblende and occasional grains or laths of magnetite. The phenocrysts are orthoclase with considerable subordinate plagioclase. In one specimen coarse grained granulated areas of quartz were noted, probably representing original quartz phenocrysts. Except in the freshest types the phenocrysts show crushing and granulation around the edges and where the ground mass is crenulated the large crystals are often bent and fractured and the cracks filled with a mosaic of quartz grains. In all cases the feldspar crystals are badly altered and some of the orthoclase is filled with fine red dust. Traces of carlsbad twining are common but the laminations characteristic of albite are rare. Alteration of the orthoclase produces sericite, of the plagioclase, epidote, biotite zoisite and albite. A peculiar and persistent feature of

*Leith, C. K. Bulletin 239, U. S. G. S., page 49, Pl. XIV B.

the porphyrites is the occurrence of micropegmatitic phenocrysts of quartz and orthoclase, quartz always subordinate. The structure is emphasized by the simultaneous extinction of the angular quartz areas and the contrast between the clear quartz and the badly altered orthoclase. Phenocrysts of this type have been noted by Iddings in rhyolite from the Eureka district of Nevada* and in obsidian from Yellowstone Park**. The ground mass of the non-schistose variety presents some suggestive features in the arrangement of epidote grains when observed in ordinary light. Fairly clear traces of flow structures appear and also less distinct indications of original perlitic parting.

There can be no doubt that the rocks in this vicinity are metamorphosed effusive lavas of composition near trachite. The determination of original character is rendered difficult by extreme alteration.

In section 29, T 46 N, R 43 W, on the south edge of the magnetic belt there is an exposure of similar altered effusive porphyrites intruded by granite.

Hornblende Schist. Closely associated with the iron formation in section 15, 21 and 22, T 46 N, R 42 W, Michigan, are a number of exposures of hornblende schist. They are dark gray to greenish black and are extremely fine grained and schistose. The schistosity controls a platy parting, in many cases so perfect as to give the rock the appearance of slate. Rarely a faint banding may be observed. Under the microscope the schists are seen to be composed almost entirely of a matte of small prisms and needles of compact green hornblende. Filling the interstices between the amphibole fibers are minute clear grains of limpid feldspar (albite) with subordinate quartz. Magnetite in small lathshaped individuals, oriented parallel to the schistosity, is abundant.

No traces of original structure or texture remain and it is therefore impossible to assign a definite origin to these schists. It is regarded as possible that they are metamorphic tuffs or squeezed basic lavas, an inference based upon the fact that in mineral composition and structure they are almost identical with the ground mass of the altered porphyrites found in section 7, T 46 N, R 41 W and at other localities on the Marenisco and Turtle ranges.

In section 15 the hornblende schists are intruded by massive greenstone, and in sections 21 and 29 by granite.

Relation of the Effusives to the Huronian Rocks. The outcrops of fine grained hornblende schist thought to be metamorphic lavas or tuffs, are closely associated with the magnetic belt marking the position of the iron formation in T 46 N, R 42 W, Michigan. Outcrops

*Monograph 20, U. S. G. S., p. 375, Plate V-2.
**Seventh Annual Report, U. S. G. S., pp. 274-276. Plates XV and X-2.

of this rock were found both north and south of the pits in iron formation in section 13. If these schists are altered lava flows it is probable that they are interbedded with the lower portion of the Huronian series.

The porphyrites exposed along the west branch of Trout creek in section 7 are located about 250 paces north of a large exposure of basal quartzite. The relation between the lavas and quartzite is unknown. About all that can be said is that the lavas dip under the quartzite but whether they are stratigraphically above or below it can not be determined. The attitude of the regional schistosity and the general succession of the Huronian series indicate that they are above the quartzite.

Intrusives.

The following discussion is applicable only in T 46 N, Rs. 41 and 42 W, Michigan. Southwestward, intrusive rocks are found in contact with the greenstone porphyries in section 29, T 46 N, R 43 W, Michigan. It was noted in connection with the description of the iron formation that a large exposure of granite occurs in the middle of the magnetic belt in section 4, T 45 N, R 44 W, Michigan. The position of this outcrop with reference to the magnetic belts in that locality suggests that the granite is intruded into the Huronian series. No other Huronian intrusives are known southwest of T 46 N, R 42 W, Michigan. However, the strong magnetism together with the metamorphic character of the exposed rocks is presumptive evidence that igneous intrusion has played an important role in metamorphism throughout the entire range.

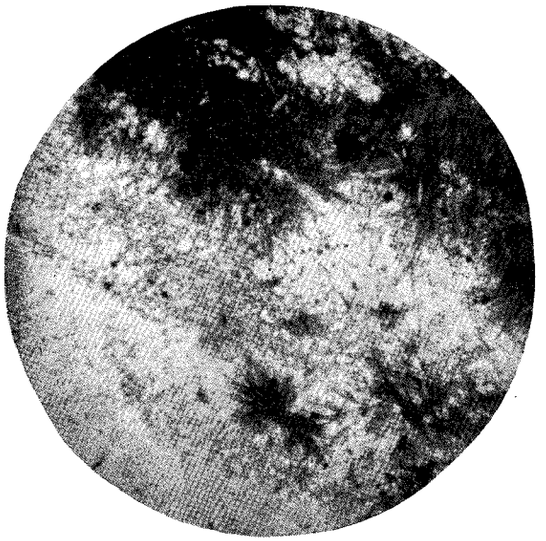
Inasmuch as the intrusives form the most abundant exposures in T 46 N, Rs. 41 and 42 W, Michigan, and are believed to have been the most important agents in the metamorphism of the Huronian rocks they will be dicussed in considerable detail.

The following description is not a thorough treatise of these rocks. From data at hand regarding the field relations and the limited number of thin sections available for study we can attain no more than a broad view of the field as a whole with the hope of bringing out the more general relations and characteristics of the intrusives.

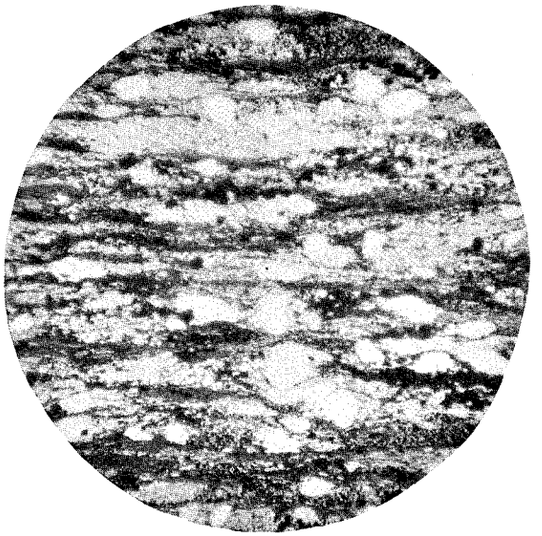
From the standpoint of composition, the intrusives fall, roughly, into three general classes; viz., *hornblende bearing greenstone, granite, and fresh massive diabase.* All three types are found in contact with both the Huronian rocks and the southern schist series. Whether the intrusives in the southern schist belong to an earlier period of igneous activity, or are contemporaneous and to be correlated, in whole or in part, with similar rocks intrusive in the Huronian series can not be determined with certainty. However, consideration of their petro-

(A). (Without analizer, X 16). Amphibole-magnetite-quartz rock from test pits in the NW¼ of NW¼ of section 12, T. 46 N., R. 41 W., Michigan. The rock is typical of the metamorphic iron formation found on this part of the Marenisco range. The black specks are magnetite, and fibrous mineral is grünerite and actinolite, the light areas are finely crystalline quartz and iron carbonate. The intimate association of the amphibole and magnetite with the siderite, while not apparent in the plate, is a marked feature of this rock.

(B). (Without analizer, X 16). Iron formation with intermixed detrital material from exposure along the Chicago and Northwestern Railway one-half mile south of the station of Marenisco, Michigan. The clastic grains of quartz and feldspar are easily seen. The remainder of the rock is composed of magnetite, chert, carbonate, amphibole and chlorite.



(A)

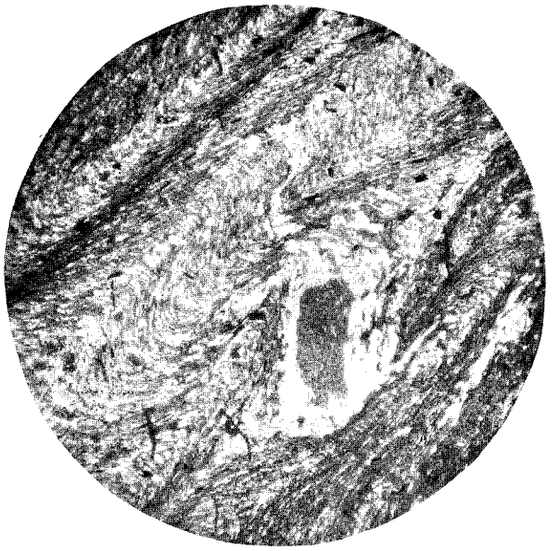


(B)

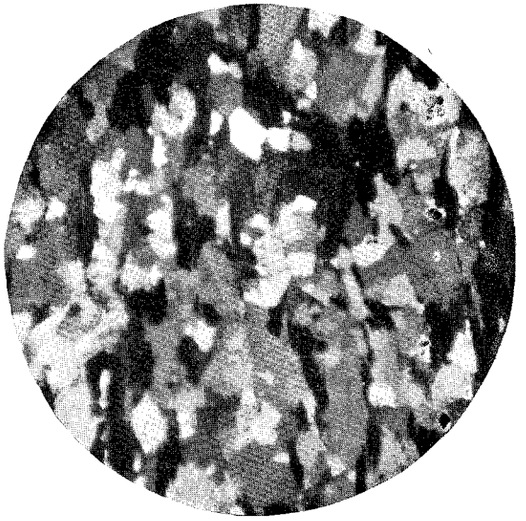
Plate VI.

(A). (Without analizer, X 16). Greenstone porphyrite from SW¼ of NW¼, section 7, T. 46 N., R. 41 W., Michigan. This is one of the more basic varieties from this locality showing the development of false cleavage in the arrangement of the hornblende needles of the groundmass. Near the center of the plate is a phenocryst of plagioclase showing saussuritic alteration in the center. Under crossed nicols the plagioclase phenocryst exhibits granulation around the edges.

(B). (With analizer, X 16). Feldspathic biotite-schist from Archean (?) area lying south of the east end of the Marenisco range. This is one of the coarser grained and thoroughly crystalline types. It is composed of plagioclase (albite and albite-oligoclase) quartz and biotite. Accessory minerals are sericite, epidote, apatite and zircon. These rocks are believed to be altered sediments.



(A)



(B)

graphic character and, more especially, the relation of the various types to each other in both areas renders it likely that in the case of the diabase and granite, and probably in large part the greenstone also, most of the similar intrusives in both the Huronian and Archean are of about the same age.

That the three main types, greenstone, granite, and diabase, represent three fairly definite periods of igneous activity seems to be established from a consideration of the field evidence. A more detailed study would undoubted modify this statement to a considerable extent, and would probably furnish evidence of a greater number of periods of intrusion, but it is believed that these would be largely in the nature of substages under one or more of the three major divisions.

The earliest intrusives are the greenstones. These rocks comprise altered diabase, diorite, and possibly gabbro. They are regarded as older than the fresh diabase and granite because where the relations were observed, the granite and diabase intrude the greenstone. Furthermore, the greenstones are in all cases badly altered and largely converted into schists in which nearly all, and in extreme cases all, traces of original textures and structures are obliterated. On the other hand, the granite, while in places rendered gneissose, is generally massive and fresh in appearance. The characteristic lath-shaped feldspar is a pronounced feature of the diabase. Thin sections exhibit fresh feldspar and the augite shows little uralitization.

While the evidence that the diabase and granite are younger than the greenstone is conclusive, the relation between the diabase and granite is obscure, as no contact of the two were observed. The extreme freshness of the diabase coupled with the fact that the granite nowhere intrudes the Keweenawan, whereas the diabase does, lends presumption in favor of the older age of the granite.

The most abundant types of intrusive rocks are *hornblende bearing greenstone and green schists.* The only mineral that can be universally recognized in hand specimen is green hornblende. Occasionally, in the more massive varieties, feldspar, or rather gray saussurite, can be recognized in blotches between the green hornblende crystals. In general, the structure is massive but where the rocks are in contact with granite they are characterized by a markedly schistose structure and development of considerable biotite which may entirely replace the hornblende. Near some contacts the schists are cut by many stringers of granitic material and pegmatitic veins and here and there blocks of schist are enclosed by granite. In other cases the contact is sharp and about parallel to the strike of the prevailing schistosity.

The most striking and constant features of the greenstone are the universal presence of green hornblende and the badly altered condition

of the rock as a whole. The minerals are green hornblende, plagioclase, quartz, chlorite, biotite, epidote, magnetite, leucoxine, calcite, zoisite, saussurite, sericite, rutile, anataze and apatite. Badly altered original feldspar with a tendency toward idiomorphic development in the prism zone is ordinarily present in the massive types. Traces of ophitic and granitic textures are not uncommon but more often, even in the massive types, original textures and structures are nearly obliterated. The feldspar is almost destroyed, but obscure twinning lamellae are occasionally visible in a mass of alteration products. The common alteration products of the feldspar are quartz, albite, epidote and calcite. Cloudy saussurite is less often observed. The hornblende is in large green fibrous individuals generally showing a tendency towards crystal development in the prism zone but fraying out at the ends. In some cases this mineral is compact but in general it is sedgy and fibrous. Where the hornblende is compact it is commonly cellular. Alteration of the hornblende to chlorite may proceed to such extent that chlorite predominates over the amphibole. No trace of original augite occurs although hornblende is occasionally pseudomorphous after the pyroxene. Biotite is a minor constituent of the massive greenstone and occurs in part as a parallel intergrowth with hornblende, and in part as an alteration product of feldspar. Irregular grains of epidote are abundant. Magnetite is an important accessory mineral, largely associated with clusters of rutile or surrounded by leucoxine. Irregular blotches and small grains of calcite are very common.

In summary, the greenstones are all badly altered; green hornblende is a universal constituent; wherever traces of original texture or structure remain they are those of igneous rocks. Owing to the badly altered condition of the feldspar, and the entire absence of primary augite it is extremely difficult to define the exact original character of the rock from which they were derived but the majority are probably altered diorites and diabase. Hornblende pseudomorphs after augite probably means that gabbro is included in the parent rocks. However, the common idiomorphic development of feldspar in the prism zones, and the development of secondary albite and quartz rather than saussurite favor the assumption that diorite or diabase was the prevailing original rock. On the other hand, the tendency of the pyroxene to pass over into green hornblende or uralite may account for the present apparent absence of rocks of the gabbro type.

Granite. Granite is exposed in two areas in the southwest portion of T 46 N, R 42 W, and the west central portion of T 46 N, T 41 W. The rocks are light gray and pink and for the most part massive and fresh in appearance. Near the contact with the greenstone the granite is usually gneissose. In texture it varies from fine grained normal

granite to coarse pegmatite. The minerals include orthoclase, plagioclase, microcline, quartz, biotite, sericite, chlorite, hematite, pyrite and apatite. The orthoclase and plagioclase show considerable alteration but the microcline is very fresh. The granite exhibits no other petrographic features of importance.

Diabase. Fresh massive diabase occurs in abundance in dikes and small knobs. It is dark greenish gray to black with an occasional outcrop showing a reddish tinge. The rock is easily recognized by the universal presence of lath shaped feldspar. Many of the dikes cut the greenstone at wide angles to the prevailing schistosity. Under the microscope the diabase appears to be very fresh or only slightly altered.

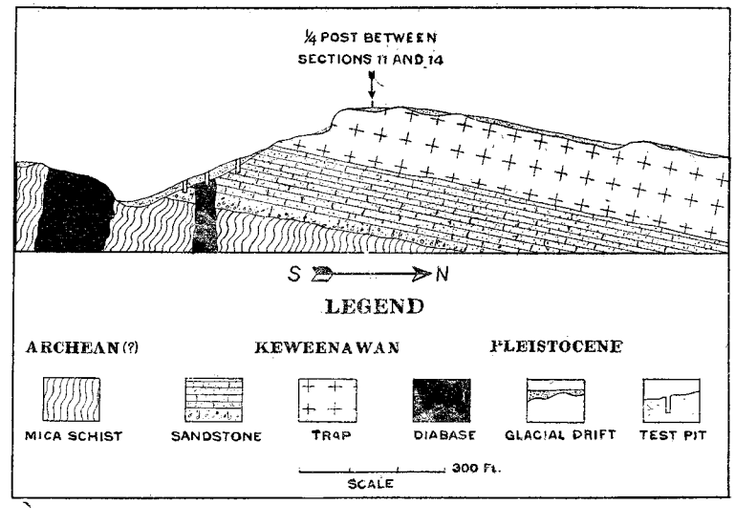


Figure 3. Diagram showing relations between Keweenawan sandstone, trap and intrusive diabase in sections 11 and 14, T 46 N, R 41 W. (After Seaman).

The minerals are plagioclase, augite, olivine, uralite, serpentine, magnetite and hematite. The texture varies from fine grained basaltic to coarse grained. The feldspar is idiomorphic giving the rock a well developed ophitic texture. The interstitial material is augite, somewhat altered to uralite and olivine showing alteration to serpentine, hematite, and magnetite.

Relations of the Intrusives to the Algonkian and Archean. Diabase is intrusive into the lower sandstone member of the Keweenawan in section 14, T 46 N, R 41 W. This relationship was noted by A. E. Seaman* in 1891 during the examination of the South Trap range.

*Unpublished field note. Michigan Geological Survey. Notebook 85.

There are a number of pits on the slope of the rise leading to a steep southwest facing bluff of Keweenawan trap (see *Fig. 3*, reproduced from drawing in Seaman's notebook). Diabase, showing the characteristic lath shaped feldspar, occurs in a shaft 35 feet deep about half way up the slope of the hill. About 35 feet southwesterly from the shaft and 15 feet down the slope is a shallow pit of sandstone (quartzite). Seaman describes this occurrence as follows: "The rock is quite hard and appears to be indurated by the diabase. The dip is under and toward the diabase at an angle of about 12°. The rock is composed of finely rounded grains of quartz and minute reddish specks of feldspar material evenly distributed through the mass with what appears to be a siliceous content." Twenty five feet southwest of the pit in sandstone and about 20 feet lower is another pit "in a somewhat closely consolidated aggregate of rounded grains of quartz and feldspar with a cement of iron oxide and silica. The dip here is the same as in No. 2 and the rock bears no evidence of disturbance. The strike as indicated by the dip is a little south of east." The above facts establish with certainty that the diabase is later than the lower sandstone member of the Keweenawan series. Correlation of the many diabase dikes and knobs south of this locality with the rock here exposed must rest on lithological similarity alone. Fresh diabase intrudes sedimentary members of the Huronian as well as the greenstone effusives of probable Huronian age in section 7, T 46 N, R 41 W. It also intrudes the mica schist on the southern Archean area, and the northern Laurentian granite.

The southern granite was not observed in contact with the Upper Huronian sediments, but certain of the specimens from the test pit dumps, section 22, T 46 N, R 42 W, show intimate injection of feldspathic material and the slate formation in section 20 of the same township is cut by narrow pegmatite dikes. In sections 29 and 30, T 46 N, R 42 W, granite is intrusive in fine grained hornblende schist described as metamorphic Huronian lava or tuff. The mica schists of the southern complex are intruded by granite in section 8, T 46 N, R 42 W. Aside from the above occurrence granite was found in contact only with greenstone.

The predominating intrusive in T 46 N, Rs. 41 and 42 W, as before noted, is the greenstone. Actual contacts between this rock and the micaceous schists of the southern complex are plentiful and in all cases the greenstone is intrusive in the schists. In section 22 the greenstone intrudes the graywacke at the base of the Upper Huronian. Although the greenstone is not known to intrude the iron formation, abundant outcrops of the former in close proximity to the test pits, the finding of igneous material mixed with the iron formation in some of the pits, and the general metamorphic character of the iron formation are evidence that the greenstone is also intrusive into the iron bearing rocks. The coarsening of grain and the tendency toward recrystallization shown by the southern part of the slate series is presumptive evidence that this formation has also been intruded by igneous material, although it is apparent from the character of the central exposures and general lack of outcrops of igneous rocks inside the slate area that this formation has been the least affected by the tremendous igneous activity which wrought such extreme metamorphism in the two lower formations.

There can be no doubt that the metamorphism of the Huronian rocks, both sediments and lavas, is mainly the result of igneous intrusion and injection. The type of metamorphism is that characteristically induced and affected by igneous action. Abundant iron amphibole and magnetite, the completely recrystalline character of the quartz, the occurrence of intimately injected feldspathic material in the iron formation and the entirely recrystalline character of the basal quartzite and graywacke are evidence of metamorphism induced by igneous intrusion.

CHAPTER V.

GEOLOGY OF THE TURTLE RANGE.

R. C. ALLEN AND L. P. BARRETT.

INTRODUCTION.

The Turtle Range extends from T 41 and 42 N, R 1 W, Wisconsin, northeast about 76 miles to the central portion of T 46 N, R 40 W, Michigan, where it is cut off by the overlapping Keweenawan rocks of the South Trap Range. The range has been traced by magnetic survey about six miles farther east underneath the Keweenawan sandstones and trap to the vicinity of Barclay in T 46 N, R 39 W. (?) Its position is marked, except for short breaks at each extremity, by a continuous magnetic field. In many places there are double, triple, and even quadruple parallel belts. The Turtle range is separated from the Marenisco range north of it by a territory from two to seven miles wide in which there is little magnetic distortion and, except in the northeastern portion, no rock exposures. The geology of the territory between the two ranges was described in connection with the Marenisco range under the heading, "Southern Archean Area."

The Turtle range is separated for the greater part of its extent from the Manitowish ranges south of it by a similar territory almost devoid of rock exposures and characterized by absence of magnetic belts. In places, however, the Turtle and Manitowish ranges are apparently connected by magnetic belts bridging the stretch of non-magnetic territory, although in no instance can a magnetic belt of either range be traced to a direct connection with a magnetic belt of the other. This relationship is shown on fig. 1. In T 45 N, R 41 W, Michigan, the magnetic belt which has an east west strike through the south half of the township to the east takes a sudden turn to the north and can be traced as far as section 2 of the former township. There is an apparent connection of the Turtle and Manitowish ranges in T 43 N, R 6 E, Wisconsin, in the vicinity of sections 14 and 15. In T 41 and 42 N, Rs. 2 and 3 E, Wisconsin, there are nine parallel magnetic belts separated by narrow intervals of non-magnetic territory. Of these we include the three south belts in the Manitowish range and the six north belts in the Turtle range. Rock exposures are known in the area be-

tween the two ranges only at the northeastern extremity in T 46 N, R 39 W, and T 45 N, R 39 W, Michigan.

The Turtle range comprises rocks of both the Middle and the Lower Huronian series. There are exposures and explorations on its opposite ends, but its middle section of 25 miles from the Banner locality in section 1, T 45 N, R 43 W, Michigan, southwest to Mercer, Wisconsin, is entirely drift covered. The succession and character of the sedimentary rocks are determined mainly from data obtained from explorations for iron ore. Natural exposures of the sediments are almost entirely lacking but in some localities there are abundant exposures of the associated intrusive and extrusive igneous rocks.

Explorations for iron ore were conducted many years ago in Wisconsin at the old Michigan mine in section 22 and at the Broomhandle location in section 29, T 42 N, R 1 E; on the Lucas-Ford and Whiteside farms in sections 5 and 3 T 41 N, R 1 E, at other localities in this township, and in T 42 N, R 2 E. In Michigan the only exploration of importance is at the Banner mine in section 1, T 45 N, R 43 W. Recent diamond drilling by R. B. Whiteside and associates in section 4, T 41 N, R 1 E, Wisconsin; by the F. I. Carpenter syndicate in the vicinity of Mercer and Winegar, Wisconsin, and by the E. J. Longyear Company at the Banner locality, has added definiteness to some of our earlier conceptions of the geology of the Turtle range and has furnished the only evidence of the occurrence of the Lower Huronian series. As in the case of the Marenisco range, we know of no reference to the existence of the Turtle range in geological literature. In 1877, F. H. King* mentioned the occurrence of granite, hornblende, and mica schist on the Turtle river in the southern part of T 41 N, R 1 E, and the occurrence of greenstone at Turtle Falls in section 6, T 42 N, R 3 E, Wisconsin.

The following expresses the succession of formations so far as known:

*Geol. of Wisconsin, Vol. IV, Part IV, Geology of the Flambeau Valley, by F. H. King.

SUCCESSION ON THE TURTLE RANGE.

	Keweenawan (?)		Intrusive diabase, granite and greenstone.
Algonkian	Huronian	Middle Huronian (Animikie)	Granite Effusive, agglomeratic and ellipsoidal greenstone. Basic tuffs (?). Black slate and graphitic schist. Iron formation. Quartzite and mica schist.
		Unconformity (?)	
		Lower Huronian	Mica schist (May be Middle Huronian.) Dolomite and dolomitic quartzite. Quartzite.
		Unconformity	
Archean		Keewatin (?)	Mica schist and green schist.

ARCHEAN.

With the exception of those described in connection with the Marenisco range, exposures of Archean rocks are confined to the territory south of the east extremity of the range.

The mica schists and banded mica and hornblende gneisses exposed along the Flambeau River in T 41 N, R 1 E; T 41 N, R 2 E; and T 42 N, R 2 E, Wisconsin, are assigned doubtfully to the Archean merely because there is no evidence of later age. These were described by King in 1877. Garnetiferous feldspathic biotite schist occurs also in test pits near the N$\frac{1}{4}$ corner of section 11, T 41 N, R 1 E. The strike of the gneissose and schistose structures of these rocks is in general N 45° to 60° E. The schist from the pits in section 11 is very similar to the mica schist from the Southern Archean area of the Marenisco range.

HURONIAN GROUP.

LOWER HURONIAN SERIES.

Dolomite and quartzite. The Turtle range has been cross-sectioned by recent diamond drilling at Winegar, Wisconsin, by the F. I. Carpenter syndicate, and at the Banner location, Michigan, by the E. J. Longyear Company. At both localities dolomite underlies a slate iron formation series. The dolomite is massive, light colored and recrystalline, very similar in general to the Lower Huronian dolomite formations of the Marquette, Menominee, Crystal Falls, and Gogebic districts but apparently lacks the characteristic chert bands of these formations. The dolomite in the Winegar section is almost pure calcium magnesium carbonate and contains few other minerals or impurities. Cores from a drill hole on the south end of the Winegar section show a dolomitic quartzite with abundant development of tremolite; the hole on the extreme opposite end of this section shows a vitreous quartzite and mica schist intruded by granite and greenstones. It is therefore possible that the dolomite is underlain by quartzite in which event the analogy between the Lower Huronian here and on other Michigan ranges is practically complete.

There is evidence in the drill hole sections at Winegar that the dolomite is strongly developed; it can hardly be less than 1000, and it may be as much as 2000 feet thick.

The drilling does not determine an unconformity between the dolomite and the overlying slate-iron formation series for none of the holes cross the contact horizon. On the basis of analogy with other Michigan ranges unconformable relations may be assumed pending definite determination.

MIDDLE HURONIAN (ANIMIKIE) SERIES.

At the west end of the range the Middle Huronian is represented by quartzite, iron formation, and slate, the succession characteristic of this series in the greater part of the Lake Superior region. In the east central portion of the range, at the Banner mine and at Winegar, black slate apparently underlies the iron formation, and at both localities the rocks are compressed in close synclinal folds and the formation overlying the iron bearing rocks has been removed. The Middle Huronian series is associated with effusive greenstones showing in many places ellipsoidal and agglomeratic structures and porphyritic textures. Rocks of this type are abundantly exposed from Mercer, Wisconsin, southwestward to the vicinity of the old Michigan mine. On the opposite end of the range from the Banner location northeastward outcrops of effusive greenstones are plentiful. In general it may be

said that basic effusives are characteristic of the range in all localities where rocks are exposed, and that they occur throughout the range is a reasonable assumption. In certain localities the Huronian rocks have been intruded by diorite, diabase, and granite.

The sedimentary rocks of the Middle Huronian may be studied to best advantage in townships 41-42 N, R 1 E, Wisconsin, where many old exploration pits furnish a basis for a definite determination of the series. Natural exposures are limited to a single outcrop of iron formation found at the Michigan mine locality in section 22, T 42 N, R 1 E. At this end of the range the Huronian rocks are apparently thrown

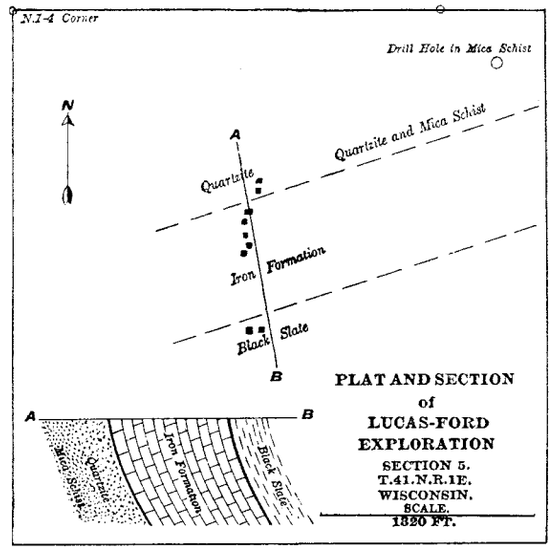


Figure 4.

into a number of close parallel folds whose position is marked by parallel magnetic belts.

From the present information description of a general succession applicable to the entire range is impossible. We will therefore describe in detail the rocks from a number of different localities.

Ford-Lucas Section (Fig. 4). At the Ford-Lucas exploration (NE$\frac{1}{4}$ of the NE$\frac{1}{4}$ and SE$\frac{1}{4}$ of the NE$\frac{1}{4}$, sec. 5, T 41 N, R 1 E, Wisconsin) the Middle Huronian rocks were cross sectioned many years ago by a number of test pits. The material thrown out on the dumps of these pits furnishes abundant evidence of the character of the underlying rocks. The succession is quartzite-iron formation-slate forming the north limb of a syncline, both limbs of which are indicated in the

Whiteside exploration one and three quarters miles east. No other rocks are exposed at this locality. The accompanying figure shows the location of the pits. There are a number of other pits in the vicinity but their dumps give no indication that bed rock was opened in them. No natural exposure of the Middle Huronian sediments is known at this locality.

The *basal quartzite* is exposed in the two most northerly pits while additional information as to its character is furnished by a recent drill hole put down by R. B. Whiteside near the northwest corner of section 4. This hole is reported to have passed through 400 feet of muscovite-quartz schist. The rock exposed in the test pits is a dense, fine grained, faintly banded, gray quartzite through which are scattered numerous small cubes of pyrite. It is composed of quartz, pyrite, and innumerable particles of black dust. The quartz is entirely recrystalline and in thin section is arranged in a finely grained mosaic of roughly hexagonal individuals. Pyrite is plentiful in small cubes, slightly larger than the individual quartz crystals, and the black dust is scattered throughout as inclusions in quartz. Metamorphism has obliterated all traces of clastic texture but the mineral composition and the presence of definite though faint banding admit of no doubt that the rock is an altered sediment. The thickness of this formation is not less than 150 feet and is probably greater than 300 feet.

The *iron formation* is exposed in a number of pits south of the quartzite. In general, it may be described as finely banded, dark gray to black, siliceous amphibole-magnetite schist carrying a little residual carbonate. Narrow bands of brown amphibole and wider bands of rather coarsly crystalline quartz are abundant. The wider, light colored bands are mainly quartz, the magnetite and amphibole being concentrated in the narrower and darker colored layers. The important minerals are quartz, grünerite, and magnetite with subordinate carbonate, (probably siderite) and brown iron oxide. In general, the minerals are arranged in definite layers or bands. The quartz is entirely recrystalline and appears in thin section as a typical interlocking mosaic. The coarser grained bands are nearly pure silica, while those of finer grain contain abundant magnetite. The amphibole is, in all specimens examined microscopically, grünerite, but it is very probable that the varieties actinolite and commingtonite are present. Grünerite commonly occurs in fairly large individuals oriented parallel to the banding; to a less extent as small twinned individuals and in compact bundles of needles. In the larger grünerite individuals alteration to brown iron oxide occurs along cleavage cracks and around the borders. Many irregular shaped crystals of magnetite are included in grünerite and the contact between the grünerite individuals is often marked by concentration of magnetite and carbonate. Certain bands are made up of small, well formed, twinned crystals of grünerite with considerable magnetite, the latter partly in parallel intergrowth with the former. The grunerite has a well developed parallel alignment.

Unaltered ferruginous chert and cherty iron carbonate are not found in this locality. The formation is highly metamorphic and offers little promise of containing workable bodies of iron ore in the immediate vicinity. The thickness is not less than 650 feet, and probably not more than 700 feet.

The overlying formation, exposed in the two southerly pits, is *soft black spotted slate* that weathers yellow. Under the microscope small, well crystallized, colorless garnets appear imbedded in an exceedingly schistose ground mass which under high magnification is resolved into a felty mass of minute flakes of biotite between which can be dimly seen limpid grains of dull gray quartz and feldspar (?) filled with carbonaceous dust. The quartz and feldspar (?) are barely discernible because of the abundance of the mica and carbonaceous inclusions. The garnets, which give the rock the spotted appearance in hand specimen, are colorless and usually well crystallized. The schistosity curves around them producing a characteristic augen structure.

No data is available upon which to base a determination of the thickness of the slate. In *Fig. 4*, the dip given to the formation in the cross section is entirely theoretical. The drill cores from the hole shown in the NE corner of the section indicate a very steep dip. Inasmuch as the structure in this region, as revealed a short distance east, is probably synclinal, a southerly dip was assumed in constructing this section.

Whiteside Exploration (Fig. 5). The Upper Huronian series here apparently forms a syncline with opposite limbs exposed in the exploration pits. The north limb of the syncline is continuous with the Lucas-Ford exploration to the west. The succession at the latter locality is repeated in the Whiteside pits.

The *basal quartzite* so well exposed at the Lucas-Ford locality is represented here by a few large angular fragments of hard, gray, vitreous quartzite thrown out on the dump of the southernmost pit.

The *slate* is almost identical in character with that in section 5. It is a typical, pyritic, black slate.

The *iron formation* is well exposed in the dumps around the old shaft and pit on the north limb and on the dumps of several pits on the south limb of the syncline. On the north limb it is for the most part a rather lean, limonitic chert containing considerable magnetite and a little unaltered iron carbonate. The rock is typically banded, yellowish-brown limonitic bands alternating with other bands composed predominantly of white, grayish-black, and occasionally reddish chert.