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[Monograph XIX.]

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WASHINGTON, D. C., *July*, 1893.

DEPARTMENT OF THE INTERIOR

# MONOGRAPHS

OF THE

# UNITED STATES GEOLOGICAL SURVEY

VOLUME XIX

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1892

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

# THE

# PENOKEE IRON-BEARING SERIES

OF

# MICHIGAN AND WISCONSIN

BY

ROLAND DUER IRVING

AND

CHARLES RICHARD VAN HISE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1892

CONTENTS.

# ILLUSTRATIONS.

# LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY, LAKE SUPERIOR DIVISION,
*Madison, Wis., May 1, 1890.*

SIR: I transmit herewith the manuscript of a memoir upon the Penokee iron-bearing series of Michigan and Wisconsin, by the late Prof. Roland D. Irving and myself.

Prof. Irving's death occurred so early in life that, while his contributions to geology are large, his later works show that he had but fairly entered the period which would have been the most fruitful in scientific results. The report submitted was designed by Prof. Irving to be the first of a series which should treat each of the important iron-producing districts adjacent to Lake Superior. To him who built up the division and who planned this investigation is very largely due whatever excellence this volume may have. I must necessarily assume, for the most part, the responsibility for the present form of the memoir.

The field survey for the present report began five years ago. The seasons of 1884, 1885, and the larger part of that of the following year I gave to this work. For a time in 1885 and in 1886 Prof. Irving accompanied the party in person. When the work began the district was one which explorers had but fairly entered and no railroad reached any part of the range except the Wisconsin Central, which crosses it at Penokee gap. The district has since developed into one of the most important iron-producing areas of the country, its product in the lake Superior region being exceeded by that of the Marquette district only.

Before the beginning of this investigation Prof. Irving had done a large amount of field work upon a portion of the range for the Wisconsin

Geological Survey and had prepared a systematic report upon this part of it. He was thus able to direct the more detailed examination of the whole area so that no loss of time should occur. The plan of the work and of the present book is very largely his.

The descriptions of the formations and thin sections are, for special reasons, given in greater detail than is intended with any subsequent area. This is the first of the iron-producing districts of lake Superior in which the geology has been worked out in detail, and the fundamental conclusions reached are in opposition to those expressed by some geologists; so that it was thought necessary to make the facts fully accessible to those who desire to have them. The succession of formations is so clear also that it is believed that the results contained in this report will serve as a key to unlock, in a measure, the more complicated geological structure of the adjacent iron-producing districts. In order to enable the general reader to avoid details, the descriptions of particular rock exposures and their thin sections for each of the formations are placed together in small type.

To Mr. J. Parke Channing our especial thanks are due for a large amount of gratuitous work, and in particular for his detailed examination and drawings of many of the mines, and for the facts contained as to the structural relations between the dike rocks and ore bodies. As mining inspector of Gogebic county, he resided in the district and has from time to time given us the results of the latest developments. Mr. J. M. Longyear, of Marquette, Michigan, has also given us much assistance, including access to his very large collection of specimens of the Gogebic end of the range, made as the agent of the Lake Superior and Portage Ship Canal Company. To Mr. B. N. White and Mr. Charles Oley, woodsmen, we are indebted for all the assistance which could be given by skilled men somewhat familiar with the district. To numerous miners and mine superintendents we are indebted for many courtesies. With a few exceptions, information with reference to mining properties has been freely granted to us by all.

The original design was to publish the whole book as a joint production, but the death of Prof. Irving occurred in the midst of the preparation of the volume, so that much of it has wholly devolved upon me; consequently, I have not felt warranted in using his name in this general way. Chapter I he prepared, with the exception of a few pages, and this is credited to him; chapters III, IV, and V were jointly prepared; the remaining chapters have fallen upon me. In order to make it perfectly clear to what extent the work can have the shelter of Prof. Irving's authority, each chapter is headed by the name of its author.

Very respectfully, your obedient servant,

C. R. VAN HISE,
*Geologist in charge.*

HON. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C*

# OUTLINE OF THIS PAPER.

The Penokee series proper is a succession of formations extending, with some breaks, from lake Gogebic, Michigan, to lake Numakagon, in Wisconsin, a distance of about 80 miles. It is a monoclinal series, its dips being universally to the north. The three formations making up the Penokee succession are the Quartz-slate member, the Iron-bearing member, and the Upper-slate member, and below these is the Cherty limestone formation. The series is sharply separated geographically from a crystalline complex to the south, called the Southern Complex. It is separated with equal sharpness from the Keweenaw series to the north.

Chapter I gives a history of the geological explorations in the Penokee district and a full summary of previous literature.

Chapter II treats of the Southern Complex. This consists of two main types of rocks—light colored, coarse grained granites and granite-gneisses, and dark colored, fine grained, finely laminated schists. In passing from west to east are found in order the Western granite, the Western green schist, the Central granite, the Eastern green schist, and the Eastern granite areas. The rocks of the Southern Complex are always completely crystalline. If any of them are of fragmental origin their present constitution gives no evidence of this. The contacts between the granite and the schists are eruptive, the granite being the intrusive rock. The schists are consequently older. Certain of the most laminated schists grade into rocks which are of distinctly eruptive types, and hence the only rocks in the Southern Complex the origin of which is known are igneous.

Chapter III treats of the Cherty limestone below the Penokee series proper. This formation, instead of being continuous, is found only at intervals, and varies in thickness up to 300 feet. It consists of cherty dolomitic limestone alternating with layers of chert. The Cherty limestone is a water-deposited sediment, but whether of chemical or organic origin, or of both, is uncertain.

Chapter IV treats of the Quartz-slate member. This member rests directly upon the Cherty limestone or upon the Southern Complex. It is a persistent, well characterized horizon, having an average thickness of about 500 feet. The Quartz-slate is always plainly clastic, and quartz is its prominent constituent, although other minerals, and especially feldspar, are not unimportant. Its uppermost horizon is a layer of pure vitreous quartzite.

Chapter V treats of the Iron-bearing member. This persistent formation, averaging about 800 feet in thickness, rests upon the vitreous quartzite of the Upper-slate member. It now consists of three main types of rock, cherty iron carbonates, ferruginous slates and cherts, and actinolitic and magnetitic slates. The first of these is the original type of rock and from it, by means of chemical changes, the second and third types, as well as the ore bodies, have been produced. Theore bodies are found in the lowest horizons of the formations and are secondary concentrations. They occur in V-shaped troughs, one side of the V's being the upper quartzite of the Quartz-slate, and the other diabase dikes. In the Animikie series, on the opposite side of lake Superior, is an iron-bearing formation which has the same types of rock, derived from the same original form as in the Penokee series.

Chapter VI treats of the Upper-slate member. This formation rests upon the Iron-bearing member. It has a maximum thickness of 12,000 feet, and has an extent east and west for many miles, although it is not so extensive as the Iron-bearing and Quartz-slate members. The formation is of clastic origin and consists mainly of graywackes and graywacke-slate. It is now locally altered by metasomatic changes so that it has become a crystalline mica-schist.

Chapter VII treats of the eruptives. The Penokee eruptives are diabases, which structurally are of two classes, dikes cutting the formations, and interbedded sheets which are probably intrusives of the same age as the dikes. The eruptives are fresh in the slate members, but are much or completely altered in the Iron-bearing member, showing that environment, not age, is the important factor in the preservation of these rocks.

Chapter VIII treats of the Eastern area. In the eastern part of the district, as a result of contemporaneous volcanic action, the Penokee succession is disturbed, and associated with the ordinary detrital rocks are surface basic volcanic flows, and also greenstone-conglomerates and agglomerates. Consequent upon this volcanic disturbance the regular alternation of clastic and nonclastic members of the Penokee succession is much modified, so that the number and order of the formations here found differ from those in the remainder of the district.

Chapter IX treats of the general geology of the region. While the outcrop of the members of the Penokee series as a whole are gently curved, sharp flexures and faults are not common. One fault occurs at Bad river, another at Potato river, and perhaps one in the Eastern area. The base of the Quartz-slate member contains fragments derived from the Cherty limestone member, showing that between these formations there was an erosion interval. How great the time gap represented by this is there is no means of judging, except that the chert of the limestone was certainly in its present condition at the time of the deposition of the Quartz-slate. The Quartz-slate, Iron-bearing and Upper-slate members form a conformable succession. Between the Penokee series proper and the Southern Complex there is a very great unconformity. Before the deposition of the Penokee series the Southern Complex had reached its present completely crystalline condition and was reduced nearly to a base level. Between the Penokee series and the overlying Keweenawan is a second very considerable unconformity, sufficient to have removed in places the entire Penokee succession. After the erosion and deposition of the Keweenaw series the whole was tilted toward the north, so as to give the present monoclinal structure, after which the Eastern sandstone was deposited upon the upturned series in its present horizontal attitude. The Penokee series is limited on the east by the overlapping Eastern sandstone; on the west it was cut away by erosion before Keweenawan time, so that the Copper-bearing series rests directly upon the Southern Complex. The Penokee series proper is the equivalent of the Animikie, the Upper Original Huronian, and constitutes a part of the Upper Huronian of the lake Superior region. The Cherty limestone is the equivalent of some part of the Lower Huronian. These two together are a part of the Algonkian, and the Southern Complex is Archean.


| PLEISTOCENE (Concealing other formations.) | CRETACEOUS | CARBONIFEROUS: Coal Measures | CARBONIFEROUS: Sub Carboniferous | DEVONIAN | SILURIAN: Upper Silurian | SILURIAN: Lower Silurian |
|---|---|---|---|---|---|---|
| p | K | Cc | Cs | D | Su | Sl |

PRELIMINARY GEOLOGIC

Compiled by R D. Irving to accomp


Sackett & Wilhelms Litho. Co. New York

| BRIAN | ALGONKIAN | | ARCHEAN |
|---|---|---|---|
| | Keweenaw Series | Huronian | (Granite Gneiss and Schist.) |
| Ca | Ak | Ah | a |

HURONIAN

- Ah 1 *The Original Huronian*
- Ah 2 *The Marquette - Menominee Iron-Bearing Schists*
- Ah 3 *The Wisconsin Valley Slates*
- Ah 4 *The Penokee Iron Bearing Schists*
- Ah 5 *The St Louis Slates*
- Ah 6 *The Chippewa Valley Quartzites*
- Ah 7 *The Black River Iron Bearing Schists*
- Ah 8 *The Baraboo Quartzites*
- Ah 9 *The Sioux Quartzites*
- Ah 10 *The Animikie Series*
- Ah 11 *Folded Schists of Canada*

# MAP OF THE NORTHWEST.

f Progress of the Pre Cambrian Formations

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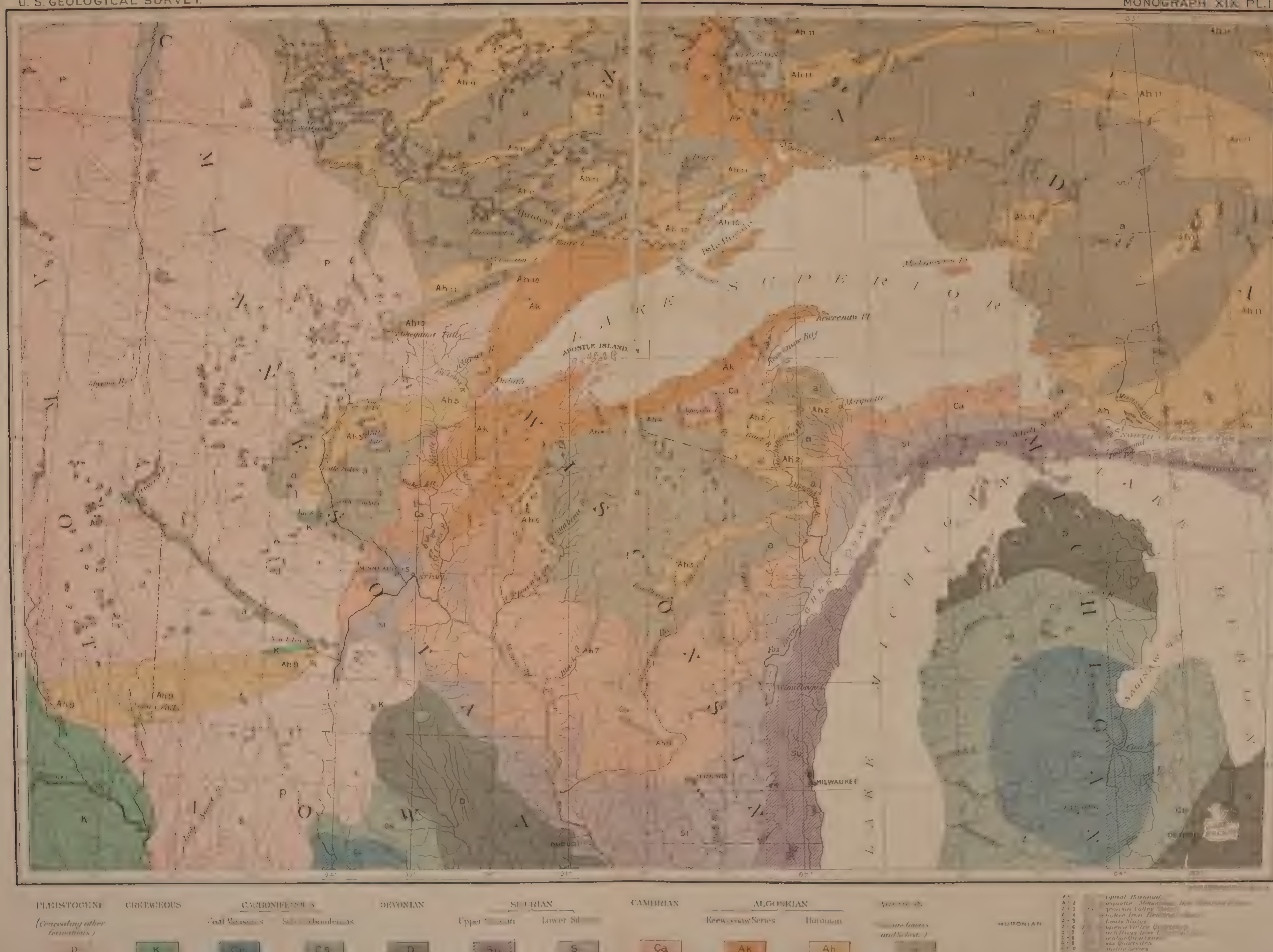



PRELIMINARY GEOLOGICAL MAP OF THE NORTHWEST.

Compiled by R. D. Irving to accompany Report of Progress of the Pre Cambrian Formations

# THE PENOKEE IRON-BEARING SERIES OF MICHIGAN AND WISCONSIN.

By R. D. Irving and C. R. Van Hise.

## INTRODUCTION.

In a previous publication of the Survey[1] one of the writers of this memoir has provisionally mapped under a common color all of the various areas in the lake Superior region, the rocks of which are now regarded by any authority as the equivalent of the Huronian series of the Canadian geologists. The provisional mapping was preliminary to a thorough study of each of these areas in the United States, with the object of determining not only its own structure and stratigraphy and the genesis of its rocks, but also the general stratigraphy of the pre-Cambrian formations in the northwestern states. This map, with corrections up to date, is reproduced in this volume (Pl. I). The areas there included are:

The Original Huronian (H).
The Marquette-Menominee Iron-bearing schists ($H_2$).
The Wisconsin valley slates ($H_3$).
The Penokee Iron-bearing series ($H_4$).
The St. Louis slates ($H_5$).
The Chippewa valley quartzites ($H_6$).
The Black river Iron-bearing schists ($H_7$).
The Baraboo quartzites ($H_8$).

[1] Preliminary Paper on an Investigation of the Archean Rocks of the Northwestern States, by R. D. Irving. U. S. Geol. Survey, Fifth Annual Report, pp. 181–241, Pl. XXII.

The Sioux quartzites ($H_9$).

The Animikie series, which includes the Mesabi range ($H_{10}$).

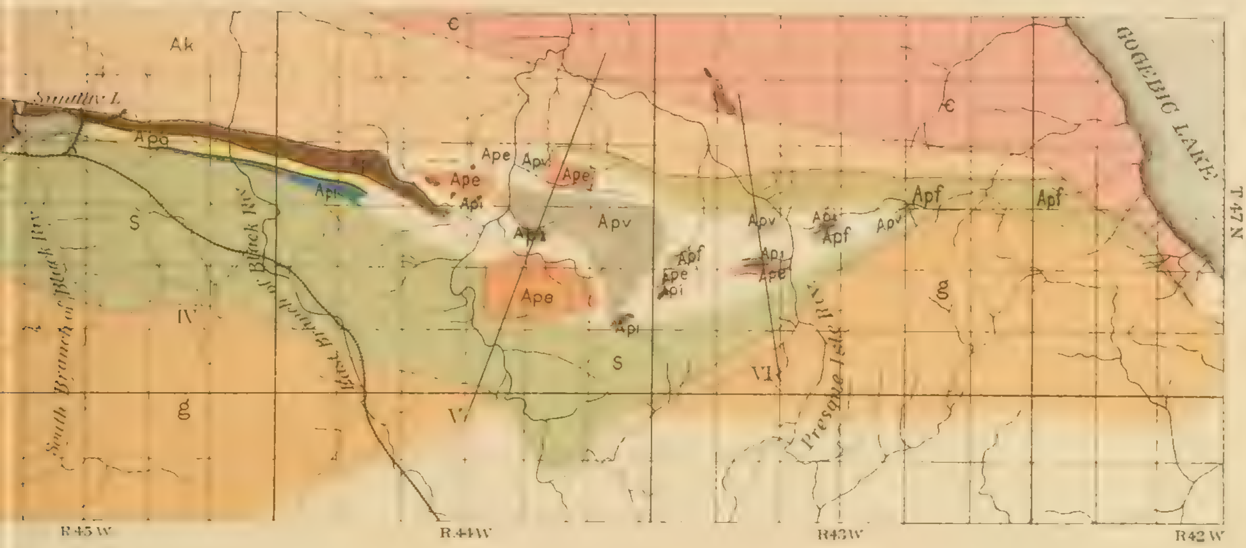
Folded schists of Canada, including Vermilion lake series ($H_{11}$).

This classification has reference not only to a certain geographical separateness of the various areas, but also to certain peculiar geological characteristics which each area or group of areas displays.

In the six and a half years that have elapsed since the beginning of our present study of the older formations of the Northwest, work has been done in a number of these areas, much new material has been collected, and many interesting new conclusions have been reached. In the case of the Penokee area, this study has been completed. An account of this region is particularly called for, because of the absence of folds and of the accompanying changes due to pressure—which so greatly increase the difficulties of study in the Marquette-Menominee region, for instance—and because of the clear and unmistakable nature of its relations to adjoining formations. Our design, then, is to publish at the present time a full account of the area, showing in detail the processes by which the principal results are reached, and to use these results in future in the study of other areas of the Northwest.

The general geographical position of the Penokee belt will be best understood by reference to Pl. I. The larger scale map of Pl. II will serve to show more definitely the extent and position of the area the geology of which is to be discussed. This belt stretches from lake Gogebic, Michigan, to lake Numakagon, in Wisconsin, a distance of about 80 miles. Its course from lake Gogebic to the Montreal river is about west, and from the Montreal to lake Numakagon about 20° south of west. Our more detailed investigations have extended over an average width of 5 miles. Of this width, the iron-bearing series, which particularly forms the subject of the present volume, occupies from a quarter of a mile to about 3 miles, the remainder being occupied to the south by granites, gneisses, and schists, and to the north by the interbedded eruptives and fragmentals of the Keweenaw series.

Whatever the relations of the schist, gneiss and granite mapped in Pl. II to one another and to the rocks adjacent, they are sharply separated in surface




# PENOKEE DISTRICT

ISE.

ARCHEAN

SOUTHERN COMPLEX.

| NGLOMERATES. | FERRUGINOUS SLATES. | ERUPTIVES. | GRANITE & GRANITOID GNEISS. | SCHIST & FINE GRAINED GNEISS. |
|---|---|---|---|---|
| | Apf | Ape | g | S |

Sackett & Wilhelms Litho. Co. New York


GENERAL GEOLOGICAL MAP OF THE PENOKEE DISTRICT
BY R. D. IRVING AND C. R. VAN HISE.
SCALE OF MAP 1 IN = 3 MILES
SCALE OF SECTIONS 1 INCH = 1 MILE
CAMBRIAN.
EASTERN SANDSTONE.
ALGONKIAN.
KEWEENAWAN.
PENOKEE SERIES.
UPPER SLATE MEMBER
IRON-BEARING MEMBER
QUARTZ-SLATE MEMBER
CHERTY LIMESTONE MEMBER
GREENSTONE CONGLOMERATES
FERRUGINOUS SLATES
ERUPTIVES
ARCHEAN
SOUTHERN COMPLEX
GRANITE & GRANITOID GNEISS.
SCHIST & FINE GRAINED GNEISS
Ak
Apu
Apq
S
I
II
III
IV
V
VI
N
S

distribution from the series of parallel belts northward. These belts, four in number, follow in regular succession, with the exception of a few miles at the east end of the area. They are separated from each other upon the principle of fragmental and nonfragmental character. This memoir treats of the rocks between the gneiss-granite areas and the Keweenaw series, and to them is applied the name Penokee series.

The Wisconsin geologists, as will be seen by the literature, called the iron-bearing rocks and associated slates the Penokee series. On the Michigan side of the boundary the course of travel was largely by the way of Agogebic, or as it is now contracted, Gogebic lake, and the geologists, explorers, and miners gave to that part of the area the name Gogebic district. As the areas are parts of continuous geological series, one or the other of these two names must be accepted for the whole, or else a new name be coined by their combination. The latter course would be perhaps the less objectionable if the resultant name Penokee-Gogebic were not so awkward. The only systematic geological treatment of any part of the district is that by Irving and Wright in the Geology of Wisconsin; hence, under the law of priority, the term Penokee series is in this volume used to cover the whole area.

The southernmost of the belts of the Penokee series is called the Cherty limestone. This name sufficiently indicates its character. Whether it is of direct chemical or of organic clastic origin, it now gives no evidence of having been fragmental. The next belt to the northward is called the Quartz-slate member, because quartz is the preponderating constituent and a slaty structure the normal one. It is sharply separated from the underlying Cherty limestone member by the fact that it everywhere reveals in thin sections its essential fragmental character, and also by the fact that it bears debris from the Cherty limestone. Next to the north is the Iron-bearing member, so called because all the known ore-bodies occur within it. Whatever its origin, it, like the Cherty limestone, never gives any evidence of a fragmental character. North of this belt is the Upper slate member. This is in places several times as thick as the three lower members combined, but the whole width is included within a single belt because it is everywhere substantially alike. It is a graywacke, graywacke-slate, mica-slate, or mica-schist, which is chiefly composed of quartz and feldspar. Like the Quartz-slate member, in thin section it usually reveals its fragmental character. The area of rocks situated at the same geologic horizons as these four belts, between Gogebic lake and the middle of T. 47 N., R. 44 W., Michigan, does not make up so plain a succession, so that this part of the district is separated from the four belts just spoken of as the Eastern area, and under this title is given separate treatment.

# CHAPTER I.

By R. D. Irving.

## GEOLOGICAL EXPLORATIONS AND LITERATURE.

Geological exploration in the district—Barnes (1847); Whitney and Barnes (1847); Randall (1848); Whittlesey (1849 and 1860); Lapham (1858); Brooks and Pumpelly (1871); Irving (1873, 1876, 1877, 1885); Wight, Sweet, and Wright (1875); Wright (1876); Chamberlin (1877); Conover (1878); Rominger (1882); Van Hise (1884–1887). Object of the work under the U. S. Geological Survey. Annotated list of the literature of the subject.

As in the case of most other regions on the south side of lake Superior, the first geological explorations made in the Penokee country date quite far back, but no attempt at detailed work was made before that done west of the Montreal river by the Wisconsin survey, 1873–1878. East of this river, in Michigan, the only approach to a detailed study prior to that by the authors of the present volume was by Dr. C. Rominger, then state geologist of Michigan, in 1882. Dr. Rominger's results have not yet been published, but he has been kind enough to send me a manuscript copy of that portion of his last report which covers this district. While this report is unaccompanied by maps, and while Dr. Rominger's locations of specimens are not closer than the quarter section, it yet contains much valuable material.

I add a few notes with regard to each of the geologists who have personally investigated any portion of the Penokee district, arranging these notes chronologically, the date after each name being the time of exploration.

Barnes (1847).—Mr. George O. Barnes was one of the assistants on the U. S. Geological and Mineralogical Survey of the lake Superior land district, then under the direction of Dr. C. T. Jackson, and subsequent to

1848 under the joint charge of Messrs. J. W. Foster and J. D. Whitney. Mr. Barnes appears to have been the first geologist to enter any portion of our district.[1] In the summer of 1847 he accompanied the township land surveyors, noting and locating all rock exposures met with on the lines surveyed, from a point on the Ontonagon river where it crosses the east line of T. 49 N., R. 41 W., Michigan, southward for 28 miles; then westward 12 miles, north 12 miles, west 6 miles, north 6 miles, and east 6 miles to the northeast corner of T. 47 N., R. 43 W., Michigan; and thence northward to Gogebic lake. Mr. Barnes's exploration was thus chiefly in the granitic and gneissic region in the southern part of the southern end of our district. One of his lines, however, crossed the iron-bearing slates, but without affording him any indication of their existence.[2]

**Whitney and Barnes (1847).**—Later in the same season Mr. Barnes accompanied Mr. J. D. Whitney, then one of the chief assistants under Jackson, in a second trip into the country between Gogebic lake and the Montreal river.[3] Their course was from the mouth of Black river to the northwest corner of T. 48 N., R. 46 W., Michigan; thence along the range and township lines (then the only surveyed lines in the region), south 12 miles, east 6 miles, north 12 miles, and west 5 miles to the Black river, on the north line of T. 48 N., R. 46 W., Michigan. This route, as also that previously traversed by Mr. Barnes, is indicated on Fig. 1. Thus Messrs. Barnes and Whitney made in 1847, in all, three traverses of our district, the easternmost one lying 6 miles west of lake Gogebic, and the westernmost 2 to 5 miles east of the Montreal river. Whitney also saw nothing on his trip to suggest to him the existence in the region of any other formation than the granites to the south and the eruptive greenstones of the copper-bearing series to the north. Accordingly this portion of their district was mapped by Messrs. Foster and Whitney with the granites to the south and the eruptive greenstones to the north coming directly into contact with one another, without any intervening slates. This mapping was reproduced on all later

[1] Diary of field work for the summer of 1847, in Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in the State of Michigan; by C. T. Jackson, United States Geologist. Senate Docs., 1st sess. 31st Cong., 1849–50, vol. III, No. 1, pt. 3, pp. 371–605, also 627–801.

[2] See p. 34.

[3] Whitney's diary, in same report as that of Mr. Barnes just referred to, pp. 33, 34.

geological maps of the lake Superior country until after the exploration by Pumpelly and Brooks in 1872.

**Randall (1848).**—In 1848 Dr. A. Randall, one of the assistants of Dr. D. D. Owen on the U. S. Geological Survey of Wisconsin, Iowa, and Minnesota, accompanied the linear surveyors along the fourth principal meridian from lake Superior southward.[1] Dr. Randall appears to have been the first to note the existence in this region of any of the rocks of the iron-bearing series, he having observed exposures of lean magnetic ore.

**Whittlesey (1849 and 1860).**—Col. Charles Whittlesey was one of the "heads of sub-corps" on the survey above referred to[2] under Dr. D. D. Owen. After Dr. Randall's discovery of iron ore on the fourth principal meridian in 1848, Col. Whittlesey followed the iron-bearing slates from the meridian westward to the vicinity of English lake, or Lac des Anglais, as it was then called by the French voyageurs. Col. Whittlesey's report covers all of the region drained by the Bad and Montreal rivers in northern Wisconsin. It is quoted at some length below. Eleven years later Whittlesey made a somewhat more thorough study of the same region for the Wisconsin state survey then organized under James Hall.[3] His earlier work, however, was, of course, no more than a very rough reconnaissance. It could not indeed have been more, considering the difficulties of travel in the region and the fact that there existed in it at the time but a single surveyed line, that of the meridian above mentioned. These difficulties considered, we must credit Whittlesey with having accomplished a good deal. In fact, to his earlier work for Owen's survey and later work for the Wisconsin survey was due all really definite information at hand with regard to the geology of the Penokee country, previous to the investigations of the Wisconsin survey of 1873–79.

**Lapham (1858).**—In September, 1858, Dr. I. A. Lapham, afterward chief of the Wisconsin Geological Survey, made rapid trips along the Penokee range from Bad river at Penokee gap eastward as far as the fourth

[1] Report of a Geological Survey of Iowa, Wisconsin, and Minnesota, David Dale Owen, 1852, pp. 151, 153, 155, 444; see also C. Whittlesey in an article on the Penokie Mineral Range, Proc. Bost. Soc. Nat. History, Vol. IX, 1862–'63, pp. 235–244.

[2] Op. cit. p. XV.

[3] The Penokie Mineral Range, Proc. Bost. Soc. Nat. Hist., vol. IX, 1862–63, pp. 235–244.

meridian, and westward to the end of the range in the vicinity of English lake.[1] Dr. Lapham's object was an economic one mainly, his investigation being made in behalf of a Milwaukee iron company. Dr. Lapham located a number of the exposures of the lean magnetic ore that makes up so much of this range and some of the exposures also of the associated rocks. These exposures he indicated on a simple map accompanying his report. His map was thus the first attempt at a definite platting of any portion of this interesting belt.

Brooks and Pumpelly (1871).—In the fall of 1871 Messrs. T. B. Brooks and R. Pumpelly, then engaged for the State of Michigan in a geological survey of the so-called upper peninsula of that State, made a rapid reconnaissance along the iron belt from the passage of Bad river through the Penokee range in Wisconsin eastward to the Ontonagon river in Michigan. No definite mapping was attempted, but some very interesting new conclusions were reached, as announced shortly afterward in publications below quoted from.

Irving (1873, 1876, 1877, 1885).—The writer's studies in the Penokee region began in June, 1873, under the auspices of the Wisconsin Geological Survey, then recently revived under the direction of Dr. I. A. Lapham.[2] Subsequently this work was continued under the same auspices during the seasons of 1876 and 1877, under the direction of Dr. T. C. Chamberlin, the successor of Dr. Lapham as state geologist.[3] The attempt was made to do such detailed work as would furnish the necessary material for the construction of maps and the determination of the true order of succession of the rocks of the region. The results obtained were finally published in 1880 in full, with numerous maps and other illustrations, in the third volume of the Geology of Wisconsin. This report covers not only that portion of our present district which is included within the State of Wisconsin, but also all of northern Wisconsin lying north of T. 43 N. and east of R. 6 W. Many of the results contained in this report are made

[1] The Penokee Iron Range, Trans. Wis. State Agr. Soc., vol. V, p. 391-400; also Report of the Directors of the Wisconsin and L. S. Mining and Smelting Co., Milwaukee, 1860, pp. 22-37.

[2] Geol. of Wis., vol. II, pp. 7, 8.

[3] Annual Report of Progress and Results of the Wisconsin Geological Survey for the year 1876, pp. 13-18. Annual Report of the Wisconsin Geological Survey for the year 1877, pp. 17-25.

use of in the present volume. The routes followed, so far as they traverse our present district, and the exposures located are all indicated on the detailed maps herewith. The writer's visit to this district in 1885 was made partly for the purpose of supervising the field work then going on under Prof. C. R. Van Hise for the U. S. Geological Survey and partly for the purpose of studying in detail certain points along the contact between the iron-bearing series and the gneissic rocks south of it.

Wight, Sweet, and Wright (1875).—In 1875 the control of the Wisconsin Geological Survey passed into the hands of Dr. O. W. Wight. By his order Messrs. E. T. Sweet and C. E. Wright made together an extended geological reconnaissance in northern Wisconsin, being accompanied by the chief geologist in person.[1] In the course of this reconnaissance the party crossed the Penokee range at the passage of Bad river, where a cross-section of the iron series was attempted. The results obtained were subsequently published in brief by Mr. Sweet.[2]

Wright (1876).—In January, 1876, Dr. Wight was superseded in the direction of the Wisconsin Survey by Prof. T. C. Chamberlin, who invited Mr. Wright to continue his study of the western portion of the Penokee range, with particular reference to the occurrence there of iron ores. Accordingly Mr. Wright, accompanied by Mr. F. H. Brotherton, a well known lake Superior woodsman and explorer, spent the weeks from August 22 to October 3, 1876, in making a detailed examination of that portion of the iron series lying between Bad river and lake Numakagon. Mr. Wright's results[3] were published in the form of an itinerary, as below noted, accompanied by a series of maps showing the positions of rock exposures, etc. Mr. Wright's routes of travel and the exposures located by him are platted on the detailed maps accompanying the present volume.

Chamberlin (1877).—In the fall of 1877, Prof. T. C. Chamberlin, accompanied by A. D. Conover, carried the detailed mapping of the Penokee

[1] Geol. of Wis., vol. II, pp. 72-79.

[2] Notes on the Geology of Northern Wisconsin, Trans. Wis. Acad. Sci. and Letters, vol. III, pp. 40-53.

[3] Annual Report of Progress and Results of the Wisconsin Geological Survey for the year 1876, pp. 18-23. Also Geol. of Wis., vol. III, pt. IV, pp. 239-301.

series from the Potato river eastward to the Michigan boundary at the Montreal river.[1]

Conover (1878).—In the summer of 1878, Mr. A. D. Conover made a somewhat extended trip through the country between the Montreal and Bad rivers for the purpose of filling up certain gaps left by work of previous years. His routes were mostly north of our present district, the upper portion of which they touched, however, in T. 44 N., R. 2 W., and T. 45 N., R. 2 W., Wisconsin.[2] Mr. Conover's results were embodied in my final report[3] on the eastern lake Superior district.

Rominger. (1882).—Dr. C. Rominger, acting in his capacity of State geologist of Michigan, made a study of the region between the Montreal river and Gogebic lake in the summer of 1882, spending three weeks in that field. While Dr. Rominger's results have not yet been published, they are embodied in a manuscript report of which he has been kind enough to furnish me a copy.

Van Hise (1884-1887).—The particular investigation upon which the present volume is especially based was begun in 1884. The object was the extension of the detailed work done by the Wisconsin survey eastward from the Montreal river to lake Gogebic. Nothing very definite was then known with regard to the latter district save that there existed in it, contrary to Foster and Whitney's reports, an eastward continuation of the Penokee Iron series. It was then thought that a single season's work would be sufficient, with the aid of the published results of the Wisconsin Survey and of my own familiarity with the country west of the Montreal river, to furnish the material needful for such an account of the Penokee series as it would be desirable to include in a final report on the Huronian of this part of the lake Superior region. Accordingly, to Prof. C. R. Van Hise, who had already acquired a thorough acquaintance with the original Huronian of the north shore of lake Huron and with the iron-bearing series of the Marquette and Menominee districts, was assigned the work of making a detailed survey of the district

[1] Annual Report of the Wisconsin Geological Survey for the year 1877, pp. 25-28. See also Geol. of Wis., vol. III, pt. III, p. 56, atlas Pl. XXVI.

[2] Annual Report of the Wisconsin Geological Survey for the year 1878, pp. 5-6.

[3] Geol. of Wis., vol. III, pt. III, pp. 53-214.

between the Montreal river and lake Gogebic. In this work he was occupied during the months of July and August of 1884, returning with a large collection and copious notes. His routes of travel are indicated on the accompanying detailed maps.

During the following fall months Prof. Van Hise carefully studied the material collected, a large number of thin sections having been made; and the locations of exposures, made always by pacings from section corners or quarter-posts, were platted on a large scale map. This study served chiefly to convince us that the whole belt, including the Wisconsin portion, was worthy of still further research. Although certain very interesting new conclusions were reached, still more important lines of study were suggested. The Wisconsin Survey work was done at a time when the microscope was only just coming into use in this country as a petrographical instrument, and consequently numerous important petrographical points were missed by that survey; while its type collection had meantime been destroyed by fire. But what more particularly urged us on was the great value of the iron-bearing series of this region as a type series. Accordingly, it was decided that Prof. Van Hise should spend another season in the region, not only in filling up gaps in his own work of the previous season, but in carefully revising the Wisconsin Survey work and extending it when possible. On this work he was engaged from June 26 to September 4, in which time he succeeded in covering the entire distance from lake Gogebic to lake Numakagon. As has already been said, the writer joined this party for a time during the summer, making a special study of the southern contact. The routes followed and exposures located are all indicated on the accompanying detailed maps.

During the winter following this field season the material collected was carefully studied, and it became evident that additional field work was needed, certain points having been overlooked, and certain others which could not then be determined had become determinable by the great activity in mining and prospecting which during this winter and the following season went on along the Penokee-Gogebic range. Accordingly, Prof Van Hise returned to this field June 16, 1887, and was there continuously occupied until July 25, taking advantage of all of the light which had been thrown upon the structure of the region by mining operations, and examining again many of the more important exposures. Among other things, the eastern termination of the Gogebic range had not been ascertained, but exploring operations enabled Prof. Van Hise to determine that the horizontal Eastern sandstone overlies the Penokee-Gogebic series just west of Gogebic lake. Later in the same season, August 15, in company with Prof. Van Hise, I visited the district to examine personally the numerous interesting localities which had been discovered or developed by mining since the previous season.

During this season's field work was noticed the remarkable association between the ores and an altered greenstone, which the miners called either soapstone or diorite dike, and the conclusion was reached that between the two there must be some genetic connection. Mr. J. Parke Channing, mining inspector for Gogebic county, was induced to investigate the relations of the ore bodies and dike rocks. This work he did during the latter part of the season, reaching some very interesting conclusions. Mr. Channing has also given a good deal of attention to all new points shown by mining development of the region up to the present date, and has, with great kindness, promptly furnished us information as to them.

In this connection should be mentioned the fact that Mr. J. M. Longyear, who is in charge of the lands of the Lake Superior and Portage Ship Canal company, a large part of which lie between lake Gogebic and the Montreal river, kindly allowed us, after the work of 1886 was completed, to make use of the notes as to locations of exposures obtained by parties of woodsmen under his direction. These parties, crossing each section a number of times, made notes, not merely as to timber and topography, but also located and collected specimens from every exposure encountered, with a view to discovering indications of the existence of iron ore deposits. Going over these notes and specimens carefully, Prof. Van Hise has been able to add to the information obtained by himself. Just how far his own studies have extended between lake Gogebic and the Montreal river will be seen from his routes of travel indicated on the accompanying maps.

## LITERATURE.

The following is a list of all publications which we have met with in any way referring to the Penokee-Gogebic district. Being arranged chronologically, the notes and quotations attached to the name of each work will serve to show more fully than has been done in previous pages the history of our subject, up to the time of the special investigations upon which the present volume is particularly based. The dates are the years of publication.

### 1849.

WHITNEY (J. D.). Letter to Dr. C. T. Jackson, in Jackson's Report on the Mineral Lands of Lake Superior, Senate Documents, 1st session, 30th Congress, vol. II, No. 2, 1847–'48, p. 223–230.

Whitney's two traverses of the Gogebic iron belt have already been mentioned and indicated on Fig. 1. In this report we find the first mention of the results of his observations on the two lines followed, as also

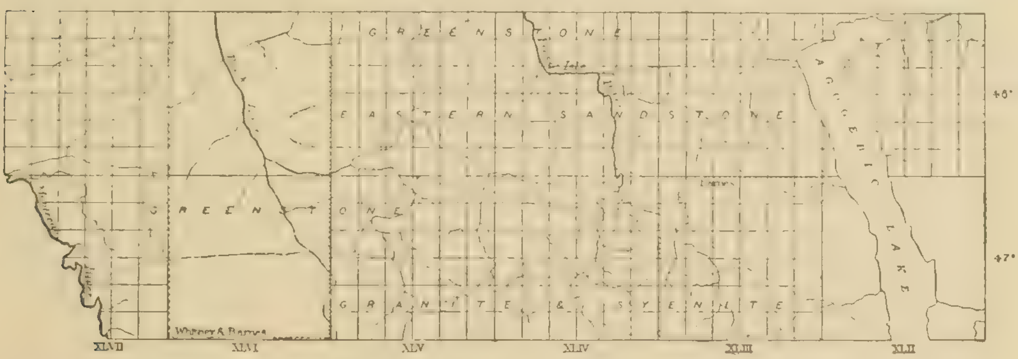



FIG. 1.—Reproduction of Barnes and Whitney's geological map of region between Agogebic lake and Montreal river.

of the observations of Mr. Barnes along a line 12 miles farther to the east. The exact courses of these traverses are given in a volume subsequently referred to, from which also is taken the geology of the map of Fig. 1. From this map it will be seen that no suspicion was raised in Whitney's mind as to the existence in this region of his "Azoic slates," these slates appearing under this name over a large part of the very map of a portion of which Fig. 1 is a reduced copy. The trappean rocks which belong to what we now designate as the Keweenaw or copper-bearing series, are made to lie directly against the "granite and syenite," without intervening slates. The same conclusion is indicated in the following remarks quoted from this letter (p. 230):

On crossing the southern edge of the trap range, we no longer find, on proceeding south, a belt of sandstone similar to that on the north, as is the case between the Portage and the Ontonagon. The only rocks which we have found in place are granite and greenstone; not, however, arranged in regular order, but scattered confusedly without order of superposition or direction. The whole country to the south, as seen from any one of the high points of the trap range, as far as the eye can reach, seems to be almost an unbroken plain. On traversing it, it is found to be made up of alternate swamps and low ridges of granite and greenstone, which are sometimes hidden by soil and covered with pine, hemlock, and especially sugar maple. Sometimes, again, the granite rocks rise with almost vertical walls, yet never to any considerable height, from the midst of the swamps, and are covered only by thick moss. It will be impossible to draw any line of demarcation between the granite and greenstone rocks, since they occur together constantly, neither being confined to any particular portion of the district.

The whole of this country is almost inaccessible from its swampy nature; neither does it promise to be of any value for its mineral contents, since we have never found any other ores than a few scattered magnetic masses of iron ore and iron pyrites; neither, however, in any considerable quantity.

1850.

BARNES (GEORGE O.). Diary of field work for the summer of 1847, in Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in the State of Michigan, by C. T. Jackson, U. S. Geologist, Senate Docs., 1st sess., 31st Cong., 1849–'50, vol. III, No. 1, pt. III, pp. 371–605, also pp. 627–801.

Although a further and final report was published by Dr. Jackson in 1852, this one is essentially the closing report of his work, covering the period up to the time of his resignation of the survey into the hands of Messrs. Foster and Whitney. Mr. Barnes's diary of field work is given in this report. The larger part of the region west of Gogebic lake was at the time without surveyed lines. His course of travel and his failure to discover a series of iron-bearing slates have already been noted. Mr. Barnes crossed the Gogebic belt once and made an extended trip in the granite region farther south. Later in the same season (see diary pages 738–740) Mr. Barnes accompanied Whitney in his traverses of the Gogebic district, and designated the positions of a number of rock exposures on the lines followed.

WHITNEY (J. D.). Diary in same report with that of Mr. Barnes just referred to.

In Whitney's diary of field work (pp. 738–740) an account is given of the journey made by him in company with Mr. Barnes. His course of travel has already been given and mapped, Fig. 1. The observations made on three lines of travel by Barnes and Whitney in the country between Gogebic lake and the Montreal river are all the basis for any statements with regard to this region made by Jackson and by Foster and Whitney in their respective reports. All later published statements with regard to the geology of this region, up to the time of the rapid trip made by Brooks and Pumpelly in 1871, depend also upon these few observations by Whitney and Barnes. It is interesting to note that although these gentlemen found nothing in the region but granite and greenstone, they must have passed on at least two of these lines within a short distance of large exposures of slate and jaspery iron ore.

FOSTER (J. W.) and WHITNEY (J. D.). Synopsis of Explorations of the Geological Corps in the Lake Superior Land District in the Northern Peninsula of Michigan, Senate Docs., 1st sess., 31st Cong., 1849–'50, vol. III, No. 1, Pt. III, pp. 605–626.

This is the first report made by Messrs. Foster and Whitney after they had superseded Dr. Jackson in the control of the Geological Survey of the Mineral Lands of the United States in Michigan. In it are embraced the results of work done by these gentlemen in the capacity of assistants to Dr. Jackson. Among other results thus obtained were those by Whitney and Barnes in the summer of 1847, in the country west of lake Gogebic. It appears evident that no further work was done in that district for this report, or for their final report below noticed, by either of these gentlemen or by any of their assistants.

Accompanying this report are several geological maps, one of which, entitled "The District between Portage Lake and Montreal River," drawn on a scale of 3½ miles to the inch, includes that portion of the district which forms the subject of the present volume as far west as the Montreal river. This is the map referred to above in connection with Whitney's letter of 1847 to Dr. Jackson.

1851.

FOSTER (J. W.) and WHITNEY (J. D.). Report on the Geology of the Lake Superior Land District, Part 2, The Iron Region, together with the General Geology, Senate Docs., special session, 32nd Cong., Washington, 1851, vol. III, No. 4, 406 pp., with maps.

This is Foster and Whitney's final report on the iron regions of the upper peninsula of Michigan. In it several brief references are made to the region west of Gogebic and south of the trappean beds of the Copper range. We quote as follows (p. 39):

Farther west another granite belt starts from the head waters of the Ontonagon river, and thence extends to the western limits of the district, intersecting the head of Agogebic lake and crossing the Montreal river about 15 miles from its mouth. Southward it forms the watershed between the rivers of lake Superior and the Mississippi and passes beyond the limits of this district into Wisconsin. It is probable that this belt is a continuation of that first described, but we have not been able to trace the continuity. There is an interval of 20 miles where the surface of the country becomes nearly horizontal and is strewn with accumulations of clay and gravel, burying up the subjacent rocks.

In the extreme western portion of the district, west of range 40, granite is the predominating rock below the southern boundary of township 47 and is associated with a hornblende rock which sometimes assumes a slaty structure. The granite is mostly a binary compound of feldspar and quartz, the former largely predominating and giving a reddish tinge to the whole rock; mica is present only in very small quantity, while hornblende and chlorite are occasionally scattered in minute particles through it. Nearly the whole of the granitic region in this part of the district presents the most forbidding and desolate aspect. Though it forms the most elevated portion of the country, being the watershed between lake Superior and the Mississippi, it is low and swampy and filled with numerous lakes, of which over fifty were crossed by Mr. Burt in surveying the boundary line between Lac Vieux Desert and the Montreal river. There are occasional elevations, which are dry and wooded with sugar maple and which undoubtedly are covered with a good soil, but the larger portion of the region presents almost interminable cedar swamps, in the midst of which the granite and hornblende ridges rise, with precipitous walls, rarely to more than 50 feet in height above the surrounding country. These ridges are generally very narrow, and their sides are covered with a thick coating of moss and lichens. Nothing can exceed the desolate solitude of this region. Not even the Indian traverses it; it is destitute of game and its stillness is never broken except by the crashing of the tornado through the dense forest, tearing up the trees and piling them together so as to present an almost impassible barrier, as if still further to repel the intrusion of man into a region so little fitted for his reception.

The granite of the whole of this portion of the district is very coarse grained and crystalline and is characterized by a predominance of feldspar and an almost entire absence of mica. (Pp. 47, 48.)

The statements in the above quotations rest, of course, upon the few observations by Messrs. Whitney and Barnes. It is manifest that no thought of the existence of iron-bearing slates between lake Gogebic and the Montreal river was entertained. This is the more singular since the discoveries of iron-bearing slates by Mr. Whittlesey west of the Montreal river (subsequently noted) were known to Messrs. Foster and Whitney, as appears from their statement (page 51).

1852.

WHITTLESEY (CHARLES). Geological Report on that portion of Wisconsin bordering on the south shore of Lake Superior, surveyed in the year 1849, under the direction of David Dale Owen, U. S. Geologist, by Charles Whittlesey, head of subcorps. In Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, by David Dale Owen, U. S. Geologist, Philadelphia, 1852.

It seems that Dr. Owen himself must have crossed the westernmost end of the district with which we are concerned near Numakagon lake. This appears to have been in 1848 or 1849, but no observations of importance were made (pp. 159–160). Dr. Randall, one of Owen's assistants, appears to have made the first discovery of iron-bearing slates in this district while following the Fourth Principal meridian in 1848 (p. 444).

Col. Whittlesey's own exploration was made in 1849, in which year he followed the belt of iron-bearing slates from the vicinity of Montreal river to English lake. The following quotation will serve to show what were his views as to the general structure of the whole Bad river country in Wisconsin:

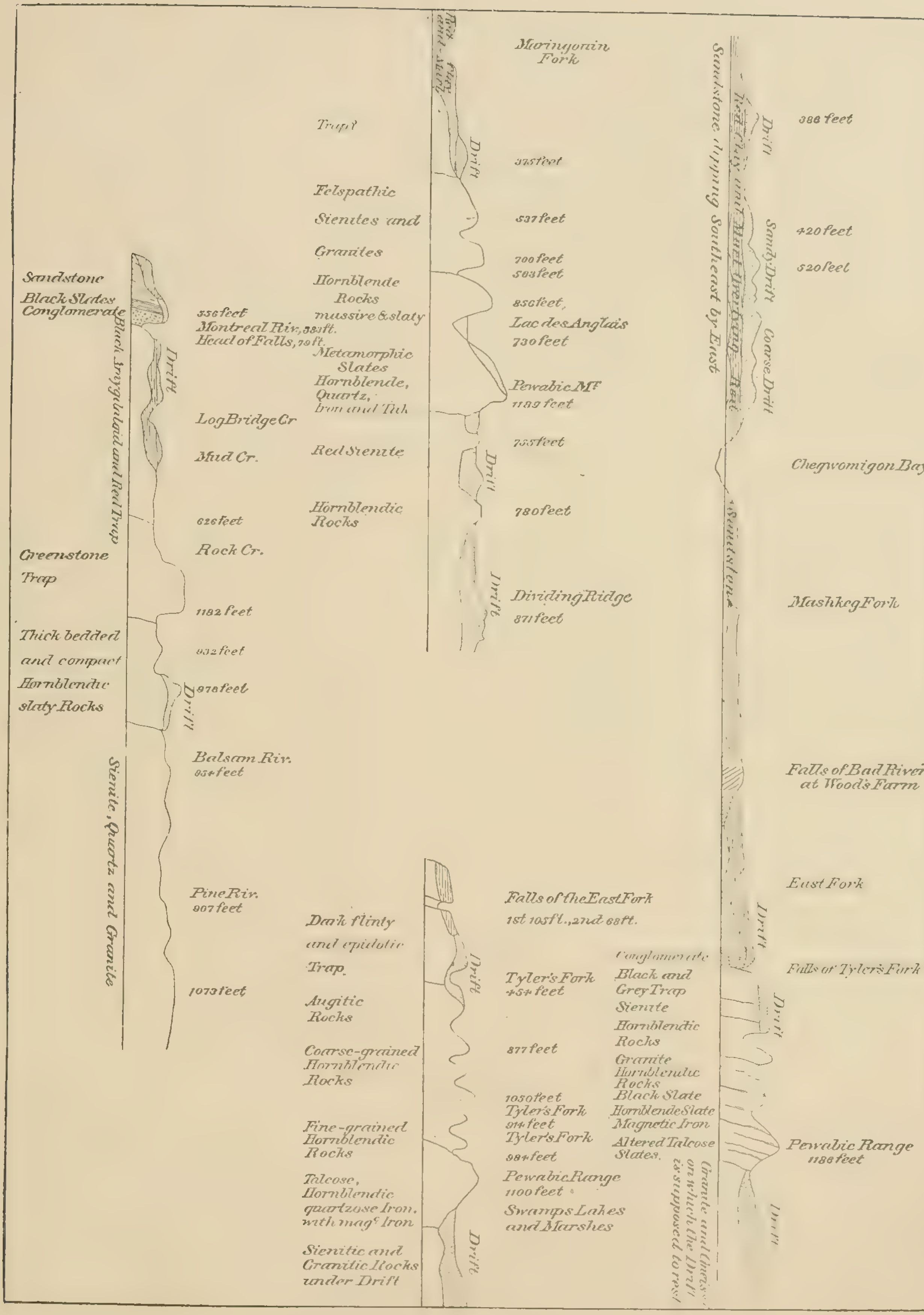
The accompanying map and sections are intended to represent at one glance the principal features in the geology of this region. The extent, elevation, and relative thickness of the various formations, as well of solid rock as the looser earthy deposits, will there appear in a more compact and intelligible form than I could give them by written descriptions, however elaborate.

There are four formations or great classes of rocks shown on each section. These all appear in the same order of succession, reckoning from the lake southerly, and may be grouped thus:

1. *Sedimentary.*
    *a.* Red sandstone.
    *b.* Black slate.
    *c.* Conglomerate.
2. *Trappous Rocks, or those of volcanic origin.*
    *a.* Black and red amygdaloid and greenstone trap.
    *b.* Augitic, hornblendic, and feldspathic rocks, embracing syenite and granites of the same age.
3. *Metamorphosed Rocks.*
    *a.* Hornblendic slates.
    *b.* Iron slates.
    *c.* Black slates, in large, thin, rectangular sheets.
    *d.* Talcose slates, with quartz.
    *e.* Slaty quartz.
4. *Granitic.*
    *a.* Syenite, and
    *b.* Granite, occupying the country south of the mountain range or uplift, are the oldest rocks seen. (P. 425.)

*The Sedimentary and Igneous Rocks.*—The relative *age* of the rocks beneath the clay and drift is a subject upon which a prolonged discussion would be in place if theoretical consideration might be introduced here at large. The granites and syenites of the interior are no doubt the most ancient rocks of the district. After the protrusion of those extensive interior granitic masses many successive changes have occurred, but in what precise order is a question not easily determined. The immense sandstone deposits of the basin of lake Superior must have been subsequent to the granites of Wisconsin, Chippewa, and Montreal rivers, and probably rested on them. Since that era a prolonged and intense internal igneous action has taken place, and the trap, hornblendic, and greenstone masses have been ejected, and also with them irregular protrusions of *recent* granite and syenite. The metamorphic slates have been elevated during these convulsions, and the sedimentary rocks thrust away to the northward and tilted up at high angles.

The old granites and syenites have been rent, and fluid matter, such as quartz and hornblende, inserted in the fissures and between the beds. Along the northern portion of the Penokie range an outburst has taken place, as it were, between the sedimentary rocks and their ancient basis, on a line from the Montreal to Lac des Anglais; but the overflows have not been confined to one volcanic effort. The black and red trap, against which the conglomerate abuts, is doubtless due to a different effort from that which produced the greenstone trap-rocks that rise between the East fork of Bad river and the Montreal. The augitic, hornblendic, and syenitic mountains between the East fork and the main stream differ in form, in chemical constitution, and bedding or stratification from either the greenstone or black trap.




REPRODUCTION OF WHITTLESEY'S CROSS SECTION OF PENOKEE RANGE.

Proceeding along the mountain ridges of the northern part of the range, between the main stream and the outlet of Lac des Anglais, we encounter other varieties of rocks, feldspathic, granitic, and hornblendic in their composition, apparently an independent uplift or outburst. Along this whole line, however, the metamorphic rocks of the southern ridges of the range are continuous from near the Montreal to lac des Anglais. They have, at different times, been pushed over the granites at the south, distorted, broken, and tilted up in different degrees, but always in the same direction. The northern portion of the range exhibits to my mind evidence of *four* periods of igneous action, producing *four* formations of rocks of a trappose cast, which I have represented separately on the map.

They are: 1st, black and red trap; 2d, greenstone trap, embracing or graduating into massive hornblende and syenite at the west; 3d, augite and hornblende rocks in mass, also embracing granite and syenite; 4th, granite, syenite, and coarse hornblende rocks, north of Lac des Anglais.

But how to decide the *order* or relative age of these protrusions? It appears that the same materials under different circumstances of fluidity, pressure, and rapidity of cooling may take all these forms.

At present I can only place these four varieties in *one group*, filling a geological epoch of no great duration, and place it between the era of the red sandstone deposits and the metamorphic uplifts; for it is by the appearance of this group that both those systems have been pushed aside, one to the north, the other to the south. Whether the schistose rocks, before their upheaval and metamorphosis, were older or newer than the sandstone I do not decide; but both the schists and the unaltered sedimentary rocks are *more ancient* than the above group numbered from one to four (pp. 429–430).

The geological map mentioned in the above quotation was never printed; but its main features were embodied in Owen's general geological map of the northwest.[1] Pl. IV is a reproduction, save as to the omission of colors, of the original. In a similar manner Whittlesey's four cross-sections of the Bad river country are reproduced in Pl. III.

In Whittlesey's classification of the formations of the Bad river country, above given, the red sandstone (1*a*) includes horizontal sandstones belonging, as our belief is, to the Potsdam sandstone, and also vertically placed sandstones belonging to the Keweenaw or Copper series. To the latter series belong Whittlesey's formations from 1*b* to 2*b*, inclusive. His group of metamorphosed rocks (3) is about equivalent to the iron-bearing series which forms the subject of the present volume. His group of granitic

[1] See volume of illustrations accompanying the Report.

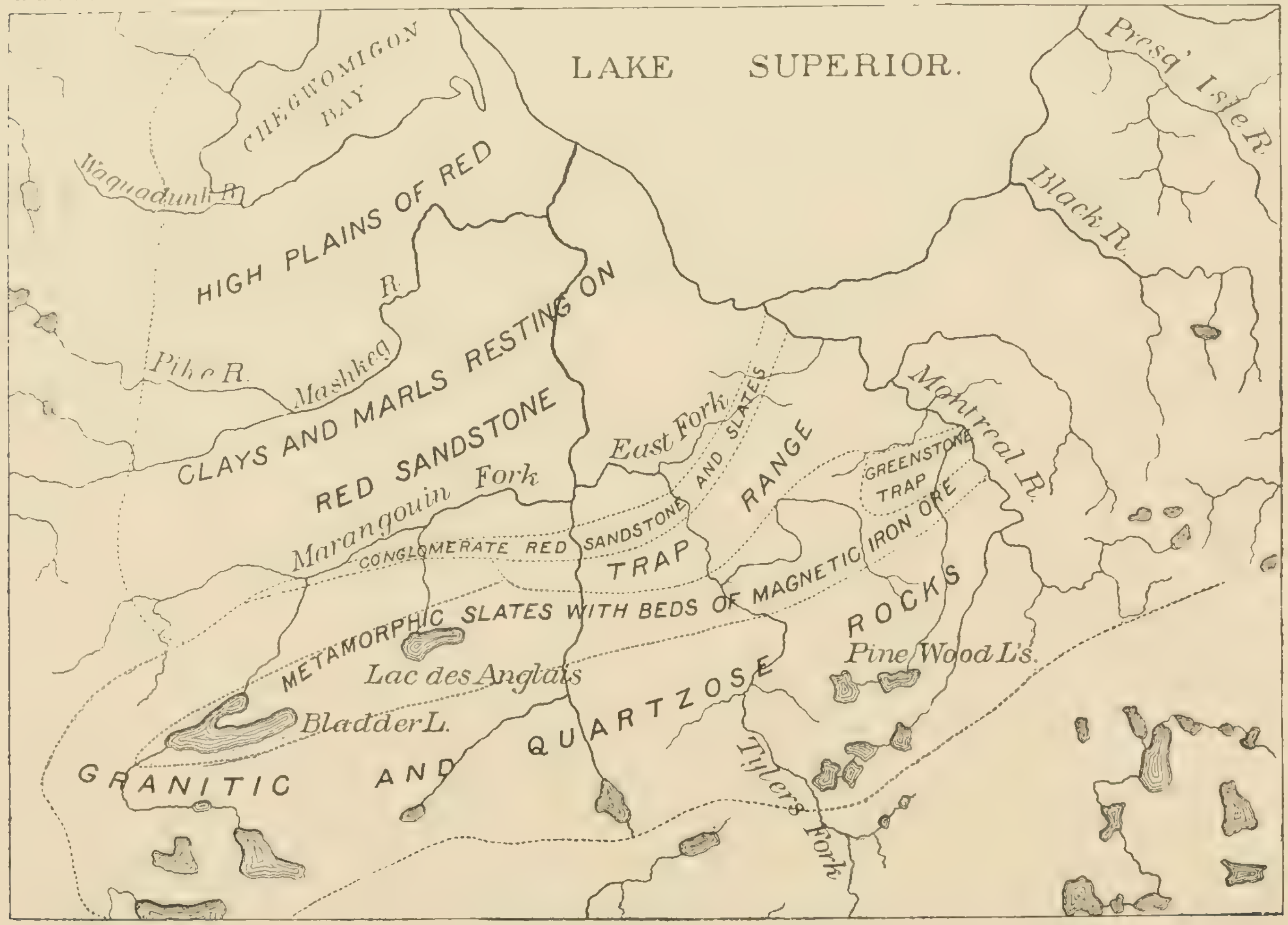
rocks (4) includes the granitic, gneissic, and schistose rocks which lie to the south of the Penokee range and form, as he says and as we also believe, the oldest division of the region. We are not sure that we fully understand Whittlesey's statements at the close of the quotation above, as to the relative ages of the different rocks of the region. It seems that he would say that the various eruptive rocks of the Keweenaw series which occupy the belt of country between the red sandstone on the north and the iron-bearing slates on the south are all of them of an intrusive nature, having been thrown to the surface after the formation of the red sandstone, which they have thrust northward, at the same time pushing the slaty series to the south. His position as to the more recent origin of these trappean rocks relatively to the red sandstone is one which, of course, can not be maintained. It has been abundantly proved by the work of the Wisconsin Survey (1873–1879) that these eruptive rocks antedate the red sandstones. In large measure they originated as surface flows; and, moreover, certain of them have yielded the most of the fragmental material, coarse and fine, of which the sandstones are built.

The following quotations have more especial reference to the iron-bearing formation:

There is a continuous mountain chain from the Montreal river to Bladder lake, the prolongation of the Porcupine mountain range in Michigan. I have called it the *Penokie* range, this being the Indian word for iron, which is found in its westerly portion in great force (p. 434).

The most easterly appearance of magnetic iron which I observed was in fissile black slate, about 4 miles west of the Montreal trail, along which the section No. 4 W. is made. The bed lies back of the trappose range, about 16 miles from the lake, in a protrusion of metamorphic slates, the argillaceous portions merely tinged with iron. About 4 miles along the strike of the beds, southwest by west, the bed was seen by Mr. Randall in 1848, in the fourth principal meridian, in township 44 north, 18 miles from the lake. From thence I and my assistant, Mr. Beesly, an active woodsman and faithful and acute observer, traced it at moderate intervals along the uplift to the west end of "Lac des Anglais," or about 15 miles, to where the range terminates. Here the metamorphic slates that first show themselves between the Montreal river and the Montreal trail on the east sink beneath the level of the country and are replaced by syenitic rocks.

By examining the sections Nos. 1, 2, 3, and 4 W., attached to this report, the position of the iron-bearing rocks will be found to be the same in each, and the




REPRODUCTION OF WHITTLESEY'S GEOLOGICAL MAP OF PENOKEE RANGE AND SURROUNDING REGION.

details of the rocky beds above and below the iron are also the same, so that we may with confidence pronounce it to be a continuous bed from the meridian westward to Lac des Anglais. Its thickness, richness, and value vary very much, but we found it more or less developed whenever we crossed the range and could get a view of the rock.

The geological relations of the iron-bearing strata are exhibited in the two following sections, the first taken near the trail that passes over the Pewabic range between the forks of the Tyler branch of Bad river, the second south of Lac des Anglais.

On the Pewabic range the strike of the beds is east by north; the dip north by west 80° to 85°. The beds of quartz are of great thickness—200 to 250 feet. Near the junction of the quartz and talcose slate the latter assumes the aspect of novaculite. The iron bed is schistose in its structure and is composed of magnetic oxide, sometimes alternating with beds of quartz. The total thickness of the talcose slate is not seen; it must be very thick and is traversed by numerous veins of quartz. Its dip and strike are variable.

The bed of magnetic iron ore south of Lac des Anglais is of extraordinary thickness—25 to 60 feet. The dip here is northeasterly, and the layers variable in thickness that alternate with quartz, which latter repose upon hornblendic slate, running downward into talcose slate. Here, as well as on the Pewabic range, the dip and strike of the beds are variable.

The metamorphic strata are very much disturbed throughout this range, but agree in having the mural faces of the uplifts to the south and southeast, and the dip northerly and northwesterly at various angles of from 5° to 60°. The effect of this irregular action is to make detached ridges and crests, sometimes 2, 3, and 5 miles long, thrown up at different elevations and inclinations.

Sometimes the iron stratum is composed of laminæ of quartz and magnetic oxide, alternating, as at the crossing of the trail between the forks of the Tyler branch of Bad river; also south of Lac des Anglais.

The proportion of iron and quartz is very variable, but the separation of them by mechanical means would in general not be difficult. The bands of ore vary from mere thin laminæ to a thickness of 12 and even 18 inches, presenting sometimes a black surface, contrasting with the white and gray color of the quartz, and sometimes a bright metallic gray color. The thickness of the metalliferous portion varies in the extreme from 5 and 10 feet up to 50 and 70 feet, and at the passage of the main portion of Bad river through the range reaches 250 feet. These exposed faces frequently extend beneath the surface, where, of course, no estimate can be formed of their entire thickness.

There are many places in the mountain, west of Bad river, which present more than 50 feet of quartz and iron, in about equal proportions. In the wild and deep ravines where the Bad river breaks through the range there is a cliff of slaty ore, most of which comes out in thin, oblique prisms, with well defined angles and straight edges, probably 300 feet thick, including what is covered by the talus or fallen portions. I estimate more than one-half of this face to be ore, and in places the beds are from 10 to 12 feet in thickness, with very little intermixture of quartz. There are portions of it not slaty, but thick bedded. The dip of the laminæ is mostly north and by east, 80° and 85°. The convulsions that have occurred at this point have thrown a part of the range beyond the rest of it, to the northward, so that in crossing the river and passing along the mountain to the eastward for several miles the ferruginous bed, as well as many of the associate strata, were not visible above the general surface of the ground. It should, however, be borne in mind that the whole region is not only covered so thickly with timber that no distant views can be had without climbing trees, but the drift often conceals the rocks over a large proportion even of the elevated ridges. In addition, the rocks themselves, previous to the era of the drift, have been the sport of giant forces, which tossed and tilted them about at various angles and elevations, realizing the fable of Atlas (pp. 444–446).

It will be noted that the two names "Penokie" and "Pewabic" are used in the above quotation for the bold range which runs from the Montreal river to the vicinity of English lake, near the southern boundary of the iron-bearing formation. Whittlesey tells us in a later publication, subsequently noted, that the word "Penokie" here used is a misprint for "Pewabic" (more properly "Biwabik"), which latter term is the Chippewa word for "iron." However this may be, the former term in its more usual form of "Penokee" has since become thoroughly fixed by general usage.

Whittlesey's early work in this region was, of course, no more than a very rough reconnaissance. However, considering the difficulties of travel in the region and the fact that there existed in it at the time but a single surveyed line, the fourth principal meridian, we must give Whittlesey the credit of having achieved a good deal. In fact, including the further examinations made by him some ten years later, and below noticed, he supplied all the information of any value obtainable at the time of the inauguration of the Wisconsin State Survey, in 1873.

1859.

LAPHAM (I. A.). The Penokee Iron Range. Wis. State Agricultural Society Transactions, 1858–'59, vol. 5, pp. 391–400, with map.

This is a very brief and general account of the Penokee Iron range, based on trips made along it by Dr. Lapham in September, 1858, from Bad river, at Penokee gap, eastward to the fourth principal meridian, and westward to the end of the range south of English lake. The map accompanying the paper is topographical only and is very simple, having been compiled from the U. S. Land Office township plats; the only addition on it to information afforded by these plats being the course of the crest of the range. It is to be noted that Lapham's publication is the first giving any geological facts based on an examination of the region subsequent to the completion in it of the Land Office Survey.

The following quotation includes all of geological interest given in this paper:

This remarkable mountain range has been traced from a little east of the fourth principal meridian in township 45, in a direction a little south of west, across three ranges of townships; its length being about 20 miles, as shown on the accompanying map. At the west the range appears to slope down and terminates, but toward the east its extent is not known. The highest summits are about 1,200 feet above lake Superior, or 1,800 feet above the sea; the mean height is 100 or 200 feet less. Tyler's fork crosses the range at a place called "The Gorge," and Bad river crosses at Penokee, through a gap cut down to a depth of about 300 feet; the river here having an elevation above lake Superior of 668 feet.

On the north side the slope of the range is moderate, and covered with "drift;" but on the south it is quite abrupt, and steep, rocky precipices occur, looking as if they had at some remote period of the past formed the shores of some great body of water.

What gives this great ridge its peculiar interest and importance is the immense stratum or bed of magnetic iron ore which it contains, extending, with varying thickness and value, throughout its whole length. It is not, therefore, an Iron mountain simply, like those heretofore known in Missouri and elsewhere, but, as its name imports, an Iron range; as if mountain masses of iron had been passed between gigantic rollers and drawn out for a length of 20 miles. The ore is found in a very ancient chloritic slate, so ancient that it is supposed to have been deposited long before the existence of vegetable or animal life upon the globe. The slate rests upon a light colored quartz-rock, which usually extends to the base of the range on the south side. The ore is laminated, like the slate, and apparently has had the same origin; for, as we ascend from the quartz-rock the slate becomes more and more ferruginous until it passes into pure iron ore. This change is so gradual that it is often difficult to determine where the slate ceases and the ore begins, or how much should be classed as iron ore and how much as ferruginous slate. We noticed places where the ore had a thickness of 60 feet, at other places 10, and wherever we could get access to the rock at the proper place the ore was found.

Above the ore, that is north of it, the slate has been hardened, probably by some volcanic agency, into a compact mass, but still showing traces of its original laminated structure. This highly indurated rock is the nucleus of the ridge, usually forming the crest or highest part; and it forms the north slope, except where covered with the bowlders and other coarse materials of the Drift formation. If we may judge from the polished and grooved surfaces, we may suppose that this excessively hard rock has resisted the action of the powerful currents and icebergs that once flowed over the very top of the ridge, which, with its invaluable beds of iron ore, was thus saved from destruction.

All the rocks, including the ore, have a considerable dip toward the north, or toward the great basin of lake Superior; and they are always found in the same relative position in regard to the ore. If we, at any new locality, could find either of the rocks in place, we at once knew which way to turn to find the ore.

The magnetic ore of the Penokee Iron range contains a notable and much varying proportion of silica in its composition, but is free from sulphur and other deleterious qualities, corresponding in this respect with most of the iron ores of this remote geological epoch. It is in some localities so highly magnetic that particles adhere to the hammer when struck, like iron filings to a magnet; and the compass needle as often pointed toward the east or west as to the north, in one instance being entirely reversed, the north end pointing to the south. At Penokee, where Bad river crosses the range, the ore exists in such abundance that it may be obtained from the face of the hill, much as stone is taken from an ordinary stone quarry. Large masses that have fallen from the cliffs now lie loose upon the surface, and will supply a furnace for many years before it will be necessary to resort to the original bed (pp. 394–396).

1860.

Lapham (I. A.). Report to the Directors of the Wisconsin and Lake Superior Mining and Smelting Company, in the Penokee Iron Range of Lake Superior, with Reports and Statistics, showing its Mineral Wealth and Prospects, Charter and Organization of the Wisconsin and Lake Superior Mining and Smelting Company, Milwaukee, 1860, pp. 22–37.

This is a private economic report based on the same exploration as the paper immediately preceding. It contains, however, some further generalizations of interest. Dr. Lapham's investigations appear to have been confined almost entirely to the ferruginous belt and its immediately adjacent layers, which form the Penokee ridge proper. The higher members of the series received only very slight and incidental attention. The following quotation gives the more important generalizations reached:

I will now proceed to explain the geological relations of this vast bed of magnetic iron ore, show how it is associated with other rocks, and its mode of occurrence and characteristics.

The general direction of the range is about 12° north of east, and south of west and this is also the direction of the strike of the several strata of which it is composed. The dip, or inclination of the layers of rock, is toward the north and at right angles to the strike. The dip varies from 30° to 60°, and in a few cases it is almost perpendicular, or 90°. West of Bad river the dip is usually less than it is east of that stream.

The rocks with which the ore is immediately associated are of the kind called Primary or Azoic, having been formed, as is supposed, at a very early epoch, and prior to the existence of animal life upon the earth.

The lowest formation noticed at the base of the range on the south side was a light colored, often white, quartz rock, consisting of minute, closely aggregated grains of quartz or sand. Sometimes this rock forms a large proportion of the height of the cliff; at other places it is quite subordinate. . . .

Next above the quartz rock, and often alternating with it, is found a chloritic slate, . . . more or less silicious; in some localities so much as to resemble the novaculite or oil stone, and might be used for whetstones, though we saw none of much fineness of texture. In many respects this slate is one of much interest, being often associated with metallic ores, and at this place actually passing into iron ore. As we ascend toward the north, the slate gradually becomes more and more ferruginous, until it is changed to a very pure iron ore. . . . It is often quite difficult to decide by the external characters alone where the slate rock ends and the slaty iron ore begins, so gradual is the change. The ore possesses the same slaty character and has the same dip or inclination of its layers.

Immediately above the ore (or north of it) is found a very hard rock, . . . with obscure marks, indicating its original slaty structure, which is supposed to be hardened (metamorphic) slate. It is everywhere filled with thin seams of highly magnetic ore. These seams . . . vary in thickness from one-eighth of an inch to several inches, and correspond in direction and dip with the mass of the rock. They are so hardened and so intimately connected with the rock in which they are imbedded that the ore can not be separated; and it is, therefore, only when these seams are so abundant as to justify the smelting of the whole (ore and rock) together that they possess practical value. It forms the crest and north slope of the range, except where covered with drift. . . .

These several rocks—the quartz rock, chloritic slate, magnetic iron ore (for this is so extensive here that it may be ranked as a rock formation), the "hard rock," and the drift—are all coextensive with the range, so that wherever we find either we could with certainty predict the occurrence of the others in the proper relative order. . . .

It is supposed by geologists that slate rocks were originally deposited from water, and that the layers were at first nearly horizontal. Whatever may have been the origin and original position of this slate, the same must be assigned to the iron ore, the same causes continuing to operate throughout the whole period of the formation of the slates and the iron.

These strata have all been tilted or lifted up from the horizontal to nearly a vertical position, without otherwise materially modifying their structure and composition. That part of the slaty deposit which rests upon, and was therefore of later formation than the iron, has been subjected to still other influences (probably heat and pressure), which have transformed the fissile slate into a very hard subcrystalline rock.

The geological relations of this prolonged ore bed are quite the same as those of the nonmagnetic ores near Marquette. We have the same granitic rocks at the north, the same quartz rocks at the south, and the same slate in which the ore is found. Hence we must assign to each a similarity of origin, and whatever theory may be adopted for one must be equally true of the other. (Pp. 26–29.)

The following quotation is of interest as showing that Dr. Lapham was the first to notice indications of the occurrence at Penokee gap of the fault whose existence was subsequently demonstrated and details worked out by the Wisconsin Survey.[1]

The range here appears to have made a sudden offset northward in passing the river, and the strata are more or less disturbed, the dip and direction not being so uniform and regular as at most of the other localities examined.

Dr. Lapham held, with regard to the value of the strongly magnetitic rocks of the Penokee range, the usual unfortunately favorable opinion which later experience has not justified.

It will be seen that we have already discovered good ore in such quantities as to be practically inexhaustible, situated at points accessible to water power and having bold fronts, rendering it comparatively easy to be quarried. For many years to come only the richest and most accessible ores can be brought into use, rejecting—at least for the present—all such as have too large a proportion of silica, and such as are not in a condition to be easily and cheaply removed from the natural bed. Though it is clearly shown that the ore is coextensive with the range, yet it must not be supposed that it constitutes a continuous workable mine throughout this whole distance of 20 miles. It is only at the points indicated where the ore is easily worked and where water power is at hand that very great immediate value can be put upon

[1] Geology of Wisconsin, vol. 3, pp. 150–152, and Atlas, Plate XXIII.

these mines, for the reason that the difference in the expense of quarrying the ore from the side of a high cliff, and of mining it below the surface of the ground, will be sufficient to dissipate all the profits that can be made from the use of ores so obtained. (P. 33.)

1863.

WHITTLESEY (CHARLES). The Penokie Mineral Range, Wisconsin, Proc. Bost. Soc. Nat. Hist., vol. IX, 1862–'63, pp. 235–244.

The work done by Col. Whittlesey in 1849 in connection with Dr. Owen's general survey of the northwest antedated the linear surveys of this region. Eleven years later, August to October, 1860, he made a further examination of the Bad river country, under the auspices of the Wisconsin Geological Survey, then organized under James Hall. This time he had the advantage of the linear surveys. His report was never published, the survey being very short-lived. He afterwards published a few brief details in reports to iron companies and the summary contained in this pamphlet, from which we quote quite fully. The map accompanying Whittlesey's report to the Wisconsin Geological Survey was not published until 1880, when it appeared in an appendix to the third volume of the Geology of Wisconsin, but it is properly reproduced here, having been prepared in 1860. (Pl. IV.)

The copper-bearing strata of point Kewenaw (lake Superior) extend southwesterly across the boundary of the state of Michigan into Wisconsin. These strata constitute a long, narrow, and bold mountain range from Copper harbor to Long lake, a distance of 160 miles. There are no stratigraphical breaks along this line, the order of the rock being everywhere the same. The dip of the beds is always northerly or northwest and the strike to the northeast or east, the general line of outcrop being northeast by east. On point Kewenaw and as far southwest as the Akogebe lake, on the west fork of the Ontonagon river, the copper veins have been found valuable.

Beyond the waters of the Ontonagon, in the same direction, veins have been discovered, but, after limited workings, have been abandoned. The Montreal river forms the boundary between *Michigan and Wisconsin*, and as early as the year 1845 mining locations were made on its waters where they pass the range. Locations were also made upon the waters of the Bad or Mauvaise river, a stream with numerous branches, draining the country from the Montreal to the head waters of the Chippeway and St. Croix rivers.

Historically considered, the exploration of this region commenced in the year 1840, when Dr. Houghton, as a commissioner of the State of Michigan, accompanied Capt. Cram, of the United States Topographical Engineers, who was then surveying the Menominee and Montreal rivers.

In 1840 and 1841 Dr. Houghton examined the rocks on both these streams and the country between their sources. I am in possession of a transcript of his field notes during these explorations. In 1845–'46 I made examinations along the range across the Montreal to the westward, as far as the main branch of Bad river.

Up to this time the public lands in this part of Wisconsin had not been surveyed. The fourth principal meridian was extended northward through Wisconsin to lake Superior in 1848. Dr. A. Randall, one of the assistants of Dr. Owen upon the survey of the Chippeway land district in reference to mines and minerals, accompanied the linear surveyors along this line. In T. 44 N., Dr. Randall discovered an outcrop of magnetic iron ore and brought in a specimen. The next season, as a member of Dr. Owen's corps, I made an exploration on the western branches of Bad river, crossing southerly to the head waters of the Chippeway. Near Lac des Anglais, and thence easterly across the middle or main fork of the Bad river, I found cliffs and bluffs of siliceous magnetite. The results of this examination may be seen in the final report of Dr. Owen, published at Washington in the year 1850.

In the Chippeway language the name for iron is *pewabik*, and I thought it proper to designate the mountains where this metal exists in quantities that surprise all observers as the "Pewabik range." The compositor, however, transformed it to *Penokie*, a word which belongs to no language, but which is now too well fastened upon the range by usage to be changed.

Soon after the publication of Dr. Owen's report the excitement of 1845–'46 in reference to copper was repeated in reference to iron. The government was at last induced to make surveys of the region. Preemptors followed the surveyors, erecting their rude cabins on each quarter section between the meridian and lac des Anglais, a distance of 18 or 20 miles. The iron belt is generally less than one-fourth of a mile in width, regularly stratified, dipping to the northwest conformable to the formations, and having its outcrop along the summit of the second or southerly range. Viewing this mountain region from La Pointe, or from the open lake, it has the appearance of a single crest. Its outline against the sky on a clear day is very distinct and regular. Along the range this crest line is nearly level, its elevation above the lake being 1,000 to 1,100 feet. But there are two ranges, known in the country as the first and second, or the "Copper" and the "Iron" range. There is not much difference in their elevation. The copper range, being nearest the coast, covers the iron range, which, at the distance of 30 miles, is visible only through gaps and notches, the whole forming one blended line in the horizon. To the south, beyond the iron range, the country is lower and swampy.

Two roads were soon constructed to the mineral deposits through the dense evergreen forests of this latitude. One of them commenced at the lake, near the mouth of the Montreal river, and near the termination of the fourth principal meridian, extending thence south and not far from the meridian line. The other began on Chegoimegon bay, at Ashland, pursuing also a southerly course, and, after reaching the second range, connected along it to the eastward with the first road, passing the cabins of the preemptors. In 1859, Mr. Daniels, of the Wisconsin Geological Survey, and Mr. Lapham, of Milwaukee, examined the iron range in behalf of a company which had made extensive purchases there and had caused a survey for a railway to be made with a view to the manufacture of iron (pp. 235–237).

The following is a general view of the structure of the formations in the descending order:—

*Formation No. 1.—Potsdam Sandstone.* On the Montreal river, *strike* northeast by east, in places N. 60° E.; *dip* northwest by north, 75° to 90°. It embraces four members, *a*, *b*, *c*, and *d*.

| | Feet. |
|---|---|
| *a. Sandstone proper*, corrected for bevel, thickness | 8,500 |
| *b.* Alternations of sandstone and black slate, thickness | 750 |
| *c.* Conglomerate, thickness | 1,800 |
| *d.* Alternations of trap and sandstone, thickness | 800 |
| Total | 11,850 |

*Formation No. 2.—Trappose, in two members.*

| | Miles. |
|---|---|
| *a.* Brown amygdaloid; dip and strike conformable to formation 1; thickness along lac Flambeau trail | $3\frac{1}{2}$ |
| *b.* Compact red and blue | $2\frac{1}{2}$ |
| Total | 6 |

*Formation No. 3.—Hornblendic.*

| | |
|---|---|
| Compact, subcrystalline and slaty; black or dark colored; strike N. 60° E.; thickness on trail | $2\frac{1}{4}$ |

*Formation No. 4.—Siliceous, two members.*

| | |
|---|---|
| *a.* Quartz, slaty, and in layers; dark colored, but less than formation 3; thickness variable; separated from *b* by a bed of magnetic iron and iron slate. | |
| *b.* Quartz, slaty, in layers and beds; more compact and lighter color (gray and straw color) than *a*; novaculite; strike N. 60° to 65° E.; dip variable, 30°, 45°, 60°, 75° to the northwest; breadth across the edges on trail | $3\frac{1}{2}$ |

*Formation No. 5.*

Granites and syenites of central Wisconsin (pp. 238–239).

1872.

Brooks (T. B.) and Pumpelly (R.). On the Age of the Copper-bearing Rocks of Lake Superior. Am. Jour. Sci., 3d series, vol. III, 1872, pp. 428–432.

Messrs. Brooks and Pumpelly, in the fall of 1871, made a very rapid trip from the passage of Bad river through the Penokee range in Wisconsin eastward to the Ontonagon river in Michigan.

The statements below quoted from this paper with regard to the country between the Montreal river and Gogebic lake contain the first published announcement of the existence in Michigan of an eastward continuation of the Penokee Iron series of Wisconsin. The width of the iron-bearing series often greatly exceeds the "one-fourth to one-half mile" given in this quotation, reaching as much as 2½ miles or more, while at other times it is below their lowest figure, or is even cut out altogether by the overlapping of the overlying Keweenawan rocks.

During last autumn, traveling sometimes together and sometimes apart, we made a reconnaissance of the country between Bad river in Wisconsin and the middle branch of the Ontonagon east of lake Gogebic in Michigan. Our route was chiefly confined to the surface of the upper member of the Michigan Azoic, which we have provisionally considered to be the equivalent of the Huronian.

From Penokie gap on Bad river to near lake Gogebic, a distance of nearly 60 miles, the quartzites and schists of this formation are tilted at high angles and form a belt one-fourth to one-half mile in width, bordered on the south by Laurentian gneiss and schists. On the north it is everywhere overlain by the bedded melaphyre (containing interstratified sandstones) of the Cupriferous series. These form ridges and peaks which rise 200 to 300 feet above the surface of the Huronian belt.

These ridges, forming the "South Mineral range," unite at their western end with the Mineral range proper, which forms really through its whole length the tongue of land known as Keweenaw point. Between these two ranges lies the southwestern part of the Silurian trough, which has been mentioned before as extending inland from Keweenaw bay.

Here, as there, it is filled with the horizontally stratified Silurian sandstone, forming a generally level country. For a distance of nearly 30 miles, between the Montreal river in T. 47 and lake Gogebic, we found the Cupriferous series apparently conforming in strike and dip with the Huronian schists, and both uniformly dipping to the north at angles of 50° to 70°. But in approaching lake Gogebic from the west we find that erosion of Silurian or pre-Silurian age has made a deep indentation entirely across the Cupriferous series and the Huronian, and into the Laurentian, so that at a short distance west of the lake these rocks end in steep and high declivities, at the base of which lies the level country of the Silurian sandstone, in which is cut the basin of the lake. From this point eastward this ancient erosion had made great inroads upon the continuity of the Cupriferous and older rocks before the deposition of the Silurian sandstone. The melaphyre ridges are broken into knobs, or are wanting, and no Huronian was found as far as the Ontonagon river, 7 miles away, and the limit of our observations. (Pp. 430–431.)

1873.

BROOKS (T. B.). Geological Survey of Michigan, Upper Peninsula, 1869–1873, vol. I, New York, 1873, with an Atlas.


FIG. 2.—Reproduction of a portion of Brooks and Pumpelly's geological map of the upper peninsula of Michigan.

In Part I of this volume, chapter VI (pp. 183–186) is entitled "Lake Gogebic and Montreal River Iron Range." This gives a brief outline account of the occurrences in the iron belt between Montreal river and Gogebic lake. The account is somewhat fuller than that given in the paper quoted immediately above, but is based on the same rapid examination, and contains no details. On the general map of the Northern peninsula, given in the atlas which accompanies this report, the Michigan end of the Penokee series is first mapped. Fig. 2 is copied from the western portion of this atlas map.

The iron range under consideration may be regarded as the eastern prolongation of the Penokie range of Wisconsin, as well as the western extension of the Marquette series, the whole being Huronian. The position of the range is tolerably well defined by magnetic observations and notes on the U. S. Land Office plats. On these we find mention of iron and magnetic attractions on Secs. 7 and 8, T. 47 N., R. 45 W., as also in Secs. 13 and 14 of the town west. The belt of Huronian rocks, as made out by us, extends nearly east and west through the north part of T. 47, ranges 44, 45, 46, and 47, crossing the Montreal river in Secs. 16 and 21 of the last named township. Going east, the range was lost before it reached lake Gogebic.

The geological boundaries of this range are fortunately of the most unmistakable nature and render a detailed description of its position unnecessary.

On the north is the high, broad, irregular ridge, or series of ridges, constituting the South Copper range, the rocks of which are greenish and brownish, massive and amygdaloidal copper-bearing traps, their bedding being exceedingly obscure, with occasional beds of sandstone and an imperfect conglomerate. The strike of these rocks, so far as it could be made out, was east and west, with a dip to the north at a high angle, thus *conforming* with the Huronian rocks underneath.

Against and over the copper series on the north abut the horizontally bedded lower Silurian sandstones, which are beautifully exposed on the west branch of the Ontonagon river, in Sec. 23, T. 46, R. 41. These sandstones form the surface rock, and occupy the broad belt between the two copper ranges from the region we are describing to Keweenaw bay, but taper to a point before reaching the Montreal river in going west.

On the south of the Iron-bearing rocks are a series of granites, chloritic gneisses, and obscure schists, which, except the latter, are unmistakably Laurentian in their lithological character, and are *nonconformably* overlaid by the Huronian rocks. The general structural relations of the four great systems here enumerated are shown in the accompanying diagram. (Pp. 183, 184.)

The best locality in which to study the character of the iron series in the West region, is on Black river and its tributaries, especially on the outlet of Sunday lake, T. 47, ranges 45 and 46. Here will be found banded ferruginous jaspery schists, chloritic greenstones, brown ferruginous slates, black and gray banded siliceous slates, siliceous flag ores, several varieties of quartzites, and clay slate. The whole series strike east and west, and dip north away from the granites and gneisses and under the copper rocks at an angle of from 40° to 90°. (P. 185.)

In Part II of the same volume (being Prof. Pumpelly's report on the Copper-Bearing Rocks), Chapter I contains the same statements, reproduced almost verbatim, with regard to the Montreal-Gogebic iron belt, as are above quoted from a paper published jointly by Brooks and Pumpelly.

JULIEN (ALEXIS A.). Lithological Descriptions, etc., of 259 specimens of the Huronian and Laurentian Rocks of the Upper Peninsula, appendix A, Geological Survey of Michigan, New York, 1873, vol. II, pp. 1–197.

This report contains nonmicroscopic lithological descriptions of a few rock specimens collected by T. B. Brooks and R. Pumpelly in the Gogebic region in 1871, during the trip already several times referred to.

1874.

IRVING (R. D.). On the Age of the Copper-bearing Rocks of Lake Superior; and on the Westward Continuation of the Lake Superior Synclinal. Am. Jour. Sci., 3d series, vol. VIII, 1874, pp. 46–56, with a map and section.

This is a paper giving an account of several conclusions reached after a first season's work in the Bad river country of northern Wisconsin. Its main object is to set forth conclusions on the points indicated in the title. The following paragraphs are quoted as bearing on the district which forms our present subject:

2. *The Huronian rocks* (II on the map and section), which directly overlie the Laurentian, and unconformably, as shown by Brooks and Pumpelly from observations made by them in Michigan just east of the Wisconsin line, constitute in Ashland county a continuous narrow belt, whose central portion is the well known "Penokie Iron range," and whose width never exceeds 2 miles, being usually much less than this. This belt extends without break into Michigan, almost as far as lake Gogebic, where the rocks are lost sight of, being covered by accumulations of drift, and finally by horizontal Silurian rocks. They do not reappear until, 100 miles farther east, the Marquette iron region is reached. Here they are found again, with some important changes and covering a much wider extent of territory. Toward its western extremity the Huronian belt appears to come to an abrupt ending, the underlying Laurentian and overlying Copper-bearing series coming together. Farther west, however, just on the west side of Ashland county, are two isolated belts of these rocks, in every way similar to the main area, each having in the same manner its central ridge. As to the continuation still farther westward of the Huronian, nothing whatever is known, as is indicated on the map by an interrogation point. The rocks of this group in northern Wisconsin are siliceous schists, talco-siliceous schists, black slates of undetermined composition, white quartz rocks, quartzites, magnetic and specular schists of various kinds, magnetic and specular iron ores, diorites, diorite slates, and diorite schists. The beds of one portion of the group, about 500 feet in actual thickness and continuous for over 30 miles, are impregnated throughout with the specular and mag-

netic oxides of iron in proportions varying from 1 or 2 per cent up to 60 and 80 per cent of the whole. The entire series has a nearly uniform dip west of north, generally at a very high angle. The thickness never varies far from 4,000 feet, a figure obtained by actual measurement. (P. 48.)

The estimate thus given for the thickness of the iron series falls far short of the truth, as the writer himself was able to show after further work. The mistake arose from a misconception during the first field season's work, of the nature of the upper mica-schist or micaceous quartzite member of the iron series. This member was not at the time examined closely and was supposed to belong with a higher series.

IRVING (R. D.). On Some Points in the Geology of Northern Wisconsin. Trans. Wis. Acad. Sci., Arts and Letters, vol. II, 1873–'74, pp. 107–119, with map and section. (Published 1874.)

This is essentially the same paper as the last referred to.

1876.

WHITTLESEY (CHARLES). Physical Geology of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1875, 24th Meeting, part 2, pp. 60–72. (Published Salem, Massachusetts, 1876.)

This paper is published only in abstract. It gives in outline some of the author's views as to lake Superior geology. It contains only a few very general and incidental references to the Penokee-Gogebic district.

BROOKS (T. B.). On the Youngest Huronian Rocks South of Lake Superior, and the Age of the Copper-Bearing Series. Am. Jour. Sci., 3d series, vol. XI, 1876, pp. 206–211.

This paper maintains that the large development of granite south of the Menominee river in Wisconsin is the youngest member of the Huronian or Iron-bearing series of that region, and then proceeds to draw a parallel between this Menominee granite area and certain granites that lie north of the Penokee range in the vicinity of Bad river, Wisconsin, which he maintains are in the right position to be again the uppermost member of the Iron-bearing series of this region. We quote from his argument:

A careful consideration of all the facts to be observed in the Menominee region confirms me in this hypothesis, which is further supported, as it seems to me, by observations in the Penokie Iron region (Bad river), Wisconsin.

Col. Whittlesey's maps and sections, given in Owen's report, 1852, represent a belt of granite, syenite, and hornblende rocks as dividing the Penokie series (Huronian) from the overlying Copper-bearing amygdaloidal traps and sandstones, which lie to the north and nearer the lake.

I observed these rocks at several points in 1871, and noted their general lithological resemblance to the Laurentian, as well as the almost insurmountable structural difficulties in assigning to them that age, and recorded in my notes the probability of their being Upper Huronian. Rowland Irving mentions these rocks as being coarsely crystalline aggregates "chiefly of labradorite and orthoclase feldspar, hornblende, and some variety of pyroxene," with occasional evidences of bedding, which points toward their entire conformability with the underlying Huronian. He regards them as of the period of the Copper-bearing series, constituting its lowest and oldest portion.

Having been, so far as I know, but little studied, it is perhaps impossible at this time to determine their age; but what is known can here be briefly surveyed, and an inference drawn, which will not be without value in directing further investigations.

1. The general lithological similarity of this granitoid belt to the Laurentian has been remarked. It has quite as much similarity, if not more, to several members of the Huronian, and is, I believe, not identical with any rock known to belong to the Copper series.

2. Its geographical extension is peculiar in this, it wedges out rapidly to the east from the vicinity of Penokie gap, entirely disappearing at the Montreal river, which divides Michigan and Wisconsin. Prof. Pumpelly and myself traced the boundary between the Copper and Huronian rocks 30 miles farther eastward beyond lake Gogebic, without again observing it, which we should certainly have done if it had existed there, for we often found the two series very near together, although the actual contact was not seen.

3. Not only does this granitoid formation thin out and disappear in its eastward prolongation, but the same is true of the whole Huronian series, the belt of which becomes narrow as followed east, and finally disappears in the neighborhood of Gogebic, where the Laurentian is seen very near the Copper series.

4. The fact that the granite mass does not cross either the Copper or Huronian series, or, so far as observed, give off dikes in either, renders it improbable that it came into its present position as an eruptive mass subsequent to the formation of both series of rocks.

5. The various ores of iron, which are so generally and abundantly diffused in the Lower and Middle Huronian, are entirely absent so far as observed from the upper three or four members as developed in the Marquette and Menominee regions, and also in the Penokie series if the following hypothesis is true; but they occur in all forms, although it is believed not abundantly in the uppermost *exposed* member

on Black river. If we suppose this iron to have been mostly precipitated as a carbonate, then we might expect it would be more generally diffused through the rocks of certain epochs than those materials derived from the erosion of adjacent coasts.

There is evidently but one hypothesis which will reconcile these facts, which is, that the granitoid formation in question is of the Huronian period, and probably the youngest member, which series are here *nonconformably* overlaid by the Copper-bearing rocks. I conceive that this view is supported by the observations in the Menominee region above recorded, and suppose this Penokie granitoid formation may be the equivalent of granitic bed XX of the Huronian series as developed in that region. On this hypothesis it is possible that the valley dividing the Penokie range proper from the granitoid belt may be underlaid by a soft slate, the equivalent of the micaceous schist, bed XIX. (Pp. 207–208.)

We are not in accord with Brooks as to the views here expressed. We can not allow that the granite of the Menominee is Huronian at all, inasmuch as we think it plainly belongs to the older or gneissic series; nor can we agree with the statements of Brooks as to the granites north of the Penokee range. As to the Menominee granite, we do not now need to present any arguments in defense of our belief. As to the Penokee granites, we may merely repeat the substance of what one of us has already said in several publications, viz, (1) that the belt of "granite, syenite, and hornblende rocks" outlined by Whittlesey really has no existence; (2) that the granites occurring in the vicinity of Bad river, and north of the Penokee range, lie in no continuous belt, but are veins and masses intersecting the gabbros at the base of the Copper-bearing series, and the micaceous quartzites at the summit of the Iron-bearing series; (3) that these granites are manifestly but a phase of the intrusive reddish, granitic porphyries which mark this horizon both north and south of lake Superior; (4) that being so manifestly intrusive, there is nothing like bedding about these granites; (5) that the "wedging out" to the eastward, which Brooks speaks of as characteristic of his supposed granite belt, is really a characteristic of a great gabbro area here occurring, and not of a granite area; (6) that this gabbro mass does traverse the Huronian beds in a most noticeable manner, in places even cutting them out at the surface altogether; and (7) that at the southern margin of this gabbro, or along its contact with the Iron-bearing slates, it is plainly involved with and intrusive in those slates, as the granite is in both gabbro and slates.

In short, we see nothing here, nor indeed anywhere in the lake Superior country to warrant the view that the Iron-bearing or Huronian series has an uppermost granitic member. The Menominee granite belt we look on as belonging to the great basement gneissic formation; the Penokee granite belt is really a great gabbro area, in which occur isolated and limited intrusions of granite, granitic porphyry, and allied acid rocks. This gabbro, with red acid eruptions, finds its exact equivalent as to stratigraphical position and associated intrusions in the great gabbro belt which forms the bold range of hills at Duluth, and stretches thence far to the northeastward into the interior of that portion of Minnesota which lies north of lake Superior.[1]

BROOKS (T. B.). Classified List of Rocks observed in the Huronian Series south of Lake Superior. Am. Jour. Sci., 3d series, vol. XII, 1876, pp. 194–204.

This paper, as its title indicates, is an attempt at a lithological classification of all the varieties of rocks observed by Brooks in those formations on the south side of lake Superior, which he regarded as the equivalents of the original Huronian of the north shore of lake Huron. It also gives a table showing the "sequence of Huronian strata at several points near lake Superior, with hypothesis of equivalency." The districts referred to in this table are (1) the north shore of lake Huron, (2) the Marquette Iron district, (3) the Menominee Iron district, (4) the district of Black river, Michigan, and (5) the district of Bad river, Wisconsin. The last two district are within the area now under description, and we therefore quote the table so far as it gives the succession of strata for Black and Bad rivers. We do not now discuss Brooks's hypothesis of equivalency for these sections with those of the other districts referred to. We need merely to say that we can not accept his scheme in many respects. Indeed, we find too many things that we can not agree with in his succession for the Penokee-Gogebic series itself to allow us to accept any scheme of equivalency based upon it. His Bad river section is particularly imperfect, there being great thicknesses of rock omitted entirely, while the granite belt

[1] Am. Jour. Sci., 3d series, vol. XI, 1876, p. 493; Geol. of Wis., vol. III, 1880, pp. 10, 13, 22, 35, 44–46, 145–149, 167–183, 193–195, 233–237; and atlas plates xxi, xxii, xxiv, xxv, xxvi, xxvii; Monograph U. S. Geol. Survey, vol. V, 1883, pp. 37–57, 56–58, 141–145, 155–157, 158, 230–238, 266, 268–275.

placed at the top of the series is really as we have already insisted, but part of the great development of gabbro which lies at the base of the Copper-bearing series. The facts given in this tabulation for the Black and Bad river sections are based on the observations made by Brooks on his rapid trip through the region in 1871, above referred to. In a later publication he accepted the Bad river section given by R. D. Irving.[1]

The following is the portion of Brooks's tabulation referred to·

| *Black river series.* | *Bad river series.* |
| --- | --- |
| | Red, gray, coarse and fine grained *granitic* rock, rarely schistose. |
| | *Greenstone* or hornblende rock, apparently chloritic (somewhat soft, but tough). |
| Compact *greenstone*, with green cherty (?) layers. Bright red specks of jasper and crystals of pyrite. | [Covered about ½ mile.] |
| *Greenstone;* holds grains of glassy quartz and appears chloritic. | Clay slate? |
| *Hematitic* and *magnetic quartzose flag* (like Marquette flag ores). | |
| Gray, green, and brown *banded ferruginous, siliceous slate*, with strong rhombohedral cleavage. | *Magnetic amphibolic quartzose flags* and quartzose magnetic ore. 148. Heavy bed forming crest of ridge. |
| Grayish and greenish *banded schist*, weathering brown, apparently *chloritic*, with *jaspery* layers Contains pyrites. In places apparently felsitic and again aphanitic. | Black *clay slate* without oblique cleavage. |
| [Covered.] | Gray *quartz* schist, banded with occasional laminæ of *magnetic ore.* |
| *Ferruginous, banded* (purple and green) *cherty schist* (magnetic). | |
| Banded ferruginous *jasper schist.* | Grayish and reddish *quartzose schist.* |
| Ferruginous, *siliceous flags* (not magnetic). | *Greenstone* (thin bed). |
| Arenaceous *quartzose schist.* | |
| Reddish *quartzite.* | Soft, light, gray-green *slate*, probably chloro-argillaceous. |
| Hydrous magnesian or *argillaceous schist.* | |
| *Greenstone.* | |
| | Gray *quartzose schist*, faintly banded. |
| Banded *cherty schist* and schistose cherty *breccia*, more or less ferruginous. 84, 85. | |
| Compact, hard *greenstone.* | |
| Very soft, apparently chloritic *greenstone.* | Gray to white, massive *quartzite.* (Thin bed.) |
| Gray, banded, *slaty schist.* | |
| [Covered 100 steps.] | |
| | Calcareous rock? |
| *Greenstone.* | |
| Banded *ferruginous, siliceous schist*, strongly magnetic. | |
| *Greenstone.* | |
| Banded *ferruginous slate.* | Amphibole schist and perhaps hornblendic gneiss in heavy beds. |
| Massive *greenstone*, apparently chloritic. | |
| Banded ferruginous *jasper schist.* | [Covered.] |

[1] Geol. of Wis., 1880, vol. III, table opp. p. 450.

SWEET (E. T.). Notes on the Geology of Northern Wisconsin. Trans. Wis. Acad. of Sci., Arts and Letters, vol. III, 1875-'76, pp. 40-55.

This is an outline account of observations in northern Wisconsin made in 1873 and 1875 for the Wisconsin State Geological Survey. The quotation below gives certain facts with regard to the Bad river and Penokee gap section. It should be said that I afterwards measured this section in detail for the Wisconsin Survey and the results were published in the third volume of the Geology of Wisconsin. The thickness of the Iron-bearing series is more than twice as great as supposed by Mr. Sweet, the uppermost beds being far above the uppermost mentioned by him. Two magnetic belts, moreover, do not exist, as supposed by Mr. Sweet, the supposed two belts being the same belt faulted apart.

The junction between the Laurentian and Huronian is in the southern part of Sec. 14, T. 44, R. 3 W. At this point Bad river passes through a narrow gorge having nearly vertical walls on either side. In the left or northern wall of the gorge, fine grained white quartz with a vitreous coating and slaty siliceous schist occur, showing a strike nearly east and west, and dip of 66° to the north. The quartz represents the lowest member of the Penokie system examined by the party in 1873. Upon examining the opposite wall of the gorge siliceous marble was discovered for the first time to be one of the beds of the Penokie system, lying below the iron-bearing beds. A similar arrangement has long been known to exist in the Huronian of the Marquette district, which has led to the suspicion of its existence in Wisconsin. The thickness of the siliceous marble is about 50 feet. It is usually fine grained and grayish in color. Small crystals of calcite and dolomite, however, can be observed irregularly disseminated. An analysis of a specimen taken from the ledge afforded me the following result:

| | Per cent. |
|---|---|
| Carbonate of lime | 50·52 |
| Carbonate of magnesia | 33·41 |
| Insoluble matter | 13·85 |
| Oxide of iron | 1·70 |
| Undetermined | ·52 |
| Total | 100·00 |

The analysis shows that the proper name for the rock is siliceous dolomitic marble. In the Marquette region the Morgan furnace limestone, but very little purer than this, has been extensively used as a flux. One hundred feet southeast from the exposure of siliceous marble there is a large ledge of gneissoid granite showing a well defined dip of 77° to the south, and strike of north, 75° west. In following the strike west, one passes within 25 feet of the outcrop of siliceous marble which has a northerly dip. Between 100 and 200 feet south, on the line of the railroad, other large exposures of gneissoid granite are found having essentially the same bedding as that mentioned above. When the railroad cut is completed at this locality the absolute junction of the Laurentian and overlying Huronian will doubtless be exposed. There can be no doubt of the unconformability of these formations, approaching each other as they do with a persistent opposite dip and somewhat different strike. Unconformability has been shown to exist between the Laurentian and Huronian in Michigan, but this is the first time that it has been proved in Wisconsin. Northward from the granites the section has been completed for over 1,600 feet. In this space are included two "magnetic ore" beds, the southern 130 and the northern over 500 feet thick. Directly above or north from the northern "ore" bed there is a space of 1,400 feet upon which exposures have not been found. Above this blank recent railroad excavations enabled Mr. Wright and myself to subdivide and extend the belt of 400 feet, supposed to be the uppermost member of the Penokie system, into: *a*, siliceous schists, 100 feet; *b*, blank (Bad river), 75 feet; *c*, contorted black slate, 250 feet; *d*, diorites, 75 feet; and *e*, black porphyritic slates, 50 feet.

Owing to the heavy deposits of drift we were unable to find exposures for 1,300 feet north from the black porphyritic slates.

We then found what are probably the latest beds of the Huronian formation: *g*, black slate, 40 feet; *h*, quartzite, about 250 feet; *i*, slaty amygdaloid, 75 feet.

The thickness of the formation I estimate at something over 5,000 feet. The dip is about 66° to the north, showing entire conformability throughout. (Pp. 42–44.)

1877.

IRVING (R. D.). Report of Prof. Irving. In Annual Report of Progress and Results of the Wisconsin Geological Survey for the year 1876, by T. C. Chamberlin, pp. 13–18.

This report contains a brief account of the progress of the work under R. D. Irving in northern Wisconsin, but nothing that is not much more fully developed in the third volume of the Geology of Wisconsin, published in 1880.

WRIGHT (C. E.). Mr. Wright's report. In same publication as the preceding, pp. 18–23.

Contains a brief preliminary statement of results obtained in the Penokee region in 1876. The same results are given more fully by Mr. Wright in the third volume of the Geology of Wisconsin. We may merely quote the following generalization :

It has been my constant aim, and still is, to correlate the Penokee series of rocks with those of Michigan, and there exists in my own mind no reasonable doubt that the rock formations of these two districts are the equivalents of each other. In the Penokee we have the limestone and quartzite members; the belts of magnetic schist interlaminated with the greenstones; also the black slates and mica-schists, all occupying relatively the same stratigraphical position as in the Michigan series. (Pp. 22–23.)

Irving (R. D.). Note on the Age of the Crystalline Rocks of Wisconsin. Am. Jour. Sci., 3d series, vol. xiii, 1877, pp. 307–309.

The object of this note is to oppose Bradley's view, then recently expressed, and indicated also on his geological map of the United States, that the crystalline rocks of Wisconsin and Michigan may be altered Lower Silurian. It is a general outline statement of the succession of pre-Potsdam formations in northern Wisconsin, as the following quotation will indicate:

The crystalline rocks of Wisconsin include unquestionably two distinct terranes, the one lying unconformably upon the other, as is beautifully shown at Penokee gap, on Bad river, in the lake Superior country. Here a white siliceous marble of the Huronian, overlain by hundreds of feet of distinctly bedded slaty rocks, and dipping northward, is to be seen within 20 feet of large ledges of dark colored amphibolic gneiss, whose bedding planes dip southward and strike in a direction diagonally across that of the more northern beds. There are no doubt instances where the two series are difficult to separate, similar rocks occurring in both groups, but the existence of the two is incontestable, and their unconformability with the unaltered Potsdam equally so. The facts *proved* thus far with regard to the older rock series of Wisconsin may be briefly summarized as follows: The oldest (I) are gneisses and granites with other rocks; these are overlaid unconformably by (II) a series of quartzites, schists, diorites, etc., with some gneiss and granite; these in turn are overlaid—probably also unconformably, but this is not certainly proven—by (III) the Copper series, which includes greenstones and melaphyres, and also great thicknesses of interstratified sandstone, melaphyres, amygdaloids, and shales, the whole having a thickness of several miles; these finally are unconformably covered by (IV) a series of unaltered horizontal sandstones including numerous fossils, many of which are closely allied to those of the Potsdam sandstone of New York, and all of which have a marked Primordial aspect. I and II are referred to the Laurentian and Huronian systems of Canada, because they bear the same relations to one another and to the Copper series that these systems do. (P. 308.)

1878.

Irving (R. D.). Report to T. C. Chamberlin, State Geologist, of work done in the Penokee region in 1877, dated December 24, 1877. In Annual Report of the

Wisconsin Geological Survey for the year 1877, by T. C. Chamberlin, Chief Geologist, pp. 17–25. Madison, Wisconsin, 1878.

The principal work of the season of 1877 included (1) the extension of a detailed geological section begun in the vicinity of Penokee gap during the previous year, northward 5½ miles to the railroad track near the crossing of Silver Creek, Sec. 10, T. 45, R. 3 W.; (2) the making of a similar section along Bad river, somewhat farther east; and (3) a detailed mapping and magnetic survey of the Penokee range from Bad river to Potato river, T. 45 N., R. 2 E., Wisconsin.

The plan adopted for this work was to cross the iron belt, which, although quite sinuous in its course, preserves still a general east and west direction, curving more and more toward the north as it is followed eastward—from north to south at distances of about half a mile, using the section lines as much as possible. On each of the crossing lines stations were established at every hundred steps, and at every station the aneroid barometer, the variation of the magnetic needle, and the time were carefully observed, a simultaneous series of barometrical observations being carried on at Ashland. The lines were begun at points far enough to the south, on the Laurentian rocks, to be out of the influence of the iron or magnetic belt of the Huronian, and were extended northward far enough, not only to be out of the influence of this belt in that direction, but also to determine the presence or absence of any other similar belt or belts. Some of the lines, moreover, were extended farther than the rest, so as to pass on to the next series of rocks, allusion to which has been made above. Other subordinate lines of observation were frequently run across the sections in an east and west direction, and all the lines were controlled by constant reference to section corners and quarter posts. All outcrops were of course examined and located, and specimens were taken for subsequent study, particular attention being given to the magnetic belt traversing the center of the Penokee range. The largest outcrops are found where the several branches of Bad river break through the range from the southward. At each one of these gorges the work was carried into greater detail, in order that the true succession of the various layers might be made out.

Many interesting facts were developed during this detailed work, one or two of which may be mentioned here. The exact junction of the Huronian and Laurentian series was found at the gorge of Potato river, where a cliff-side over 100 feet in height and over half a mile in length is traversed near the middle by the highly inclined contact line between the "siliceous slate," one of the lower members of the Huronian, and a greenish chloritic gneiss of the Laurentian. The siliceous slate inclines at a high angle to the north, whilst the gneiss layers dip to the south and strike in a direction oblique to that of the slate layers. It is worthy of note that the two lowermost layers of the Huronian, as seen at Penokee gap and for many miles to the eastward, the "white quartz" and "siliceous dolomitic marble," are here entirely absent; but this fact is quite in accord with the relations everywhere to be observed between these two widely distinct rock series. Another fact of importance is the steady lessening of the disturbing influence exerted on the magnetic needle by the iron belt of the Huronian, as it is followed eastward. In its more western extension the variations observed on and near this belt are commonly as much as 90° to 180°, the disturbing influence extending, moreover, for a long distance to the north and south of the line of greatest disturbance. By the time the Potato river is reached the variations never approach 90°, and are to be observed along a very narrow belt only. Still farther east the attraction lessens yet more rapidly, and on the Montreal river you have yourself observed that it is essentially lost. This lessening in magnetic attraction does not necessarily indicate a corresponding decrease in the amount of iron present in the rocks of the iron belt, but rather that the magnetic oxide is giving way more completely to the nonmagnetic, or sesquioxide, which is always present, in greater or less quantity, even where the magnetic attractions are greatest. The outcrops observed bear out this conclusion; for a considerable quantity of very highly manganiferous red hematite is to be seen at points all along from the passage of Tyler's fork eastward.

Yet another point of interest brought out by this year's work is the apparent demonstration of the nonexistence of other magnetic belts in the more northern or upper portions of the Huronian series. Hematite, or specular ores, may exist here, but the gaps in the series of layers have now been so largely filled up that it appears probable that any discoveries of ore which may be made in the future will be on the already known magnetic belt. (Pp. 19–21.)

CHAMBERLIN (T. C.). Annual Report of the Wisconsin State Geological Survey for the year 1877. Madison, 1878.

Pages 25 to 28 of this report include a brief account of an examination made by Prof. T. C. Chamberlin of that part of the Penokee range which lies between the Potato and Montreal rivers. The following, as to the contact of the basal member of the Iron-bearing series with the schists south of it, is of especial interest:

At the falls of the Gogogashugun a most interesting section may be made out. The falls themselves are due to the barrier imposed by the siliceous schists that here form the lowest exposed member of the Huronian series. By going back from the falls a short distance, guided by the indications of the loose blocks of rock on the surface, the party were fortunate enough to uncover, at their first attempt, the exact junction between the Laurentian and Huronian series. The Laurentian member consists of a peculiar gneissoid rock, altogether like that which occupies a similar relation at Penokee gap. Its strike is N. 67° W., and its dip 49° NE. The Huronian rock lies in absolute contact with this, not even being separated by a fissure. Indeed, at one point the siliceous material that formed the Huronian rock had, at the time of its deposition, so insinuated itself into the irregularities of the surface of the gneiss that the two formations are interlocked, and *a hand specimen* was obtained, one portion of which is Laurentian gneiss and the other Huronian schist, the two being, of course, unconformable. It is doubtful whether a similar specimen has ever previously been secured.

The base of the Huronian series as here exposed is formed by gray and purple siliceous schists, interleaved with which are occasional purplish layers of a clay-like texture. Some of these approach a pipestone and raise the question—which, of course, they are not competent to answer—whether they are not the approximate equivalents of the pipestones of Barron county, which sustain a somewhat similar relation.

The general strike of these schists is N. 55° E., and their average dip about 60° NW. By comparison with the Laurentian strata it will be seen that the two formations strike across each other at a large angle and dip in opposite directions. (Pp. 26–27).

Hunt (T. S.). Special Report on the Trap Dikes and Azoic Rocks of Southeastern Pennsylvania. Part I, Historical Introduction, Second Geological Survey of Pennsylvania, volume E. Harrisburg, 1878.

Contains in a general historical review several brief references to certain of the accounts of the Penokee-Gogebic district previously published and above noted. Dr. Hunt had not himself been in the district.

1879.

Chamberlin (T. C.). Annual Report of the Wisconsin Geological Survey for the year 1878. Madison, 1879, pp. 5–7.

Contains a brief account of the work then still in progress under R. D. Irving in northern Wisconsin, and particularly a statement of the route followed by Mr. A. D. Conover in making certain additional explorations.

Irving (R. D.). Note on the Stratigraphy of the Huronian Series of Northern Wisconsin; and on the Equivalency of the Huronian of the Marquette and Penokee Districts. Am. Jour. Sci., 3d series, vol. XVII, 1879, pp. 393–398.

This article calls into question the scheme of stratigraphy for the Penokee district, above quoted from Brooks, and gives also a preliminary statement of certain results, further noted below, in connection with the final report of the Wisconsin Survey.

1880.

IRVING (R. D.). The Geological Structure of Northern Wisconsin. In the Geology of Wisconsin, vol. III, pt. I, pp. 1–25, with outline map and plate of sections. Madison, 1880.

As the title indicates, this portion of the final report of the Wisconsin Survey gives a general summary of the conclusions reached as to northern Wisconsin by the various members of the survey corps who had worked in this region, including the author. The following quotation shows the more general conclusions reached as to the two formations, gneissic and slaty, with which we are particularly concerned in the present volume:

In a former volume of this report, I have shown how the Silurian limestone and sandstone formations of the southern, eastern, and western portions of Wisconsin curve concentrically around three sides of the Laurentian nucleus of the northern part of the state. On the northern or lake Superior side, however, we find an altogether different structure; and it is evident at once that the Laurentian nucleus has constituted a barrier between the lake Superior and Mississippi valley regions since pre-Silurian times.

*Laurentian system.*—The rocks of the crystalline nucleus itself are referred to the Laurentian of Canada, because (1) they sustain precisely the same structural relations to the Huronian, Keweenawan, and Lower Silurian, as observed in the case of the typical Laurentian of Canada, and (2) because they have the same general lithological peculiarities that characterize the Canada series. There can, indeed, be no reasonable doubt that they are directly continuous with the Canada Laurentian. They extend to the shores of lake Superior in the vicinity of Marquette, Michigan, and appear again on the eastern or Canada shore of the lake. The separation between the Wisconsin Laurentian and that of Canada is therefore only a superficial one, the connection being concealed by the waters of the lake, and by the overlying Silurian depositions in the eastern extension of the upper peninsula of Michigan.

In Wisconsin, the northern limit of the Laurentian approaches most nearly to lake Superior on the Montreal river, which is here the state boundary—the distance to the lake shore in a direct line being only 13 miles. From the Montreal river the northern limit trends about southwest by west, and on Bad river, 25 miles farther west, it is 25 miles from the lake. From Bad river the course is in general but little south of west, to Numakagon lake, T. 44, R. 6 W. Here a rapid change to a more southerly direction comes in, and we find ourselves following the western side of the Laurentian nucleus, soon to be bounded by the regular Mississippi valley formations. The southern rim of the lake Superior trough, at an elevation of 1,000 to 1,100 feet above the lake, lies but a few miles south of the northern boundary of the Laurentian area, for about 50 miles westward from the Montreal, after which it passes on to the more northerly and newer formations.

The rocks of the Laurentian nucleus have already been partly described in former reports. Where they approach lake Superior they are almost wholly gneiss and granite. The prevailing rock along the northern border is a dark gray to black, often greenish-black, hornblende-gneiss, in which the hornblende has usually been more or less completely altered to chlorite. This alteration, when carried to any considerable extent, gives a greenish tinge and greasy feeling to the rock, and, in cases of extreme alteration, there is a passage to a green chloritic-schist. The associated granites are usually light pinkish-tinted to gray, and highly quartzose, a frequent gneissoid tendency showing their sedimentary nature. These rocks have a nearly due E.-W. strike, and, near the northern border, a high southerly dip. They are, however, beyond question greatly folded, and have as certainly an enormous thickness.

*Huronian system.*—Lying immediately against the Laurentian, and very sharply defined from it, we find, extending from the Montreal river westward for 50 miles to lake Numakagon, a belt of schistose rocks which we refer unhesitatingly to the Canada Huronian, and which are beyond question the direct westward extension of the iron-bearing series of the upper peninsula of Michigan. This belt has a width, in general, of from 1½ to 2½ miles, and includes an aggregate thickness of strata of nearly 13,000 feet, with a number of well marked subdivisions, several of which are persistent throughout the entire length of the belt. These subdivisions may be briefly summarized as follows, beginning below: (1) Crystalline tremolitic limestone, at times overlain by a band of white arenaceous quartzite, and at times absent, the next formation above them coming into contact with the Laurentian, 130 feet; (2) straw-colored to greenish quartz-schist, and argillitic mica-schist, often novaculite, 410 feet; (3) tremolitic magnetite-schists, magnetitic and specular quartzites, lean magnetic and specular ores—forming the "Penokee Iron range," 780 feet; (4) alternations of black mica-slates with diorite and schistose quartzites, and unfilled gaps, 3,495 feet; (5) medium-grained to aphanitic, dark gray mica-schists, with coarse intrusive granite, 7,985 feet—in all, 12,800 feet. These rocks all dip to the northward, the angle being usually high, but lessening toward the west, and trend with the course of the belt, which has numerous minor corrugations, while preserving one general direction. The strike directions are always oblique to the trends of the underlying Laurentian gneiss, proving the unconformability of the two systems, the actual contact of which may indeed be seen in several places.

Westward from lake Numakagon the Huronian belt is lost sight of, the Laurentian gneiss and Keweenawan gabbro and diabase coming apparently into direct contact with each other.

The reference of the schistose series of the Penokee region to the Huronian is justified by the following considerations: (1) There appears to be a direct continuation with the iron-bearing system of the Marquette region of Michigan; (2) as shown on a subsequent page, the grand subdivisions of the Bad river and Marquette systems both show the same relation to the Laurentian and Keweenawan systems as found in the Huronian of Canada; i. e., are newer than the former and older than the latter; (4) the Marquette system is found in unconformable contact with the Lower Silurian red sandstone of lake Superior. The Marquette Huronian, in its southerly extension in the Menominee region, is also found in unconformable contact with the fossiliferous primordial sandstone of the Mississippi valley, a fact which, even if the evidence were not amply sufficient without, would demonstrate the futility of the attempts made by some to refer the whole series of lake Superior crystalline rocks to the Silurian. (Pp. 5–7.)

The general succession of formations in northern Wisconsin, from above downward, is held to be as follows: (1) Lake Superior Sandstone; unconformably followed by (2) the Copper-Bearing or Keweenaw series; unconformably followed by (3) the Iron-Bearing or Huronian series; unconformably underlain in its turn by (4) the Gneissic or Laurentian. In support of the belief that there is an unconformity between the Keweenawan and Huronian series, Brooks's arguments, already noted above, are quoted and indorsed, after which the author proceeds as follows:

I conceive that further evidence of nonconformity is afforded in the Wisconsin region by the following facts: (1) In the Penokee country the uppermost beds of the Huronian are gradually cut out, as we trace them westward, by the gabbro that forms the base of the Keweenawan series, a fact which appears to me best explained by the supposition that the gabbro covers and conceals these missing beds. (2) There is not an absolute uniformity in dip between the Huronian and Keweenawan rocks in this region, the latter standing commonly at a higher angle. (3) West of lake Numakagon the diabases and other eruptive rocks of the Keweenaw series appear to completely cover the Huronian in a great overflow. Nevertheless, the approach to conformity in Wisconsin is close, and were we to draw our conclusions from this region only, the nonconformity could hardly be regarded as proved. There are no such undulations in the Huronian of the Penokee district as in Michigan, the subordinate members making long and regular bands conforming to the general trend of the formation, and also, in a general way, to the trend of the several belts of the Keweenaw series. Moreover, the lessening in dip toward the west, already noted as affecting the latter rocks, is observed also in the underlying Huronian so far as these can be traced westward. (P. 22).

IRVING (R. D.). Geology of the Eastern Lake Superior District. In Geology of Wisconsin, vol. III, Pt. 3, pp. 51–238, with 6 atlas plates, 18 volume plates (including 7 colored microscopical plates), and 4 figures.

This is a detailed account of the geology of that portion of northern Wisconsin which is drained by the waters of Bad and Montreal rivers and, of course, covers all that portion of the belt now to be studied, which lies west of the Montreal river. The chapter titles are as follows: Introduction, Topography, The Laurentian System, The Huronian System, The Keweenawan or Copper-Bearing System, The Lake Superior or Potsdam Sandstone, The Quaternary Deposits, Appendices A and B. The chapters on the Huronian and Laurentian are of chief interest in the present connection. From the former chapter we quote:

The Huronian rocks lie together in a narrow belt from half a mile to 3 miles in width, which stretches entirely across the district, from the west line of T. 44, R. 5 W., to the Michigan boundary at the Montreal river, in Secs. 24 and 13, T. 46, R. 2 E. The total length of the belt in this distance is about 46 miles. The wider portions are toward the east, the western part narrowing in places to as little as a mile or even half a mile in width, as in the sections just south of Bladder lake. The total area underlain by these rocks is just about 100 square miles. (P. 100).

Then, after giving in brief the course of the Huronian belt through the various townships and sections, the report proceeds:

The southern boundary of the Huronian, or its line of junction with the Laurentian, is a very sharply defined line, on account of the bold topography and frequent rock exposures of the Penokee range. Even in that portion of the Huronian belt where the Penokee range disappears, and the rocks are entirely concealed by drift and swamps, the magnetic attraction exerted by the iron-bearing member of the formation, one of its lower layers, serves to fix very closely the southern boundary. On the accompanying atlas plates this boundary line is laid down so accurately and the facts upon which it is based are there detailed so fully that no further explanation is needed here.

In addition to the facts given on the maps and in the details of the following pages, it is merely necessary to say here, with regard to the northern boundary, that it does not follow the strike of the Huronian beds, but cuts across them in a more or less irregular way. The width of the Huronian does not vary on account of the thickening or thinning or disappearance of any of its subordinate layers, but the wider portions include higher layers, which are wanting in the narrower portions. The irregularity, then, of the northern boundary is due to a nonconformity of the overlying rocks with the Huronian. It should also be said that these overlying rocks, chiefly gabbros, are of an igneous origin, and have certainly, in some places, and quite possibly, also, in others not yet recognized, penetrated the Huronian, producing peculiar irregularities in the line of junction.

The main topographical features of the Huronian belt have already been given in another connection. It is only necessary to notice here somewhat more definitely the relation existing between the geological structure of the series and the topography of the strip of country underlaid by it. The Huronian series includes a succession of beds, always markedly schistose and at times highly slaty, which are, for the most part, inclined at a high angle to the northward. At the base or southern side of the belt are narrow layers of crystalline limestone and quartzite, succeeded by a broad band of siliceous slate, some 400 feet in width, above which there is again a much broader band, generally as much as 800 feet wide, of magnetic and specular schists. Above these again is a series of alternating layers of mica slates, diorites, quartz slates, and quartzites—the latter comparatively inconspicuous—which reaches a thickness of several thousand feet. A close connection may be traced between the nature of these beds and the features of the surface.

The existence of the Penokee range, which marks the lower side of the Huronian belt for the greater part of its extent, and which has already been described in some detail, is determined by the broad bed of magnetitic quartzites and siliceous, magnetic, and specular schists above referred to. These, by virtue of the superior hardness and power of resisting chemical action conferred on them by their siliceous ingredient, have remained standing, while the softer beds to the north have been worn, for the most part, into deep valleys, in which streams run parallel to the trend of the Penokee range, being impelled to their courses by the strike of the underlying rocks. In places the more massive diorites and quartzites of the northern portion of the series rise from the valley in abrupt ledges, but they never constitute a continuous ridge like the Penokee range, on account of their smaller breadth and inferior resisting power. On the northern side of this valley the Huronian beds often extend well up the river on to the Copper range, being protected here by the massive rocks of the Keweenaw series, which bound them on the north. The south slope of the Penokee range, again, is made up of the siliceous schist which underlies the harder rocks that form the body of the range, and, being itself generally a quite soft and easily eroded material, the southern slope is often precipitous, or at least very bold. This is especially true of the middle portions of the range, from a few miles west of Bad river nearly to Tyler's fork. Further east this layer becomes more quartzitic and harder and forms itself the body of the ridge, the overlying beds at the same time losing their comparatively great resisting power by a change in composition. In some places in the eastern extension of the Huronian belt both the siliceous schist and the overlying beds are softer than the Laurentian below, and the crest of the ridge is made up of rocks of the latter series.

A variation in the degree of northerly dip of the beds of the Huronian has also very measurably affected the surface features. From a point on the ridge a few miles west of Bad river to the Montreal the angle of dip is always very high, 55° to 75°, while farther west it lessens to 45°, 35°, 25°, and even to 20° or 15°. In these places the result is a longer front slope to the ridge, and a very steep, frequently bold and precipitous southern face, made up usually of heavily bedded quartzitic iron ore overlying the siliceous schist, which now loses its prominence and forms only the foot of the southern face. The entire absence of the Penokee range in T. 44, R. 4 W. is perhaps to be attributed in part to a lessening in dip, though probably chiefly to a change in the character of the lower layers of the series. (Pp. 101–103).

The Huronian series consists of a succession of more or less highly schistose to slaty beds, which reach a total thickness in the widest part of nearly 13,000 feet. These layers all stand inclined at a high angle to the north, and stretch across the country in outcrops generally parallel to the southern limit of the formation, some of the more prominent ones preserving their characters across the whole width of the district, a distance of about 45 miles. Inclining, as they always do, to the north, these beds are without folds, and the series is only limited in that direction by the overlapping of masses of igneous rocks belonging to an unconformable system—the Copper-bearing or Keweenawan series—the unconformity being one, however, recognizable only on a comprehensive survey of the region, and not by any observed contact between the two formations. The absence of any folds in so highly altered and inclined strata is easily explained, if we regard them as forming part of a great bend underneath the trough of Lake Superior and reappearing on the north side of the lake with a reversed inclination. These points have been brought out on a previous page, and need only to be alluded to here.

The degree of northward inclination of the Huronian beds is, for most of the course of the formation, from 55° to 75°; most usually between 65° and 75°. To the west of Sec. 16, T. 44, R. 3 W., however, the degree of inclination is nearly always much less, becoming at times as low as 20°. The bends in the course of the formation have already been noted in a general way. Some of these are exceedingly abrupt, as, for instance, on Sec. 10, T. 44, R. 2 W.; at the crossing of the creek in sections 8 and 17, T. 44, R. 2 W., and at several places in the western extension of the formation. These bends are well marked out in the rock exposures and are noted in detail on the accompanying maps.

At the passage of Bad river, the strata are crossed by a fault, trending about N. 17° W., the layers on the west side of the fault being thrown 800 feet to the northward of those on the east side; or, regarding the throw as a vertical one, the western side has been elevated or the eastern depressed a vertical distance of over 1,700 feet; the apparent lateral throw, on this supposition, being explained by the inclined position of the strata. This fault is marked in the topography by a corresponding set-off in the Penokee range, which on the west side of the river is well to the northward of its position on the east side. It is also well marked by large rock exposures on either side, and also by an abrupt break in the line of magnetic attraction caused by the magnetic belt of the formation. The facts with regard to it are all detailed on Atlas Plate XXIII, and also in the descriptions of the following pages.

The following tabulation indicates the succession of layers of the Huronian series in the vicinity of Bad river, so far as made out, with the average thickness, surface breadth, and other prominent points of each layer. Several of the lower layers, including a total thickness of some 1,500 feet, have been traced across the entire width of the district. The higher layers, on account of their comparative softness and susceptibility to chemical changes, have been for the most part deeply eroded, and are, moreover, largely buried beneath accumulations of drift materials, so that the exposures are comparatively few and distant, and the task of making out the succession becomes much more difficult. (Pp. 103–104.) . . .

*Synopsis of the Stratigraphy of the Huronian of the Penokee region, Wisconsin.*

| Formation. | | Average thickness. Feet. |
|---|---|---|
| I. | Tremolitic crystalline limestone | 90 |
| II. | (A) Arenaceous white quartzite, often brecciated, 35 feet; (B) magnetitic quartz-schist, 5 feet | 40 |
| III. | *Siliceous slaty schists;* including quartzite, "argillitic" mica-schist, and novaculite; all having much quartz, and none ever showing any amorphous material | 410 |
| IV. | *Magnetic belt;* including: (*a*) banded magnetic quartzite—gray to red quartzite, free from or lean in iron oxides, banded with seams, from a fraction of an inch to several inches in width, of pure black granular magnetite, only rarely mingled with the specular oxide; (*b*) magnetitic quartzite, the magnetite in varying proportions, pretty well scattered throughout, and mingled with the specular oxide in proportions varying from nothing to a predominating quantity; (*c*) magnetitic quartz-slate, the magnetite pervading the whole, and mingled with the specular oxide as before; (*d*) slate like (*c*) but largely charged with tremolite or actinolite; (*e*) arenaceous to compact and flaky quartzite, free, or nearly so, from iron oxides; (*f*) thin-laminated, soft, black magnetitic slate; (*g*) hematitic quartzite, the iron oxide the red variety; (*h*) garnetiferous actinolite-schist, or eclogite; (*i*) diorite, which is restricted to the western end of the Huronian belt. Kinds, (*a*) to (*d*), all carry much pyrolusite, or other manganese oxide. These varities have no persistent stratigraphical arrangement, and are named here in order of relative abundance. Total thickness, about | 780 |
| V. | *Black feldspathic slate;* consisting of orthoclase grains imbedded in a paste of biotite, pyrite, limonite, and carbon | 180 |
| VI. | Unknown, always drift-covered | 880 |
| VII. | Dark gray to black, aphanitic mica-slate, having a wholly crystalline base of quartz and orthoclase, with disseminated biotite scales | 120 |
| VIII. | Unknown, but probably in large part the same as VII | 290 |
| IX. | Chloritic, pyritiferous, massive diorite | 150 |
| X. | Black, aphanitic mica-slate, like VII | 25 |

*Synopsis of the Stratigraphy of the Huronian of the Penokee region, Wisconsin*—Continued.

| Formation. | | Average thickness. Feet. |
|---|---|---|
| XI. | Covered, but probably mica-slate | 280 |
| XII. | *Black mica-slate;* aphanitic; at times chiastolitic | 225 |
| XIII. | Chloritic diorite-schist | 35 |
| XIV. | *Black mica-slate*, like XII, often chiastolitic | 375 |
| XV to XVIII. | Alternations of black mica-slates, with quartzites and quartz-schists | 675 |
| XIX. | *Greenstone-schist;* aphanitic; the hornblende and plagioclase much altered | 260 |
| XX. | Covered, but probably like XXI | 525 |
| XXI. | *Mica-schist;* from aphanitic to medium grained; including bands of light gray quartz-schist, the mica becoming subordinate; all varieties having a background of quartz; the mica wholly biotite; penetrated by veins and masses of very coarse, pink to brick red biotite granite; total on Bad river, 4,960 feet. Seen farther east, higher layers, 2,500 feet; in all | 7,460 |
| | Total | 12,800 |

(Pp. 104–105.)

The numerous local details of this volume are made frequent use of in the following pages and on the accompanying maps.

JULIEN (ALEXIS A.). Microscopic Examination of Eleven Rocks from Ashland County, Wisconsin. In the Geology of Wisconsin, vol. III, pt. 3, Appendix B, pp. 224–238. With one colored microscopical plate.

This paper includes detailed descriptions of the following rocks: (1) Chloritic gneiss, from the lower gneisses at Penokee gap; (2) crystalline limestone; (3) tremolitic magnetite-slate; (4) black feldspathic slate; (5) chloritic diorite; (6) magnetitic mica-slate; (7) chiastolitic mica-slate; (8) diorite greenstone-schist; (9) magnetitic mica-schist—all from the Bad river section through the Iron-bearing slates; and (10 and 11) two chrysolitic diabases from the overlying copper series.

WRIGHT (C. E.). The Huronian Series West of Penokee Gap. In the Geology of Wisconsin, vol. III, pt. 4, pp. 239–301. With one atlas plate and ten volume plates.

This report, the result of a special exploration with reference to the occurrence of iron ores in the slaty series west of Bad river, embraces three chapters, which are entitled, respectively, "Dipping Needle and Solar Dial Compass, and the Method of Employing Them," "Geological Cross Section of Penokee Iron Range," and "Special Examination of Penokee Iron Range West of the Gap." The first of these chapters calls for no consideration from us. The third chapter is occupied with local details, arranged in the form of a diary, with the results of a microscopical study of thin sections interspersed. These details have often been used in the compilation of our maps herewith, most of the important outcrops described by Mr. Wright having, however, been revisited for our work. Wright's route of travel also is laid down on our maps.

The second of Mr. Wright's chapters is of a more particular interest, because in it he gives his views as to the general stratigraphy of the Iron-bearing series, and as to its relations to the adjoining formations. The following quotations from this chapter will serve to show Mr. Wright's conclusions; the omitted portions are mainly microscopical details:

In this geological section it has been my endeavor to correlate the Penokee Iron-bearing series—Lower Huronian—as near as possible with those of Michigan, assumed to be of the same age, as they undoubtedly are.

We will adopt, for convenience of reference, the numbering first employed in the Geological Report of Michigan, 1873, to designate the Lower Huronian beds.

The first rocks we will consider, however, are those of the Laurentian series, found outcropping on the south side of the Penokee range. These rocks are granites, gneissoid granites, and gneisses. At the Gap, they have a strike a little to the south of west, and dip from 65° to 80° to the south. The granites are dark gray to reddish, depending on the predominance of the mica or feldspar. They are fine to very coarse grained, the medium grained varieties being, however, the most common. The essential mineral ingredients are usually easily recognized. The bedding planes, or "grain" of the granite, even in the massive varieties, may, generally, after careful examination, be made out. . . .

Orthoclase is the prevailing member of the feldspar family. . . .

The mica is chiefly biotite and of a dark color. . . .

The gneisses, like the granite, vary from dark gray to reddish. Usually they are distinctly laminated with the layers of quartz, feldspar, and folia of mica. It is sometimes slaty, but more generally it is heavily bedded, and passes almost imperceptibly into a gneissoid or a massive granite. The dark, fine grained, slaty varieties resemble hornblende-gneiss and hornblende-schist; in fact, I have been obliged to make microscopic sections before being able to decide which it was. . . .

Nonconformably overlying the Laurentian rocks are those of the Huronian series. We have at the Penokee Gap, where the Wisconsin Central railroad crosses the range, one of the best opportunities I have ever chanced upon for observing this interesting fact. This nonconformability on the Penokee, I believe, was first noticed by myself in 1875. The Huronian series at the Gap are plainly bedded, and have a strike of a little north of east, and dip very uniformly 66° to the north.

The lowest member which I have seen on the Penokee range is a marble, or dolomitic limestone, which we will consider as No. IV. There may be other members below the marble, as is the case in the Huronian rocks of Michigan, but I have never found them.

At the Penokee gap the marble is siliceous; in color light drab to grayish white, with shades of green; also light red and pink not uncommonly. This diversity of colors is often observable in a hand specimen. The marble is fine grained, and strongly bedded, or massive, depending on the degree of metamorphism. When massive, it is usually jointed, and weathers to a light drab. Some portions of the rock contain pale green to almost white, radiated bunches of actinolite, resembling, in the latter instances, clusters of arragonite. . .. .

*No. V.* Immediately overlying the marble at the Gap is a quartzite, varying in color from grayish white to white, and from saccharoidal to vitreous in texture. It is massive and highly jointed. . . .

*No. VI.* Next in order above the quartzite we have a chloro-siliceous schist. This member was notable for preserving its individuality wherever we found it outcropping, and was therefore easily and quickly recognized. It has a dark grayish green color, fine grain, and is jointed, and usually more or less slaty. Along the jointing planes it is often finely corrugated, and has an unctuous feeling. It cleaves readily into thin parallel and wedge-shaped plates. Examined with the lens, it is difficult to distinguish any of the chlorite. . . .

*Nos. VII, IX*, and probably *No. XI*, are represented in the near vicinity of the Gap by argillites or black slates, while west of the Gap, from 10 to 14 miles, as has been already noted, the slates are replaced by diorites and hornblende rocks. My impression is that these slates and greenstones do not vary greatly in their chemical composition, the texture and structure being due to different conditions or degrees of metamorphism.

The argillites are brownish to bluish black and have a micro-granular texture. Some of these are quite slaty and cleave freely; others are more compact. The slates are thicker and the fracture uneven to conchoidal. On the cleavage planes they have a bright, lively luster, but a fracture across the cleavage is of a dull brownish black. Disseminated through the slate is considerable carbon, which appears ragged under the microscope. Numerous slender blades resembling microlites of feldspar are visible. Small angular grains of silica are present; also brownish and slightly dichroitic leaves resembling biotite.

The diorites, above alluded to as constituting in part Nos. VII and IX of our scheme, are massive and strongly jointed, rarely ever showing any signs of bedding. They are fine to coarse grained in texture; the cleavage planes of the hornblende in coarse varieties being unmistakable; also grains of magnetite. The other mineral ingredients are not so readily distinguished. . . .

Returning now to *No. VIII* of our cross section we find it and *No. X* represented by actinolo-magnetic schists. These members are more or less magnetic, depending on the percentage of magnetite and other conditions. . . .

The magnetic schist is banded, with layers of lean ore impregnated by actinolite; also layers of arenaceous quartz and occasionally a thin one of magnetic ore. The bands vary in thickness from a mere line to one or more inches. Some portions of it are quite slaty and jointed. The texture on a fracture is usually fine grained. The color varies from gray to brownish black. . . .

*No. XII*, usually represented in the Marquette iron district by a banded jasper, which forms the "foot wall" of the iron ore, we did not find outcropping west of the Penokee gap, but since we were on the range I have been shown by exploring parties several samples of jasper and specular and magnetic ore (probably No. XIII) which they found east of the Gap. . . .

*No. XIV.* I have also seen specimens of gray quartzite from east of the Gap, which were very similar to that forming the hanging wall of the Marquette iron ore mines, and for this reason we will for the present refer it to No. XIV. The next number in the regular order, *No. XV*, a micaceous argillite or slate is found outcropping in Secs. 9, 10, and 11, T. 44, R. 3 W. The outcrops were small and formed at most only low, narrow ridges, which is no doubt due to the perishable nature of the rock. In many respects it resembles the argillites described under Nos. VII and IX.

The rock is dark brownish black, has a dull, slaty texture, is strongly jointed, cleaves into imperfect slates, the thicker ones having a conchoidal fracture. Examined on a fresh fracture the surface appears thickly sprinkled with very minute, shiny scales. . . .

*Nos. XVI to XIX.* Within these numbers are embraced a large group of micaceous quartz-schists, micaceous slates and schists, and chiastolite schist.

These, with No. XV, no doubt could consistently be comprised under one head, but in order to reach No. XIX, which corresponds very nearly with the chiastolite schist of the Michigan series, we will, for the present, retain the numbers without attempting to classify the different schists.

The most important member of these is the micaceous quartz-schist. It has an immense development immediately west of the Gap. It is of a dark iron-gray color, and has a very even, fine grained texture. It weathers to a light drab. Under the lens the dark colored mica is plainly visible. Some of the exposed surfaces are minutely pitted, owing apparently to the partial decomposition and washing out of the mica. In hand specimens the structure appears massive, but uncovering the ledge the fresh surface frequently shows a slightly banded structure. . . .

This comprises all of the rocks which I am satisfied belong to the Iron series. Overlying these, apparently nonconformably, are diorites, uralites, diabases, hypersthene, and granitoid rocks. The diabases are massive and fine to very coarse grained.

In some of them the crystals of labradorite are 2 inches across; in fact, this mineral in nearly all of them is the principal one. A weathered surface of the rock is frequently rough and knotty, with projecting grains of titanic iron ore. The augite is best recognized under the microscope. The diorites are also massive. The coarser varieties are easily distinguished from the diabases by the cleavage planes of the hornblende. (Pp. 248–255.)

With Mr. Wright's views, thus indicated, as to the unconformities between the slaty series and the gneissic and diabasic rocks which respectively underlie and overlie it, we are in entire accord. With his schemes of stratigraphy for the Iron series, and of the equivalency of its members with those marked out by Brooks for the Marquette Iron-bearing series, we are in many respects unable to agree, as will appear hereafter.

HUNT (T. S.). The History of Some Pre-Cambrian Rocks in America and Europe. Am. Jour. Sci., 3d series, vol. XIX, 1880, pp. 268–283. Read before the American Association for the Advancement of Science, Sept. 1, 1879.

This paper maintains the Neptunean origin of the Archean and crystalline schists, including also the "olivines and serpentines, and, in short, all silicated crystalline stratified rocks." It gives also an outline historical account of the pre-Cambrian formations. In the course of this account a brief reference is made to the views of Foster and Whitney maintaining the nondivisibility of the lake Superior Archean, and to the opposing views of Logan, Murray, Kimball, Credner, Brooks, Pumpelly, and Irving, the author himself maintaining a divisibility into two distinct terranes. No specific reference to the Penokee region is made, but since it affords most abundant proof of such a divisibility, Hunt's essay may appropriately be noticed here.

WADSWORTH (M. E.). Notes on the Geology of the Iron and Copper Districts of Lake Superior. Bull. Mus. Comp. Zool, vol. VII, 1880, No. 1, Cambridge.

So far as the Iron-bearing rocks are concerned, the main objects of this volume are to set forth certain observations and conclusions with regard to the rocks of the Marquette Iron region of Michigan. Since the Penokee rocks were already at that time, by common consent, regarded as the equivalents of those of the Marquette region, the conclusions are extended to the former rocks also. The following quotations will show what the principal ones of these conclusions are.

(1) As to the structural relations and origin of the iron ores and associated jaspers:

The observations and figures given in the preceding text show conclusively that the statements of Messrs. Dana, Kimball, Hunt, Brooks, and others, that the iron ore is interstratified in the associated schists, are incorrect, and only return to the view advocated by Mr. Foster in his early publication. So far as geological science has now advanced, the facts observed can only be explained by the eruptive origin of both the ore and jasper, as they make the same formation. The only escape from this conclusion is the supposition that the ore and jasper have been rendered plastic in situ, while the chloritic schist has not been. Such a supposition Mr. Brooks[1] was forced in part to adopt. That the ore and jasper have been thus rendered plastic, while the schists, quartzites, and other associated rocks have not been, is too absurd, chemically or geologically, to be tolerated for a moment as an hypothesis. . . . The ore and jasper show that they are the intrusive bodies by their breaking across the lamination of the schists and other rocks, by the changes that take place in the latter at the line of junction, by horses of schist being inclosed in the ore, by the curvature of the lamination produced by the intrusion of the ore and jasper, etc. Not the slightest sign of the plasticity or intrusion of the schists relative to the ore or jasper was seen. That the present lamination of the schist existed prior to the intrusion of the ore and jasper is shown by the effect of the latter upon and its relations to it. That this lamination is the original plane of deposition is for part of the schists not known; but whether it is or not, it has been taken to be such by the observers quoted in the establishment of their theories, and they must abide by it. The lamination, however, coincides with many of the well stratified rocks adjacent, and in some of these the ore and jasper were unmistakably intrusive. The schists that retained well marked stratification planes showed in some places extraordinary contortions, one specimen (293) showing a synclinal and anticlinal fold, requiring, were the top eroded, the counting of the same layer four times in the width of 2 inches. This is only one case out of numerous ones observed (292, 292+, 302). In the fine grained detritus composing some of the schists it is quite likely true that the lamination does not coincide with the original bedding; but if it does not, then the breaking of the ore across any chosen plane whatsoever, except the lamination plane, can be shown more easily than in the former case.

The ore and jasper seem to have been erupted in huge bosses and overflows, as well as intruded into the schist in the form of long arm and wedge-like masses or sheets. On account of the banded character of the jasper, and the intrusion generally being nearly in line of the lamination in the large mass, they have an apparently stratified character to those who believe any "striped" rock is a sedimentary one;

[1] Geol. of Mich., vol. I, 1873, pp. 139, 110.

but when examined in detail, and in places where the relations can be seen, they prove to be eruptive (pp. 66–68).

(2) As to an unconformity between the so-called Laurentian and Huronian, referring to my statement as to this relation in Geology of Wisconsin—

He states that a perfect case of nonconformability exists at "Penoka gap," Wisconsin, to which we have before referred; but, if we remember correctly Mr. Wright's personal statement to us, neither was the junction seen nor the kind of junction known that the two made with each other. It is too fast to assume, as has been done by Messrs. Brooks, Irving, and Wright, that the strike and dip of a foliated rock is the strike and dip of its stratification. This is especially the case when the view that they were ever stratified is still a disputed point (p. 25).

We have heretofore seen that the view that the "Huronian" unconformably overlies the "Laurentian" has been only supported by the fact that the foliation of the latter did not conform in its dip to the lamination of the former. This proof is of no value unless it can be shown that both rocks are stratified and in situ. That the latter is not so, we have seen in numerous localities. Heretofore the two systems have not been observed in contact, but recently statements have been published that their junctions have been seen in other regions.[1] The statement is made that both rocks are stratified, but no proof is adduced to show on what the conclusion is founded, and although the contacts were said to show beautifully, nothing was published indicating that the kind and manner of the junction was observed. It would seem that even here the decision concerning the unconformability was based on the foliation only (p. 70).

Irving (R. D.). The Mineral Resources of Wisconsin, Trans. Am. Inst. Min. Eng., vol. VIII, 1880, pp. 487–508, accompanied by a geological map of Wisconsin, and adjoining portions of Michigan, Minnesota, Iowa, and Illinois.

As the title indicates, the object of this paper is to give an account of the mineral resources of Wisconsin, as developed to date. Prefacing this, however, is given an outline account of the geological structure of the state. In this are included a number of references to the Penokee district, but nothing is given of interest in the present connection that is not included in vol. III of the Geology of Wisconsin, already referred to at length.

Wright (C. E.). Annual Report of the Commissioner of Mineral Statistics of the State of Michigan for 1880. Lansing, 1881.

[1] Geol. of Wis., vol. III, 1880, pp. 98, 108, 117.

This report, as also later ones by the same author (for 1881 and 1882), and by his successor, A. P. Swineford (for 1883 and 1884), contain brief references to the results of private explorations for iron in the Gogebic region. They contain no geological information of significance. Actual mining developments first began in the Gogebic country in the fall of 1884, and the first shipments of ore of importance were made in the summer of 1885.

1883.

CHAMBERLIN (T. C.). Geology of Wisconsin, vol. I, 1883, pt. I, General Geology, with general geological map of Wisconsin.

In chapters IV, V, and VI of this volume Prof. Chamberlin gives a general account of the older rocks of Wisconsin, which, in accordance with previous publications of the Survey, are regarded as divided into three distinct formations—Laurentian, Huronian, and Keweenawan. While in a considerable measure this account is a summary of conclusions already announced in previously published volumes of the Geology of Wisconsin,[1] it still embodies some later conclusions, as also the most comprehensive statement of Prof. Chamberlin's own views on these formations yet published. The following extracts will serve to show what these views are:

(1) As to the Laurentian:

*Synoptical notes on Laurentian formation.*—Name derived from Laurentide hills of Canada. Rocks of metamorphic class, mainly gneisses. Thickness undetermined, but great. Strata much folded and contorted. Occupies a large area in northern Wisconsin. . . .

*General character of the rocks.*—We have already referred to this as the granitic foundation upon which the rock structure of our state is builded. The rocks as we now find them consist of a series of granites, . . . gneisses, . . . syenites, . . . hornblendic, micaceous, and chloritic schists and allied rocks. With these are associated igneous diabases . . . and similar rocks, together with diorites . . . of undetermined origin. Among these rocks the gneissoid granites vastly predominate, so that the whole series in a general view is conveniently termed granitic.

*Sedimentary origin.*—But throughout the series evidences of sedimentary accumulation abound: (1) in the foliations and stratification, (2) in the alternating

[1] Vols. II, III, and IV of this series antedate vol. I in time of publication.

bands of varying chemical constitution, (3) in the verging of one kind of rock into another laterally, and (4) in kinds of rock not known to be produced by igneous agencies. The whole series has been distorted, folded, and crumpled in a most intricate manner, and the rocks, as the above names imply, are in a highly crystalline condition. It is manifest that the series was not so formed originally (pp. 64–66).

*Thickness.*—The thickness to which these sediments accumulated was something enormous. In their present crystalline state the current estimate of 30,000 feet is probably not too great for the exposed portion, though the original Canadian measurement on which it is based included beds now referred to the Huronian series. How much may lie below is not known, since the base is not exposed. So great an accumulation could only have taken place on a subsiding bottom (p. 69).

*Distortion of the beds.*—The long period of Laurentian subsidence and sedimentation at length drew to a close and the accumulated material underwent a most extraordinary transformation. The sands and clays lay originally in essentially horizontal beds, but at present we neither find horizontal beds nor sands nor clays. The strata are crumpled and folded in the most intricate manner. Not only have the great series of beds been arched and compactly folded upon themselves, but even the thin laminations have been contorted and crumpled in the most remarkable manner. The axes of the folds in the region of northern Wisconsin run mainly northeast and southwest, varying several points in either direction. On the southwestern margin, however, there is a tendency to a more westerly and northwesterly trend, somewhat parallel to that margin of the area (pp. 72–73).

*Attending metamorphism.*—The crystallization of the material is strikingly in harmony with this hypothesis of its heated condition. The sediments, while still in their horizontal position, doubtless became solidified into somewhat firm rock (1) by their own weight, (2) by their tendency to cohere, and (3) by the agency of cementing infiltrations. But there is no reason to suppose that this induced any notable degree of chemical or crystalline change. But in their present metamorphosed condition, instead of compacted sand and clay, we find thoroughly crystallized rock, in the form of granites, gneisses, syenites, hornblendic, chloritic, and micaceous schists. These show that a profound chemical change has taken place, wherein the matter assumed new combinations. At the same time, compounds of like kinds collected together, under the control of crystalline forces, and assumed the form of definitely crystallized minerals. Sediments that may originally have been a sandy clay, composed of silica, alumina, and potash, mainly, formed granites, gneisses, or mica-schists. The potash, alumina and quartz united in part to form orthoclase feldspar, or, in different proportions, together with magnesia, to form a mica, while the excess of silica took the form of crystalline quartz. The minor incidental constituents of the sediments entered into these minerals as replacement elements, or as impurities, or formed distinct accessory minerals. When, as in some cases was true, there was a larger proportion of the basic material, as lime, iron, etc., hornblende and allied minerals were formed, giving rise to syenitic rocks. Where these basic elements existed in still larger proportions, and the silica was relatively less abundant, hornblendic and allied rocks were formed, and in similar ways other variations in the constitution of the sediments gave rise to other variations in the crystalline results.

The changes were not carried so far, in most cases, as to destroy all traces of the original bedding of the sediment, or to mix the material of adjacent layers in any notable measure. There are certain massive portions, however, in which nearly all distinct traces of original sedimentation are obliterated.

To conceive in detail of the exact method by which these remarkable transformations took place, lays a heavy tax upon the scientific imagination, and certainly transcends the limits of demonstrable science. In general terms, however, the metamorphism may quite safely be said to be due to combined chemical and molecular forces, acting under the conditions of (1) pressure, (2) heat, and (3) moisture. Beyond reasonable doubt the strata in question presented these conditions, while undergoing the distortions already described (pp. 74–75).

*Igneous phenomena of the Laurentian.*—The Laurentian rocks are frequently traversed by dikes, veins, or irregular masses of intruded rock. These are most commonly composed of granite, but are sometimes of the darker basic classes. It has not been determined how far the phenomena may be due to true igneous penetration from below, and how far to the rendering of the rock of certain portions of the series sufficiently plastic by heat and moisture to be forced into cracks and fissures of adjacent portions. In either case the essential nature of the action was the same, the difference being in degree of liquefaction and the source of material (pp. 77–78).

(2) As to a separation between Laurentian and Huronian:

We have said that Laurentian sedimentation drew to a close, but it was only because the elevatory forces just described forced the beds up from the ocean, and prevented further accumulation upon them. But sedimentation elsewhere did not cease. The wash of the land, the wear of the waves, and the settling of silts beneath the sea continued ceaselessly. Even while the great elevation was in progress, the land was being worn and beds were accumulating in the adjacent sea, and as soon as it reached its loftiest height it began at once to be cut down and carried back to the sea by the agency of the great leveler, water.

Of the sediments formed during the elevation and immediately after—for a time whose limits are yet unknown—we know nothing. They are deeply buried from sight in our region, and if their equivalents elsewhere have been seen they have not yet been determined to be such. So far, therefore, as the details of the history are concerned, it is an unrevealed chapter. The record is not destroyed, as are certain pages of human history, but it has not yet been reached and read (p. 78).

(3) As to the Huronian :

*Synoptical notes on Huronian formation.*—Name derived from lake Huron, on the north side of which the formation is well developed. Known in Wisconsin and Michigan as the Iron-bearing formation. Probably embraces also the great iron deposits of Missouri, New York, and Canada. Consists of a variety of metamorphosed sediments, embracing quartzites, limestones, clay slates, micaceous, hornblendic, carbonaceous, and magnetic schists, and diorites and porphyries of doubtful origin. Thickness 13,000 feet, more or less. Strata arched and sometimes folded, but not usually closely crumpled and compacted like the Laurentian. Constitutes the Penokee, Menominee, and Black river iron ranges, the quartzite and porphyry outliers of central Wisconsin, and the quartzites of Barron and Chippewa, and probably of Marathon and Oconto counties. Existence of life probable. . . .

*Huronian geography.*—At length the unrevealed interval gave place to a known era. In the progress of erosion and subsidence the sea advanced upon the Laurentian lands, and separated from them a large island within our northern boundaries, and two or three smaller ones, as it would seem, in the adjacent territory of Michigan. . . .

*Local characteristics—Penokee region.*—Along the Penokee range the Huronian beds are found abutting against a wall of Laurentian rock, which formed the ancient shore line, and definitely marked the southern limit of the primitive *Superior sea.*[1] Here we find a series of Huronian beds nearly 13,000 feet in thickness. These are now upturned and metamorphosed, but the history of their formation remains for the most part legible.

*The Penokee series—1. Limestone.*—The lowest member exposed to view is a crystalline magnesian limestone 130 feet in thickness; the earliest limestone known in our series. Its bedding and its association with aqueous sediment show that it was deposited beneath water as a calcareous sediment. The source of its material deserves special consideration. The student will perceive, on a moment's reflection, that neither the simple decay nor the wear of the adjacent Laurentian rocks would give a material made up almost wholly of lime and magnesia, for the Laurentian rocks contain these ingredients only in very subordinate quantity, and, furthermore, these are among the ingredients *removed*—not left—by decay. The ordinary sediments resulting from decay and wear are clays and sands, not limestone.

In later ages there is the clearest evidence that the great limestone formations were made from the calcareous remains of marine life in ways that will appear more clearly as we proceed. It is probable that the ancient bed of limestone under consideration was formed in a similar way, although no distinct traces of fossils have

[1] This was not then a vertical wall as it now appears, because it has since been disturbed in common with the Huronian strata. But if the latter be depressed to their original position, the Laurentian slope where observed would be about 30°, which may be taken as the declivity of the Laurentian shore.

yet been discovered in it. It is highly magnesian, and is a dolomite rather than a limestone proper. It is also impure, from the presence of siliceous and aluminous material.

*Detrital beds.*—Overlying this formation at some points is a bed of white granular quartzite, which indicates that the deposition of calcareous sediment was followed by an accumulation of quartz sand.

Upon this lie beds of quartz-schist and argillaceous mica-schist, having together a thickness of about 400 feet. These were probably originally a deposit of sand and sandy, calcareous, and magnesian clay, derived mainly by ordinary wear and decomposition from the adjacent land.

Above these is a thick series of beds of iron-bearing and siliceous schists and quartzites, which now form the crest of Penokee Iron range. These have together a known thickness of about 800 feet. They appear to have consisted originally of beds of fine impure sand, with lenticular layers of iron ore thickly sandwiched through the mass.

*Origin of the iron ore.*—The origin of the siliceous material can be confidently referred to the atmospheric decomposition and the wearing and assorting work of streams and waves acting upon the granitic and other siliceous rock of the adjacent Laurentian land. To account for the iron ore is less easy. It occurs (1) in thin layers, or (2) more frequently in lenticular masses a few inches in thickness inserted irregularly among the laminations of the schist, and (3) in scattered particles disseminated through the rock. In its present form it is largely magnetic ore, though the specular variety is present. In some places both these forms have been reduced to hematite and limonite by subsequent changes.

The manner in which the iron is associated with quartzose material bears a somewhat close resemblance to the way in which magnetic-iron sands are distributed through the quartz sand of certain beaches, as may be seen at many points on the shore of lake Michigan[1] at the present time, and as is reported to be the case on the coast of Labrador, where the ocean is now acting upon the same formation that the ancient Huronian sea did in its day in the Penokee region. This similarity suggests a like derivation—an explanation applicable to many of the features of the deposit—but it does not very satisfactorily account for other characteristics. It certainly seems inapplicable to some of the great iron deposits that occur in the Huronian series.

The most probable explanation of the massive iron-ore beds in general refers their origin to organic agencies. Meteoric waters charged with decomposable organic matter, percolating through the soil and surface rock, change its iron ingredient from the insoluble to the soluble form and bear it onward, and at length out into some adjacent body of water, into which the drainage is discharged. Here it is

[1] Vol. II, p. 239.

reoxidized by free contact with the atmosphere and precipitated in the insoluble form, and thus accumulates in beds. Bog ore is now being deposited in this manner, and the ores of the Clinton and Coal periods are generally attributed to similar action. Little hesitancy would be felt in referring the Huronian deposits to the same agency if there were any independent evidence of the prevalence of land vegetation. There is, as we shall see, independent evidence of life, but it has not usually been thought to have been terrestrial. Lowland or marsh vegetation would probably furnish the requisite conditions, and there is no reason for doubting its existence, except the want of direct evidence of it in this and the succeeding formations. Notwithstanding this doubt, no equally satisfactory explanation of the origin of the massive iron ores has been proposed.

*Slates, schists, and diorites.*—Upon the magnetic schists there repose a series of black, mica-bearing slates, alternating with diorites (*plagi-horn*) and schistose quartzites, including several horizons which are concealed by superficial material and whose character is therefore unknown. Among these there appear to be included those horizons which in the Marquette region bear the rich iron ores. They are here doubtless concealed because of their softness, owing to which they have been more deeply eroded by denuding agencies. Whether these horizons are iron-bearing here remains to be determined by actual removal of the drift. The mica-slates were originally clay beds, probably containing some carbonaceous matter. The schistose quartzites were siliceous sandstones or quartzose clays. What the diorites were originally is yet an open question, it being maintained on the one hand that they are metamorphosed basic clays, and on the other that they are ancient lava flows, modified by long-continued chemical action. This series reaches a total thickness of about 3,500 feet.

*Mica-schists.*—Above this is found a still thicker series of mica-schists, which were probably once mixed clayey sediments. This series now measures nearly 8,000 feet in thickness, making the entire group of the region embrace, as above stated, about 13,000 feet of strata.

It will be observed, in glancing over the whole, that the great mass of the series was formed from the ordinary sediments arising from rock disintegration, and that they were unquestionably derived from the adjacent Laurentian land. The exceptions to this statement are found (1) in the limestone, probably derived from the remains of marine life; (2) in the iron ores, a portion at least of which probably arose through organic action; and (3) possibly the diorites, which may have had an igneous origin. (Pp. 80–84.)

Succeeding the period of Huronian sedimentation, whether immediately or somewhat delayed, there was an era of upheaval and metamorphism, analogous to that which occurred at the close of the Laurentian era. It produced analogous, but less extreme, effects.

*Metamorphism.*—None of the original deposits now remain precisely in their primitive condition, though only a portion of them have been so transformed that the original state is not clearly discernible. The limestone was somewhat compacted and rendered more crystalline, and scattered crystals of tremolite were formed by the union of lime and magnesia with silica—in other words, were generated from a somewhat silicious portion of the limestone. The great sand deposits were transformed into quartzite, but, for the most part, the original grains and pebbles still remain unobliterated, while in some instances fine laminations and beautiful ripple and rill marks are excellently preserved, bearing the most unequivocal testimony to their aqueous origin. The iron ores associated with the quartzites and silicious schists are now found largely in the form of magnetite or derivations from it. If they did not originally exist in that state (and they probably did not), they were doubtless transformed into it at this time of general metamorphism. Probably some of the more massive iron deposits in association with clay and carbonaceous schists, as those of the Commonwealth and Florence mines, were only compacted and dehydrated. Certain substances that accumulated incidentally with the sand of the series now constitute accessory minerals scattered through the quartzite, as pyrolusite, novaculite, mica, and others. The various finer silts, clays, and mixed sediments were changed to slates and schists. In short, the whole series was hardened, compacted, and in some measure chemically transformed and crystallized. The changes in these respects, however, were rarely equal to those of the preceding Laurentian revolution.

*Disturbance of beds.*—In respect to attitude, great changes took place. Beds which lamination, ripple marks, and other characteristics show to have been essentially horizontal when formed are now found arched and tilted at high angles. In the Penokee region the strata stand at angles varying from 20° to upwards of 80°. In the Menominee region they were warped and folded in a still more striking manner, and stand at various angles, according to situation. In central Wisconsin, instead of close folds, immense arches were formed. The Baraboo quartzite ranges are but the insignificant remnant of the north side of an arch of gigantic dimensions, which swept upward to an altitude approaching, if not surpassing, the highest existing elevations.[1] Similar broad arches were formed on the western side of the Laurentian island. (Pp. 89–90.)

(3.) As to an interval between Huronian and Keweenawan:

Between the Huronian and Keweenawan periods an interval of moderate extent appears to be indicated by the fact that the beds of the latter repose unconformably upon those of the former. The amount of this unconformity is, in Wisconsin, but

[1] For Fig., see vol. II, p. 506.

slight, though it appears to be more considerable elsewhere.[1] This interval was probably entirely occupied by the disturbance and metamorphism of the Huronian strata above described. Indeed, there is reason to think that this was only partially accomplished when the Keweenawan eruptions began. Sedimentary deposits must, however, have been in progress while the slow upheaval was taking place. If we could reach these deposits we should doubtless find them in no very essential respect different from those which preceded and followed. Prof. Selwyn, director of the Canadian Geological Survey, as the result of his studies upon the equivalent formation at the east, does not recognize any interval between the two series, and it may be that what is but a moderate break in Wisconsin is bridged by what seems to be an essentially continuous series in the eastern region. (Pp. 94–95.)

Irving (R. D.). Lithology of Wisconsin, Geology of Wisconsin, vol. I, pt. 2, chapter III, pp. 340–361.

A general account of the various rock species of Wisconsin known to date (May, 1882). So far as the Penokee district is concerned the newer material here included is the same as that given in the volume next referred to.

Irving (R. D.). The Copper-Bearing Rocks of Lake Superior, Monograph U. S. Geol. Survey, vol. V, 1883, 29 plates and maps.

This volume is of course chiefly devoted to the Keweenawan or Copper-Bearing Series, but incident to a discussion of the relation of these rocks to the older formation is given a brief summary of the results obtained in the Penokee district by the Wisconsin Survey (pp. 391–392). There is also given a map (Pl. XXII, Monograph V) of the region extending from lake Gogebic, in Michigan, to Numakagon lake in Wisconsin, and northward to the shores of lake Superior, on which the entire length of the Penokee-Gogebic belt is shown, the Michigan end of the belt having been platted from the notes on the U. S. Land Office plats and from statements in the papers of Pumpelly and Brooks, above referred to. The belt is also shown in its entire extent on the general maps (Plates I and XXVIII, Monograph V) which cover the entire lake Superior region. Other points discussed having bearing on our present subject are the relations of the Penokee series to the Animikie series of the north shore of lake Superior (pp. 386, 392), the general relations of

[1] Fuller data than are given in the Wisconsin reports, relating to the unconformity of the Huronian and Keweenawan series, may be found in the forthcoming Monograph of Prof. Irving, on the Keweenawan or Copper-Bearing Series, issued under the auspices of the U. S. Geol. Survey. See also the earlier paper of Major Brooks, Am. Jour. Sci., 3d series, vol. XI, 1875.

Keweenawan and Huronian (pp. 402–409), and the nature (pp. 37–58), origin (p. 144), distribution (pp. 231–233), and relations to the Penokee series (p. 156) of the coarse grained gabbros which are so largely developed in the Bad river country of Wisconsin.

1884.

ROMINGER (Dr. C.). Geological Report on the Upper Peninsula of Michigan, exhibiting the Progress of the Work from 1881 to 1884. Manuscript copy of Part I of vol. V (unpublished) of the reports of the Geological Survey of Michigan.

Through the kindness of Dr. Rominger, I have been furnished with a transcript of that portion of this volume which refers to the pre-Keweenawan rocks. In it are included the results of certain studies made by the author in the Gogebic district, between lake Gogebic and the Montreal river. No maps or other illustrations accompany the volume. The headings under which the subject-matter of the report is classified are the names of certain of the several rock groups, into which the author had previously divided the pre-Keweenawan rocks of the Upper peninsula (vol. IV, Geol. Survey, Mich.), viz: the Granitic, Dioritic, Iron Ore, Arenaceous Slate, and Mica-Schist groups. Under each of these headings is given the additional information obtained since the publication of the previous volume (IV) of reports, for the entire extent of the Upper Peninsula of Michigan.

The following are full extracts from those portions of the report which apply to the Gogebic district:

*Granitic group.*— . . . The granites bordering the south side of the Gogebic iron range and of its continuation into Wisconsin, the Penokee range, came under my observation during the progress of the survey. I found them in every respect analogous to the granites of the Marquette country.

The rocks of that part are not so excessively corrugated; the upheaval lifted the strata more in continuous sheets, and belts of granite intrusive into the incumbent strata could not often be observed, although several granite seams cutting across dioritic schists were seen about 4 or 5 miles west from the shore of lake Gogebic.

Following the range the granite is not always found in contact with the same kind of strata. Locally heavy quartzite strata are in contiguity with it, the lower layers of the quartzite being often represented by a conglomerate filled with rounded granite pebbles or by brecciated quartzose beds crowded with orthoclase crystals and cemented by a wax-colored hydromicaceous interstitial mass, which rocks resemble granite so much that it is difficult to distinguish the contiguous beds. These rocks correspond accurately with the rocks I have described in the previous report as occurring on the contact line between the granite and quartzite formation in the north part of T. 47, R. 25, which I then supposed to be quartzite altered by its contact with the granite into a granite-like rock. Now I am more inclined to consider the rock as a recemented mixture of granite fragments mingled with the arenaceous material which formed the overlying quartzite beds. Still it is very singular that the orthoclase crystals copiously imbedded in the mass have all sharp outlines and look as fresh, as if they had been formed where they are and were not débris of a disintegrated granite.

At the above mentioned locality, in the NW. ¼ of NE. ¼ of Sec. 24, T. 47, R. 43, this singular rock in contact with the granite contains locally an abundance of brown spar, which on exposed faces of the rock weathers out, leaving behind ochraceous matter, which fills the spaces formerly occupied by the spar. . . .

Only a short distance from the above described locality, in the adjoining Section 23, the granite is seen in contiguity with dioritic schists of a brecciated character, which inclose large angular blocks of massive diorite of various qualities. The granite comes there also in contact with massive diorite belts and intersects them in dike form.

. . . In Sec. 13, T. 47, R. 46, the granite is found in close proximity to cherty banded ferruginous beds, inclosing seams of good iron ore. Below these iron-bearing beds are light colored kaolinitic strata, which are in direct contact with the granite.

Farther west, in Section 15 of the same town, the granite comes very close to the ore-bearing quartzite formation, in which extensive exploring pits are opened, but I had no opportunity to observe in this place which sort of rock came in contiguity with the granite. The explorers informed me that diorite formed the foot-wall of the quartzites in which the ore deposits are found, and that the diorite joined the granite on the south side. Onward to the west the explorers made to me the same statements, always speaking of dioritic rocks intervening between the granite outcrops and their exploring pits.

Near the Montreal river, in the NW. ¼ of Sec. 27, T. 47, R. 47, I found granite in immediate contiguity with the ore-bearing quartzite and banded jaspery beds.

In Wisconsin, above the island in the Gogogashugun river, a belt of schistose dioritic rocks intervene between the granite and the large succession of light colored slaty rocks which form the island. Above these slaty rocks are quartzite strata partly brecciated and interwoven with seams of limonitic iron ore. From here to Penokee gap I did not make any observations regarding the contact line of the granite with other rocks, but at the Gap, in the bed of the river under a railroad bridge, the direct superposition of crystalline limestone inclosing tremolite fibers on the granite could be seen. Above the limestone succeeded some beds of quartzite, and then a large series of light colored silicio-argillaceous schists, which most likely are identical with those composing the island in the Gogogashugun river. . . .

*Dioritic group.*— . . . The extension of the survey into the Gogebic district showed to me a perfect analogy in the structure of the Huronian series with the Marquette or the Menominee region. North of the granite range previously mentioned, in many, but not in all, localities a large body of schistose and massive dioritic rocks overlies it, dipping to the north, and forms the base on which the iron-bearing rocks repose. More rarely the dioritic rock belt is found missing and the iron rocks follow immediately above the granite. The dioritic rock group there amounts to a considerable thickness. Most of the diorites are fine grained, and some of them very light colored, almost totally composed of granular plagioclase. Rocks of this kind are largely exposed along the north line of Sec. 23, T. 47, R. 44, associated with singular compact rock belts of coarsely brecciated structure, composed of large and small angular blocks of various kinds of diorite cemented by a sémé interstitial mass very similar in composition to the inclosed dioritic fragments. In this cement numerous milky plagioclase crystals of large size, or also rounded concretionary needles of feldspar, have segregated. Calcspar likewise sometimes enters freely into the composition. The cementing groundmass exhibits a distinct fluidal structure, as if the rock fragments had been stirred into it while it had the plasticity of dough. The fresh-fractured rock resembles a compact porphyritic diorite, as the color of the rock fragments and the cement does not differ much, but on the weathered faces of the rock the brecciated composition and the fluidal structure of the cement become very obvious.

Large bluffs of the same kind of breccia are also exposed on the side of the trail near Mr. Gillis's camp in T. 47, R. 43, along the north line of Section 23; it forms there the foot-wall of the galena-bearing quartzite formation, whose lowest beds are a coarse conglomerate of quartz pebbles of various color. South of these outcrops a large succession of massive and schistose dioritic beds follows, then granite follows in close contact with them.

*Iron Ore group.*— . . . The eastern portion of the range, extending from lake Gogebic to the Montreal river across the center part of the ranges 44, 45, 46, and 47, of the Town tier 47, did not prove to be much charged with iron ore this side of Sunday lake, but west of it so far as Montreal river it was found to be richer, and in a number of localities iron ore of a very good quality and in paying quantities is so far demonstrated to be present; but no actual mine has yet been opened, as these remote places must first be brought into communication with the outside world by the construction of a railroad, which is surveyed but only partly built at this time. . . .

The ore-bearing strata displayed in the Menominee region, on the north side of the Quinnesec ore range, are in all probability a perfect counterpart of those of the Gogebic region. Here, as well as there, a large belt of limestone forms the base of the series; the ore in both localities is to a great extent limonitic ore; in both places are graphitic schists associated with the ore deposits; and in the Penokee region the immediate succession of the mica-schist formation above the ore formation is a further indication of the younger age of this group. . . .

Starting from the landing on the west shore of Gogebic lake, situated in the center of Sec. 17, T. 47, R. 42, on an old Indian trail, we meet for the first two miles no rock exposures; thence repeatedly in the hillsides to the left of the path bluffs of rock are seen to project, which on examination are either granite or the brecciated diorite rock mentioned in the previous chapter; farther on quartzite beds are seen to underlie the surface, on the right hand side of the trail, as we approach the mining camp of Mr. Gillis, situated in the SW. ¼ of Sec. 14, T. 47, R. 43, where, by natural and artificial denudation, we are enabled to see a cross section of about 800 or 900 feet of strata, which dip at a high angle to the north. The aforesaid brecciated dioritic schists are seen in the hillside south of the camp as the lowest rocks; on them succeeds a belt of dark conglomerate, composed of quartz pebbles of various color, and of granite pebbles cemented by an arenaceous groundmass, in which is a considerable amount of feldspar grains besides the quartz sand. Then follow thick-bedded gray quartzite layers; on them rest a flesh-red colored compact granular quartz belt, which by exposure weathers and becomes porous and absorbent, like an ordinary sandstone.

Higher still, are brecciated quartzite layers, composed partly of chalcedonic quartz masses, and intersected by irregular fissure seams filled with galena.

On this brecciated quartzite belt follow thinly laminated quartz layers of very uneven surface, with interposed narrow wedge-like seams of black shaly material, which causes rapid disintegration of this belt into shelly fragments. Within this series occur streaky, interrupted concretionary seams parallel with the stratification, which are filled with galena.

Higher beds, likewise mainly of quartzose nature, are even-bedded, delicately striped or lineated in the direction of the bedding by the alternating intermixture of linear graphitic seams, with the granular quartzose feldspathic groundmass, which besides holds a good proportion of the carbonates of lime and of iron. Weathered surfaces of the white and black striped rock are therefore rusty brown. In some of these layers the shaly graphitic material predominates over the quartzose, which causes them to be softer and more pliable; the upheaving pressure therefore folded them throughout their substance into innumerable small wrinkles, as we often observe this same phenomenon of corrugation in still softer sericitic or micaceous schists in other geological horizons. North of these beds follow uniformly black fine grained slate-rock layers, which are from time to time interlaminated with seams of harder siliceous ledges, likewise black colored by carbon. The aggregate thickness of this uppermost graphitic slate-rock belt amounts to about 500 or 600 feet. It comes, on the north side, in direct contact with the diabases of the copper-bearing rock group, which appears to be conformably superimposed on it. . . .

The galena-bearing quartz formation and the graphitic slate series above it are traceable by extensive exposures in the hillsides along the trail until they cross the

Presque Isle river, in SE. ¼ of Sec. 17, the bed of which stream is carved there diagonally across the stratification into the black graphitic slates, which form here also a very thick succession of beds.

A mile farther west, in the SE. ¼ of Sec. 18, T. 47, R. 43, I met for the first time with outcrops of dark purple-colored banded quartzite beds, formed of alternating seams richly impregnated with specular ore grains, and others of a more purely quartzose composition. The rock belt to which these strata belong is exposed in the bed of a small creek, but the exposures are too limited to offer a cross section giving information of the thickness of this belt and of the rock adjoining it; but as the trend and dip of the beds are in conformity with the graphitic slates and the galena-bearing quartzites, it is probable that they belong approximately to the same geological horizon. West of this creek the trail follows the south line of Section 18, and then of 13 and 14 in the adjoining township as far as the Little Presque Isle river.

The quotations thus given from Dr. Rominger under the head of the Iron Ore group, refer essentially to those slaty quartzitic and partly ferruginous rocks which lie to the east of the Presque Isle river and north of the great area of brecciated greenstone-schist subsequently described. (See Plates II and X.) On account of the difficulties in reading the structural relations of this belt the quotations are made quite full. The remainder of Dr. Rominger's remarks under this heading consist only of unimportant descriptive details with regard to the exposures of ferruginous rocks between the Little Presque Isle and Montreal rivers.

In addition to the foregoing, the following general remarks are worthy of quotation here, since they define Dr. Rominger's position as to the relative ages of the granitic rocks and the iron-bearing slates which rest upon them. As already noted, Dr. Rominger had previously published the opinion (Geological Survey of Michigan, vol. IV, p. 6) that the granitic rocks of the Upper Peninsula of Michigan are all newer than the various schistose and slaty rocks of the region into which he conceived them to have erupted—as did also Foster, Whitney, and Wadsworth before him—and to have produced the crumplings and alterations these schists now present us with. Subsequently to the publication of these views certain considerations were urged on Dr. Rominger by the present writer, going to show that these granitic and gneissic rocks are really older than a large portion of the schistose and slaty rocks; for, while they have invaded a portion of these, they have yet furnished to another portion an abundance of fragmental material.

The remarks quoted below are in no part a reply to these considerations. It will be seen that Dr. Rominger, while retaining his position in the main, has yet modified it so far as to accept an older granite in addition to the areas which he regards as newer than the schists adjacent to them.

In a previous report,[1] which commences with a description of the geological structure of the environs of Marquette, I have spoken of the occurrence of large areas of granite some distance north and south of the city and of the intermediate space from 4 to 5 miles in width as being occupied by a large body of massive and schistose dioritic rocks. These in turn are succeeded upward by argillitic, chloritic, and hydromicaceous schistose layers, inclosing lenticular seams of hematitic iron ore, which on their part are overlain by a large quartzite formation and by still higher beds of siliceous limestones interstratified with argillitic or hydromicaceous schists of various color, some of them intensely impregnated with hematitic iron oxide.

All these strata I described as being steeply upheaved in a constant axial direction from east to west, and as excessively folded and corrugated, suggesting as the principal cause of these disturbances the uprising of the granite into a synclinal trough compressing the incumbent sedimentary layers.

I further stated, that particularly the lower dioritic portion of the rock beds inclosed within this trough was found intermingled with belts of granite, partly parallel to the stratification, partly transverse to it, from which circumstance I inferred the intrusive nature of these belts, and suggested that this intrusion occurred contemporaneously with the upheaval of the granite into a trough, and that part of it at least must have been then in liquid or plastic condition.

Generally, a solid crust of granite probably served as a substratum on which the Huronian sediments were laid down, but occasion is not often offered to see the rocks in contiguity well enough exposed to allow a discrimination as to whether such contact is an original primary one or resulted from subsequent dislocation.

The existence of granite as a surface rock at the time the Huronian sediments formed is proved by the occurrence of belts of granite conglomerate and breccia in different horizons of the series.

A large belt of conglomerate formed of rounded, water-worn granite pebbles and schistose rock fragments, cemented by a matrix of similar schistose material is seen in contact with a granite belt in the south half of Sec. 2, T. 48, R. 26, but this instance is not a satisfactory example of the deposition of sediments inclosing débris of the underlying rock, as the granite pebbles in the conglomerate are totally different from

[1] Geol. Survey of Mich., vol. IV, 1881, pp. 13–19, 22–39.

the underlying granite, which is a porphyritic kind largely composed of a cryptocrystalline felsitic groundmass inclosing quartz grains and orthoclase crystals of larger size. This peculiar variety of granite is typical for the smaller intrusive belts, and most likely the granite in this case came in contact with the conglomerate belt by intrusion. Better proof for the deposition of Huronian sediments on a base of granite is furnished by another locality in the SE. ¼ of Sec. 22, T. 47, R. 26, where several knobs, centrally composed of massive granite, are surrounded by a mantle of coarse granite breccia, with a well laminated quartzose material as a cement. This breccia is conformably succeeded by a series of steel gray colored shining hydro-micaceous slate rocks interlaminated with heavy belts of light colored compact quartzite. . . .

The upheaval of the granite and its intrusion into the overlying strata occurred in all probability near the termination of the Huronian period, as we find the granite in contact with any of the Huronian strata, up to the youngest, and these always in a dislocated position. . . .

The dislocation of the Huronian beds is not exclusively due to the upheaval and intrusion of the granite, as numerous other intrusive rock belts, dioritic or diabasic, intersect the granite as well as the incumbent beds.

WHITNEY (J. D.) and WADSWORTH (M. E.). The Azoic System and its Proposed Subdivisions. Bull. Mus. Comp. Zool., Harvard Coll., whole series vol. VII (Geological series vol. I), 1884, pp. 565.

Part I of this work is a critical "Synopsis of the Evidence on which the Rocks of the Azoic System have been variously grouped into Distinct Divisions by American Geologists," and occupies most of the volume, taking up in a geographical order all that has been written to date on the Archean or Azoic geology of Canada and the several states of the United States within which these ancient rocks come to the surface. Part II, which is a "Résumé and General Discussion", in which the Authors offer "a brief synopsis of the conclusions at which we have arrived in the study of these older rocks."

To any geologist who had concerned himself with the study of the pre-Cambrian formations in the years immediately preceding the appearance of this volume, it must have become very evident that some sort of a critical review of all that had been written with regard to these ancient rocks was quite necessary to future progress in investigation. For more than one reason, what had been written prior to this time had resulted in the greatest of confusion. In the first place the very nature of the rocks themselves were such as to baffle most of the attempts of the older geologists at reaching an understanding of even their mineral composition. Most of those who had written upon them up to this time had been unacquainted with the newer petrographic methods, which indeed are only recently reaching any very satisfactory development so far as the study of these difficult rocks is concerned. Then again, the structural problems presented by these rocks are always among the most difficult the geologist has to deal with. Exposed as they have been to the disturbing forces of all the enormous lapse of ages since their first production, their occurrence in anything like their normal position is the rare exception. Faulted, folded, squeezed, internally altered in every possible way, and intruded in every fashion by every sort of eruptive material, the difficulties in the way of a correct understanding of even a small area of these ancient rocks, are often well nigh insurmountable. Certainly they are to be overcome only by the most minutely accurate structural work. Approaching them from different points of view, the geologist who has acquired his experience among the unaltered sediments and he whose ideas have been developed mainly among the more modern eruptives, unrestrained by the accurate knowledge obtainable only through the modern petrographic methods, and through exact structural investigation, have arrived at the most opposite conclusions with regard to the structural relations and genesis of these ancient rocks.

A careful sifting of all that has been written upon this subject was certainly very desirable—a sifting which should not attempt to destroy all information gathered, but which should try, so far as possible, to separate what is inference only from what was a certain result of accurate observation. In the case of the present work, however, it becomes very evident within the first few pages that the authors have a distinct theory to advocate with regard to the pre-Cambrian formations, a theory, in fact, for many years past advocated by the older of the two authors. This theory is simply that the pre-Cambrian rocks constitute a truly Azoic, confused intermingling of sedimentaries and eruptives, which, though covering in their production an immense lapse of time, are not divisible on any correct geological principle into chronologically distinct terranes. All evidence found that had been presented in opposition to this view is criticised out of existence, and this often with pungency and lack of a scientific spirit, or if it does not yield so easily to destructive criticisms is dismissed with derision. On the other hand, all statements of previous authors which seem in any way to support the view advocated are accepted with a readiness which at times amounts to credulity. That very much was found among the older writings which could be rejected goes without saying, particularly so since these older writers had not become possessed of any of the modern petrographical knowledge, and, having only done the best that the development of the science enabled them, very frequently and naturally fell into serious mistakes. So generally, indeed, has the opposition of writers to the view of the authors of this volume, or an occasional unavoidable mistake, been seized upon for their condemnation that nearly all geologists who had previously written upon the pre-Cambrian formations, save the authors themselves, are included in the general censure. A satisfactory critical review of all that has heretofore been published on the Archean formations of America therefore remains still to be written. Unfortunately, however, it does not now seem probable that such a review can be prepared at an early date, for the author must not only be unbiased and ready to go where truth leads him, but, in order that the review may have any considerable value, he must have had an unusually wide experience and must have the time to verify on the ground the statements of the various writers.[1]

The following quotations from Part I include all that has direct reference to the Penokee-Gogebic district (pp. 495–497):

Passing now to the Azoic rocks of Wisconsin, we find that in 1876 Mr. E. T. Sweet pointed out a supposed unconformability between the Laurentian and Huronian at Penokee gap, stating (Trans. Wis. Acad., vol. III, 1875–'76, pp. 43–44):

"When the railroad cut is completed at this locality the absolute junction of Laurentian and overlying Huronian will doubtless be exposed. There can be no doubt of the unconformability of these formations, approaching each other as they do with a persistent opposite dip and somewhat different strike. Unconformability

[1] The above paragraph is left essentially as it was written by the late Dr. Irving. I know that now Dr. Wadsworth, as state geologist of Michigan, is working on the ancient rocks of lake Superior in a systematic and careful manner. This later work has led him to modify or abandon many of his earlier views concerning them as well as the pre-Cambrian of other regions.—C. R. VAN HISE.

has been shown to exist between the Laurentian and Huronian in Michigan, but this is the first time it has been proved in Wisconsin."

Of the same supposed unconformability at Penokee gap Prof. R. D. Irving remarks (Am. Jour. Sci., 3rd ser., vol. XIII, 1877, p. 308):

"The crystalline rocks of Wisconsin include unquestionably two distinct terranes, the one lying unconformably upon the other, as is beautifully shown at Penokee gap, on Bad river, in the lake Superior country. Here a white siliceous marble of the Huronian, overlaid by hundreds of feet of distinctly bedded slaty rocks and dipping northward, is to be seen within 20 feet of large ledges of dark colored amphibolic gneiss, whose bedding planes dip southward and strike in a direction diagonally across that of the more northern beds. There are no doubt instances where the two series are difficult to separate, similar rocks occurring in both groups, but the existence of the two is incontestable."

In the third volume of the Geology of Wisconsin (pp. 94, 98, 108, 116, 117, 248–250) accounts of the unconformability of the Laurentian and Huronian are given, but the kind of contact when seen was not observed. But if the Laurentian rocks are eruptive, then of course there would be unconformability. The proof advanced was that the foliation of the granite and gneiss dipped at a different angle from that of the Huronian rocks. Here, as in the case of the Keweenaw series, the Wisconsin geologists failed to take into account the conditions necessary to prove their points, while Prof. Irving, without giving any evidence of value, made out a beautiful fault—on paper—at the Penokee gap. So far as can be judged from the evidence presented by these geologists, it appears that they have in Wisconsin the same structure as exists in the Azoic of Michigan, namely, a series of mixed sedimentary and eruptive rocks.

From the following extracts it will be readily seen that there are no other than lithological grounds for assigning these rocks to the Huronian and Laurentian; that they are two distinct formations they entirely fail to prove. . . .

In 1880 Professor Irving gives as the reasons for assigning the rocks which are placed in the Laurentian in Wisconsin to that system, their "close lithological similarity—the only marked difference being the absence of crystalline limestones in the Wisconsin area—of similar structural relations to the Huronian, Keweenawan, and Lower Silurian systems, and of probable direct continuity with the Canada Laurentian through the upper peninsula of Michigan and underneath the waters of lake Superior." (Trans. Am. Inst. Min. Eng., vol. VIII, 1880, pp. 480, 481.)

Of the Huronian in the same article it is stated (p. 483):

"The rocks of this series have been called Huronian by Brooks, and, in the writer's judgment, correctly so, on account of their similarity to the Canada Huronian, with which they not improbably have a direct connection underneath the Silurian of the eastern part of the peninsula, but more especially because they evidently occupy the same geological interval as the typical Canadian series, exhibiting the same non-conformity with an underlying gneissic and granitic system."

It appears, then, that the only evidence that the Wisconsin geologists have that the Laurentian and Huronian are what they purport to be is lithological; and they have advanced no sound argument showing that they form distinct ages in the Azoic system. The relation of the two supposed series is not that which is seen when the Paleozoic comes in contact with the Azoic, or what it would be naturally were the Huronian laid down on the preexisting Laurentian. The contacts—when these contacts have been figured—appear rather to be those made by eruptive rocks with prior existing ones. The geologists before mentioned have assumed, not proved, the sedimentary metamorphic origin of all the rocks in question, and on the correctness of that assumption depends their argument. They have failed to observe the phenomena of the contact when seen beyond the mere fact of a different dip to the foliation observed. In fact, they have failed to prove any of the points essential to establishing their conclusions.

Since the questions of the unconformability and fault at Penokee gap and of the general separability of the Penokee Iron series from the more southerly gneisses are fully discussed in subsequent pages of the present volume, it will not be needful to consider here at any length the criticisms above quoted. I may merely say in the first place that the Penokee fault appears to us entirely demonstrated by the facts presented on the maps and in the text of vol. III of the Geology of Wisconsin; so that any question as to the existence of this fault becomes a question as to the presentation of facts and not as to the correctness of the conclusions drawn from them. Again, I may say that in case the stratiform arrangement of the gneiss at Penokee gap is a foliation (pressure result) its discordance with the sedimentation plane of the overlying slaty series is sufficiently good evidence of an unconformity; and, finally, that the general unconformable position of the Iron series of this region with regard to the more southern rocks seems completely established by the facts presented in the following pages.

IRVING (R. D.) and VAN HISE (C. R.). On Secondary Enlargements of Mineral Fragments in certain Rocks. Bulletin of the U. S. Geol. Survey, No. 8, 1884, 56 pp.

Among the special rocks with which the general conclusions of this pamphlet with regard to the origin of quartzite are fortified, are from the Penokee region vitreous quartzite, quartzite-schists, mica-schists, and graywacke, the quartz fragments of these several rocks being shown to have received secondary enlargements in optical contiguity with the original grains, subsequently to the aggregation of the rocks. Since the publication of this pamphlet, which was the first announcement of the existence of this very general and widespread mode of induration of rocks, our experience has only confirmed the conclusions presented, showing us not only these enlargements are to be widely met with in the Penokee district, but more than that, that quartzite fragmental rocks of all ages are found to be much more rarely without these enlargements than with them.

1885.

WINCHELL (N. H.). The Crystalline Rocks of the Northwest. Address before Section E., Am. Assoc. Adv. Sci., at Philadelphia, September, 1884. Proceedings, 33d Meeting, pp. 366–379.

In this address Prof. Winchell "calls the attention of Section E to some of the interesting problems that beset the geologist who undertakes to study the crystalline rocks of the Northwest, and especially that part of the Northwest which is included in the state of Minnesota," and aims at a concise review of "the broad stratigraphic distinctions of the crystalline rocks that have lately been studied in Michigan, Wisconsin, and Minnesota by the aid of the published results of the surveys of Brooks, Wright, Irving, Rominger, Pumpelly, and others," who undertook to formulate a generalized statement. To this he adds also "such published results and unpublished field observations from Minnesota as may be furnished by the survey of that state, in order that the scheme may cover correctly the crystalline rocks of the entire Northwest."

The following table indicates the six groups into which Prof. Winchell would divide all of the rocks of the Northwest which belong below the Copper-bearing series:

| Groups. | Equivalents in Michigan. | Equivalents in Wisconsin. | Equivalents in Minnesota. |
|---|---|---|---|
| Group I, Granite and Syenite with Gabbro. | XX .................. | I and I*a* at Black river. | Duluth.<br>Brulé Mountain.<br>Misquah hills.<br>Beaver bay. |
| Group II, Mica-Schist. | XIX at Marquette.<br>XVII–XIX at Menominee. | XX–XXII at Penokee. | Little falls.<br>Pike rapids.<br>Outlet of Vermilion lake. |
| Group III, Carbonaceous and Arenaceous Black Slate. | XIV-XVII at Marquette.<br>XV and XVI at Menominee. | VI–XVI at Penokee. | Animikie.<br>Black slates.<br>Grand portage. |
| Group IV, Hydromica and Magnesian Slate. | VI–XIV at Marquette.<br>VI–XI at Menominee. | IV–VI at Penokee. | At "The Mission."<br>Vermilion lake.<br>Vermilion Iron mines. |
| Group V, Quartzite and Marble. | V at Marquette.<br>II–V at Menominee. | I–III at Penokee. | Ogishke-Muncie lake. |
| Group VI, Granite and Gneiss with Honblendic Gneiss. | Laurentian. | Laurentian. | Laurentian. |

This table shows also what members of the different series that have been described as occurring in Michigan, Wisconsin and Minnesota, correspond with each one of these groups. It does not appear that Prof. Winchell would regard these several groups as necessarily separated by time-gaps from one another, but merely as certain lithologically distinct horizons, to which all of the rocks of the lake Superior region may be referred. In the original tabulation, of which the above is a partial copy, Prof. Winchell gives also four other columns, one of which indicates the equivalency of these six groups to the several divisions of the pre-Potsdam rocks of New England as recognized by Emmons. The other columns headed respectively Hunt, Brooks, and Irving, give the relations of these six groups to the divisions recognized by the geologists named. As to the relation of any of these rocks to any of the several groups recognized by Emmons and others in the East, we do not propose now to say anything, but merely to restrict ourselves to a few remarks with regard to equivalencies indicated in the table for the lake Superior region itself. To begin with, we can by no means accept the six groups of the first column even as a mere general stratigraphic succession. Group I, called "Granite and Syenite with Gabbro," should rather read gabbro with some reddish acidic rocks. Here belong the enormous masses of gabbro which appear in the Bad river country of Wisconsin, and over a large area in northern Minnesota at the base of the Keweenaw series. That these rocks belong rather to the Keweenaw series itself than a separate group, is indicated both by their lithological similarity to that series, and the very striking unconformity which they present with regard to the lower slaty rocks, both in northern Minnesota and the Penokee district.

The second, or mica-schist group, is hardly a valid one unless the term mica-schist be made to include an enormous mass of rocks which is not ordinarily covered by such a name. It is true that mica-bearing schistose rocks, quite different, however, from those completely crystalline mica-schists which belong at a much lower horizon in the lake Superior region, are met with in certain places in the lake Superior region at the summit of what has ordinarily been called the Huronian series; but these micaceous schistose rocks are after all a mere phase and by no means the predominant one of a great thickness of genuine fragmental rocks, which merge, both horizontally and vertically, into those occurring farther below, called the carbonaceous and arenaceous black slate group.

The fourth group, the hydromica and magnesian slate group, has, so far as we are aware, no distinct existence; certainly none at any such stratigraphical horizon as here indicated. Hydromica-slates and magnesian slates are here and there stratified among the Iron-bearing rocks of different parts of the lake Superior region, but they never constituted, so far as we are aware, any continuous or well marked horizon.

The fifth group, which, however, has certainly no separate and distinct existence, is fairly well represented in the Marquette, Menominee, and Penokee districts, though Prof. Winchell's reference to this one horizon of the Huronian series of Canada has, we think, no basis.

The sixth group correctly enough includes those granites and gneisses which, with certain schists, also belong throughout the lake Superior country beneath all the stratiform rocks.

Turning now to the columns showing the equivalents of these several groups in Michigan, Wisconsin, and Minnesota, we note in the first place that Brooks's horizon No. xx, which is made especially for the granite south of the Menominee river in northern Wisconsin, appears to us, on the contrary, to belong to the lowest one of Winchell's groups; in other words, to be nothing more or less than a part of the great basement series upon which the great thickness of stratiform rocks was originally spread; that numbers 1 and 1*a* of the Black river succession, Wisconsin, belong similarly to this low horizon; that while we would put the Duluth gabbro and the Brulé mountain red rocks at the horizon given (noting, however, the total dissimilarity of these red rocks to the granitic rocks just referred to), the reddish rocks of Beaver bay, on the other hand, are at a very much higher horizon, well up in the Keweenaw series; that numbers xx and xxii of the Penokee series are, as they are followed eastward from the gap, found to consist mainly of but little altered fragmental rocks, the mica-schist being in fact an alteration phase of a merely fragmental graywacke; and that the Animikie series, taken as a whole, appears to us to have a thickness several times as great as indicated by Prof. Winchell, and to correspond to the whole thickness of those rocks, which on the south shore of lake Superior intervene between the gabbro and the Lower Huronian rather than to be equivalent to so small a portion of them.

**Irving (R. D.).** Divisibility of the Archean in the Northwest. Extract from Address as retiring President of the Wisconsin Academy of Sciences. Delivered December 30, 1884. Published in the Am. Jour. Sci., 3d ser., vol. xxix, 1885, pp. 237–249.

This paper presents in brief certain arguments for a belief in the divisibility of all of those rocks which in the Northwest lie beneath the base of the Keweenaw series into two wholly distinct groups, separated from one another by a great unconformity, the uppermost of the two being in its turn separated by a great discordance from the Keweenaw or copper-bearing series. These unconformities indicate the intervention between the several groups of periods during which prolonged denudation of land surface was being carried on. These two groups are, beginning below: (1) The great basement complex of gneiss, granite, and various schistose rocks;

(2) the Iron-bearing slate series, in large measure composed of little altered fragmental rocks. The uppermost of these successions, it is maintained, is plainly enough the equivalent in general of the original Huronian series of Canada, and should be so called. To the lower series we may for the present apply the Canadian term, Laurentian. This lower group may or may not be further divisible into subordinate numbers; and indeed there are here and there indications of subordinate breaks in the upper series, but for the present the only distinct and widely applicable classification to be made is that above indicated.

The proofs cited in favor of the conclusions presented in this paper are drawn in very large measure indeed from the Penokee district. Since the same facts are presented much more fully in the present volume, it is not desirable to repeat them in this connection with any detail. We merely copy from the paper the tabulated statement that proofs of unconformity in the Penokee district were found.

1. In the manner in which the regularly succeeding belts of the higher series traverse the courses of those of the lower.

2. In the strong contrast between the two series as to rock kinds, the bedded members of the lower series having arrived at a nearly complete recrystallization, while those of the higher are but little altered.

3. In the highly folded and contorted condition of the lower series, as contrasted with the unfolded condition and simple stratigraphy of the higher.

4. In the striking contrast between the contacts of the granite with the lower schists and with the higher slates, the former being invaded by it in an intricate manner, the latter never when the two come together. (Granite in veins and intersecting masses occurs among the upper mica-schists of the Penokee series (see map), but this always of a different character from the granite at the southern contact, which has, as yet, never been found to intersect the slates.)

5. In the discordant laminations of the two sets of rocks when seen in contact or close proximity.

6. In the occurrence in the upper series, not only at horizons above the base, but also at points on the contact line, of abundant detrital material derived from the lower series.

IRVING (R. D.). Preliminary Paper on an Investigation of the Archean Formations of the Northwestern States. Fifth Annual Report U. S. Geol. Survey, 1885, pp. 175–242.

This paper, as the title indicates, is merely preliminary to a general study of the pre-Keweenawan formations of the lake Superior country, recently begun by the writer. It gives a general outline review of what was known with regard to these formations at the time of the beginning of the investigation, and also of the new material gathered to the date of the paper by the author and his assistants. Although the Penokee series is several times referred to in this publication, there is nothing that needs especially to be quoted here.

1886.

WRIGHT (Charles E.). The Agogebic Iron Range. In Mineral Resources of Michigan, 1885, by Charles D. Lawton, Commissioner of Mineral Statistics, Lansing, 1886, pp. 131–147.

The late Mr. Wright gives a brief account of the history of exploration in the range and a detailed statement as to the amount of development at each of the mining properties at the end of the year 1885. For the most part these details have little geological interest, but the irregular character of the ore-bodies and their association with the soap rock and the underlying quartzite are brought out. The only general points mentioned are given by the following quotations:

In 1879 F. H. Brotherton, Esq., and party located, for the Canal Company, very closely, the Huronian belt across ranges 44, 45, 46, and 47, T. 47, and the ore vein within this belt; in fact all the discoveries of iron ore made in the above towns are within a hundred feet or so of the line determined by Mr. Brotherton. (P. 131.)

Speaking of the Ashland mine, he says:

The quartzite on the foot wall side is in places more like a hard-pressed sand bank, caused apparently from the decomposition of the matrix or cementing material of the quartzite. This is not to be wondered at, as the water forcing its way downward naturally follows the junction of the strata, fissures, and joints, dissolving a portion of the mineral ingredients of the rocks it traverses and again replacing it with others. It is highly probable that the purity of some of the soft hematites is due to this very process, as has been noted in previous numbers of this report Many of the soft-ore veins were originally, no doubt, very siliceous, but "alkaline" water filtering through them under pressure, especially if by any means they had become broken or shattered, would in time carry away the silica in solution and leave the iron oxide and other bases behind.

Further, of the Ashland mine:

> One interesting feature is the presence of occasional rounded bowlders of quartzite in the ore. Whether these bowlders will disappear in depth is a problem that may throw some light on the origin of these hematite veins (pp. 141–142).

In his account of the Norrie mine he further states:

> As at the Ashland mine, there are large rounded bowlders of quartzite in the ore, and the quartzite next to the ore is frequently disintegrated into common sand (p. 144).

The accuracy with which the iron-bearing belt was located, by means of magnetic attractions, by the Wisconsin Geological Survey between the West Branch of the Montreal and the Montreal river, where there are no exposures, has been indicated by the quotations from its reports. It appears that Mr. Brotherton, in 1879, located this belt in the same manner on the Michigan side of the line, although no report of his work has, so far as I know, been published. The suggestion which Mr. Wright made as to the ore of the Ashland mine being enriched by percolating waters is interesting as being in conformity with the conclusions which a detailed study has developed. The appearance of rounded bowlders of quartzite in the ore at the Ashland and Norrie mines appears to indicate that here, before the beginning of the deposition of the layers of the iron-bearing formation, the underlying quartzite was broken by erosion.

VAN HISE (C. R.). Upon the Origin of the Mica-Schists and Black Mica-Slates of the Penokee-Gogebic Iron-Bearing Series. Am. Jour. Sci., 3d series, vol. XXXI, 1886, pp. 453–459.

This paper presents facts and arguments going to show that certain mica-bearing slates and schists, which in the Bad river country occur in the upper horizons of the Penokee series, are merely alteration forms of the plainly fragmental rocks which make up the greater part of these upper horizons. The process by which this alteration has been brought about, and by which in the extreme cases the original fragmental texture of the rocks has been nearly or quite obliterated, has consisted mainly in the development of muscovite and biotite from the feldspar fragments, a separation of silica taking place at the same time. Besides this main mode of change, the author shows that the process included also the secondary enlargement of quartz fragments, and occasionally of feldspar fragments. The facts which are summarized in this paper are given in detail in subsequent pages of the present volume, of which, in fact, the paper was merely an advanced announcement.

It should be said that, although these conclusions of Prof. Van Hise in this paper have stood the test of all of our later works, we have never yet been able to trace with certainty to a similar origin completely crystalline mica-schists which belong to the lower or basement series. Penokee mica-schists, as also others like them from the Marquette district of Michigan and from the Mississippi valley in the vicinity of Little Falls, are perhaps rather mica-slates than mica-schists; at least they are not highly foliated. The mica-schists, which are associated with the ancient gneisses, may or may not have had a similar origin, so far as our observations have gone.

IRVING (R. D.). **Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region.** Am. Jour. Sci., 3d series, vol. XXXII, 1886, pp. 255–272.

Like the preceding paper, this one also is a preliminary statement of results, the better proofs of which results are elaborated at length in subsequent pages of the present volume. The paper argues that the original form of the beds of the iron-bearing horizons of the lake Superior region was that of a series of thinly bedded carbonates interstratified with carbonaceous shaly layers, which were also often impregnated by the ferriferous carbonate; that by a process of silicification these carbonate-bearing layers were transformed into various forms of ferruginous rocks now met with in this region; that the iron removed from the original rock at the time of silicification passed into solution in the percolating waters, to be redeposited in various places as it became further oxidized, thus making ore bodies and various iron-impregnated rocks; that in other places, however, instead of leaching it out more or less completely, the silicifying waters seem to have decomposed the iron carbonate in place in such manner as to produce the well known actinolitic magnetite-schists of these districts; that the bodies of rich ore have probably had different origins in different cases, some having originated from a direct oxidation in place of the original carbonate, while others are redepositions of the dissolved iron in new places, and the origin of still others is as yet not understood; and that, finally, the silicifying process began before the folding of these formations, but continued afterwards.

1887.

VAN HISE (C. R.). Note on the Enlargement of Hornblendes and Augites in Fragmental and Eruptive Rocks. Am. Jour. Sci., 3d series, vol. XXXIII, 1887, pp. 385–388.

Prof. Van Hise, having previously noted and described second growths on hornblendes in certain fragmental rocks of northern Minnesota, in this paper describes similar enlargements which occur in certain eruptive greenstones of the Penokee-Gogebic district. He shows that the secondary hornblende has in these greenstones attached itself at times to a uralitic hornblende and at times to even an unaltered augite. Hornblende additions to hornblende crystals in eruptive rocks had already been described by Friedrich Becke.

IRVING (R. D.). Is there a Huronian Group? Am. Jour. Sci., 3d series, vol. XXXIV, 1887, pp. 204–216, 249–263, 365–374.

This paper, which was read before the National Academy of Sciences at Washington, D. C., April 22, 1887, presents at some considerable length a series of arguments, obtained from all portions of the lake Superior region, tending to establish the genuineness of the Huronian group for that region. The paper maintains the entire separateness of this group from the underlying basement complex of gneiss, granite, and crystalline schists and from the Keweenaw series above. It maintains also the title of the Huronian to a rank equivalent with that of Cambrian, Silurian, Devonian, etc., and argues that both Huronian and Keweenaw should be admitted to the geological column with this rank, but that, since these groups carry no fossils, they cannot be directly correlated with pre-Cambrian groups of geological provinces wholly distinct from that in which they are found. The only correlation that can be safely made is that of all of the clastic groups collectively which in any one region intervene between the Cambrian and the basement crystallines with any group or groups falling within the same interval in other regions. To cover this general geological interval, namely, that lying between the Cambrian and the basement crystallines, to which it is proposed that the term Archean should be restricted, the paper advocates the use of the new name *Agnotozoic*, of equal rank with *Paleozoic*, *Mesozoic*, etc.

BIRKINBINE (JOHN). The Iron Ores East of the Mississippi River. U. S. Geological Survey, J. W. Powell, Director. Mineral Resources of the United States for 1886, David T. Day, Chief of Division of Mining Statistics and Technology. pp. 39–103.

Mr. John Birkinbine contributes the article upon "The Iron Ores East of the Mississippi River" for this volume. In it he gives quite a full and accurate account of the development of the Gogebic range, from which the following somewhat extended extracts are made (pp. 67–72):

In order of importance as shippers the various districts comprising the lake Superior region ranked in 1886 as follows: (1) Marquette; (2) Menominee; (3) Gogebic; (4) Vermilion; and this order will be maintained in 1887, with the possibility of the Gogebic and Menominee ranges changing places, but it is probable that these two districts will not vary greatly in their outputs for 1887.

Geographically the Gogebic iron range may be described as running nearly parallel with the southern shore of lake Superior, and about 15 miles distant from it. The Montreal river (which is the boundary between the State of Wisconsin and the upper peninsula of Michigan), flowing northward into the lake, cuts through the range nearly midway between the extremes of the present exploitations, about one-half of the ore strike, as now believed to be determined, lying in Ontonagon county, Michigan, and the other half in Ashland county, Wisconsin.

The occurrence of ores similar in character to those of the Gogebic iron range in lenses or pockets in the Marquette and Menominee ranges naturally points to like deposits in this newer district, and there seems good reason to believe that the ores lie in lenses of greater or less width and depth throughout an ore-bearing stratum confined by the quartzite hanging wall of what is believed to be the north vein, and the foot wall of what is usually known as the south vein, with a greater probability of finding the ore in this newer region, owing to the apparent persistence and regularity of the foot wall. Local opinions favor, however, and not without reason, the existence of two veins, although the presence of two apparently distinct ore bodies is shown, so far, in but few instances. The belief in the existence of two veins is based upon their positions relative to the foot wall, and also to a greater percentage of manganese in the south vein.

The mines already opened and worked show a high grade of red hematite ores, most of which are strictly of the Bessemer class, the balance of the ore prepared for shipment being rich in iron and close to the Bessemer limit in phosphorus. While some ores high in manganese are mined, none can be said to be high in phosphorus, and it is doubtful if the run of any of the developed properties would show 2 parts of phosphorus in 1,000 of iron. It may be asserted as a rule that where the ore lies in large masses but little of it will require sorting, and even in mining the proportion of lean ore and foreign material is insignificant, except near the confining walls or where "horses" of rock occur. These "horses" are by no means uncommon, and are found in most of the mines now extensively opened, but they are not a cause for discouragement; for already after passing through a "horse" ore has been found below it, or the projection of a "horse" into the ore body has apparently forced the ore in front of it. A fact of apparent similarity to the older regions is in the grouping of the large producers along a comparatively limited strike, and it is probable that the Gogebic range will show the great proportion of its future shipments made from a few large mines. . . .

The appearance of the ores from the various mines and in some cases from the same mine differs materially both as to color and hardness. The colors are nearly black, blue black, brown, and almost brick red; the hardness varies from a soft mass of finely comminuted ore to compact lumps, and occasionally grape, needle, or kidney forms, with brilliant surface. . . .

From the Gogebic mines the following amounts were shipped in the first and second years of development:

*Production of iron ores from the leading Gogebic mines in 1885 and 1886.*

| | 1885. | 1886. |
|---|---|---|
| | *Tons.* | *Tons.* |
| Colby | 84,302 | 257,432 |
| Norrie | 15,419 | 124,844 |
| Ashland | 6,471 | 74,015 |
| Germania | 5,634 | 20,069 |
| Aurora | | 94,553 |
| Iron King | | 29,184 |
| Ironton | | 18,424 |
| Kakagon | | 18,497 |
| Pabst | 1,103 | 17,688 |
| Puritan | | 16,388 |
| Total for 1886 | | 671,094 |

Between the eastern and western extremes of practical exploration upon the Gogebic iron range the distance is fully 30 miles, but the properties held as iron lands extend to the east and west of these extremes. The real work of development to date is covered by a distance of about 20 miles along the ridge.

The most eastern section which may be fairly considered as open is locally known as the Sunday lake district, having Wakefield, Michigan, as its business center. Here several mines, notably the Brotherton, Sunday lake, and Iron Chief, shipped in the aggregate about 31,000 tons of ore in 1886 from underground workings, and as in this vicinity the ridge is less defined and the ground at a lower level, the exploitation has been more expensive and difficult and the progress less marked than elsewhere. The ore-bearing rocks apparently strike through Sunday lake. Following west 3 miles the Black river cuts through the ridge, and the ore has been found in this gap. Three miles still farther, the highest elevation of the ridge is found (reported as 1,100 feet above lake Superior or 1,700 feet above tide) at the Colby mine, which overlooks the town of Bessemer, Michigan, built on the northern slope of the ridge. Just west of the Colby mine the strike of the ore-bearing rocks crosses a valley about half a mile wide, and then follows the ridge for about 5 miles to where the main branch of the Montreal river cuts through it, and in the western half of this section are found three mines, the Aurora, the Norrie, and the Ashland, which, next to the Colby, have been the principal producers, and whose aggregate output for the year 1886 was about 320,000 tons. In addition others of smaller capacity are operated. After rising from the valley of the Montreal river into Wisconsin the ore mines are on elevated ground for about 3 miles, in which there are several producers.

After crossing the west branch of the Montreal river there are few more producing mines, but exploitation has been carried beyond this stream for 3 miles, and farther west large syndicates own land on which prospecting is fairly active.

The Colby mine, the best known and largest developed working in the Gogebic iron range, is at present operated under a lease which has less than two years to run. The time limit has undoubtedly encouraged the large outputs of 84,302 tons in 1885, the first year of actual working, and 248,810 tons in 1886. The mine, being located at the most elevated point in the region, is reached by a switch-back railway connection which formerly ran directly into the open workings, and the ore was dug and loaded onto the cars which carried it to Ashland for shipping. While the open pitwork of the Colby and Aurora mines are the features of the Gogebic region, the deposit as found in the Norrie and Ashland mines indicates what may be considered as specially good mines, and if one-half of those already operating can reach the output of these the district will be an enormous producer. As underground workings must eventually be generally adopted, the operations of these two mines will prove a guide as to the future possibilities of others according to the width of the ore bodies. In them are also found the "horses" which add to the uncertainty of the mining enterprises. . . .

Most of the mines that were on the shipping list in 1886 have been sinking and opening up ground for the season's work. No large deposits have been found during winter development except possibly at the Anvil and Ryan. A great many explorations are being carried on, but the most productive portion of the range seems to be in Michigan, from the Montreal river to the Colby open quarry (11 miles). The greatest depth which has been attained is 275 feet at the Ashland mine. The Norrie mine comes next, being 250 feet deep.

The Ashland mine has not opened up much ground on the fourth level, so that while it can not be affirmed that the vein widens as it increases in depth, still the lens is wider at the third than at the second level and much longer. The third level of the Ashland showed a width in the fall of 1886 of 145 feet when "soap rock" was struck. In May, 1887, a cut made through about 15 feet of this (the supposed hanging wall) was made, and ore again found that analyzed 63 per cent of iron and 0·011 of phosphorus. A cross-cut 35 feet in this ore at last reports showed no signs of a hanging wall.

*Analyses of some of the ores of the Gogebic region.*

| | Iron. | Phosphorus. | Silica. | Manganese. |
|---|---|---|---|---|
| Iron King mine: | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| North vein | 60.85 | 0.027 | 5.44 | 1.30 |
| South vein | 55.74 | .031 | 3.47 | 12.28 |
| Norrie mine: | | | | |
| From stock pile | 62.83 | .0474 | 5.18 | |
| Aurora mine: | | | | |
| From cars | 62.93 | .0278 | 3.65 | |
| Germania mine:* | | | | |
| From stock pile No. 1 | 59.38 | .058 | | |
| Number 2 | 59.70 | .056 | | |
| Pabst mine (check sample): | | | | |
| Searle, of Hurley | 58.47 | .040 | | |
| Haldeman, of Colby | 58.46 | .044 | | |
| Joilet Steel Works | | .031 | | |
| Camp, of Pittsburg | | .035 | | |
| W. J. Olcott | 58.38 | †.037<br>†.036<br>.036 | | |
| Superior mine: | | | | |
| 1 | 64.83 | .047 | | |
| 2 | 65.18 | .040 | | |
| 3 | 64.25 | .054 | | |
| 4 | 59.30 | .079 | | |
| Anvil mine | 60.00 | .035 | 4.00 | 3.88 |
| Ryan mine: | | | | |
| 1 | 61.78 | .050 | | |
| 2 | 64.15 | .064 | 3.73 | |
| 3 | 57.67 | .044 | | |
| Hoppenjar mine (magnetic ore) | 51.49 | .059 | | |
| Ashland mine (average for season's shipments, 48 cargoes) | 64.50 | .047 | 3.65 | |

* Messrs. Kerr & Olcott, analysts. † Volumetric.

The occurrence of manganese can not from present exploitations be considered as being at all regular, but its appearance in what is called the south vein is more general than in the ore of the so-called north vein. The proportions of this metal vary from a trace to 33 per cent in quantities of ore, and specimens of pyrolusite are found. Alumina is found in most of the ores, the amount varying from 0·5 to 5 per cent, while the sulphur is from 0·03 to ·13 per cent. Water to the extent of 5 per cent exists in the hard ores and to a greater amount in the softer varieties. Traces of sulphur, magnesia, and lime are also determined by analysis.

The Colby mine produces an ore which carries more manganese than most of those on the Gogebic range, the average composition of the ore as shipped being as follows:

*Average composition of shipments of iron ore from the Colby mine, Gogebic range.*

| | Per cent. |
|---|---|
| Iron | 58.5 |
| Manganese | 3.5 |
| Phosphorus | .04 |

Some of the ore taken from what was termed the south vein carried as much as 33 per cent of manganese. Other analyses of the ore from this mine show the following:

*Additional analyses of iron ore from the Colby mine, Gogebic range.*

| | No. 1. | No. 2. |
|---|---|---|
| | *Per cent.* | *Per cent.* |
| Iron | 58.67 | 59.59 |
| Silica | 5.87 | 6.13 |
| Phosphorus | .049 | .05 |
| Alumina | 1.05 | .51 |
| Manganese | 3.49 | 8.45 |

Mr. Birkinbine naturally at this time shared in the current opinion that there was in this region two well defined horizons at which the ore occurred in lenses. Suffice it here to say that, as explained at length later, the ore-bodies do not occur in lenticular but in peculiar shaped bodies which have been ascertained to have remarkable relations with the underlying quartzite and the associated soapstones. The only mention made in this report of the association of the ore and soap rock is an occurrence in the Ashland mine. Mr. Birkinbine notices that the manganese is upon the whole more prevalent in the deposits near the foot-wall quartzite. This peculiarity is subsequently used in the explanation of the origin of the ores.

LAWTON (CHARLES D.). The Gogebic Iron Range. Annual Report of the Commissioner of Mineral Statistics of the State of Michigan for 1886. Lansing, 1887. pp. 125–165.

This report contains a full account of the rapid development of the mines on this range during the year 1886. It describes in detail each of the important ore-producers, and also refers to the more promising prospects. Already several of the mines have been developed sufficiently to show that they contain large deposits of ore. While this report is of great economic value, it adds comparatively little to the previous knowledge of the geology of the district. The fact that the dike-rocks have a tendency to undercut the ore-bodies is noticed, but the generalization as to their genetic relations was not reached.

1888.

LAWTON (CHARLES D.). The Gogebic Iron Range. Annual Report of the Commissioner of Mineral Statistics of the State of Michigan for 1887. Lansing, 1888, pp. 90–114.

Mr. Lawton's report for 1888 records the collapse which followed the great speculative excitement of the previous year. Notwithstanding the abrupt termination of speculation, the product of iron ore from the range is as large as in the previous year. Detailed accounts are given of additional developments in each of the iron mines, and their condition. The fact that the dike-rocks form the northern basement of the iron-ore deposits is noted of quite a number of the mines. In the description of the Norrie mine it is said, "the foot-wall flattens out and extends a great distance north, carrying the ore-body with it." Whether this is due to a fault in the foot-wall at this point, or only represents the irregular configuration of the surface of the country at the end of the accumulation of the Quartz-slate member is not explained.

BIRKINBINE (JOHN). Iron Ore Mining in 1887. U. S. Geological Survey, J. W. Powell, Director. Mineral Resources of the United States for 1887: David T. Day, Chief of Division of Mining Statistics and Technology, pp. 30–57.

The report on "Iron Ore Mining in 1887" is again by John Birkinbine. In his account of the development of the Gogebic range for this year he adds some points of interest to his former account of the region, from which the following quotations are made:

The Gogebic range in the third year of its development outstripped the Menominee district by 38,961 long tons, the figures being:

| | Long tons. |
|---|---|
| Product of the Gogebic range in 1887 .................... | 1,237,704 |
| Product of the Menominee range in 1887.................. | 1,198,743 |

This is accounted for by the mistaken policy of over capitalization, which transformed the Gogebic range into a center for stock speculation, rather than for legitimate iron-ore mining enterprises. The result was that, with the desire to realize on the money invested, developments of some mines were made in advance of actual requirements and without studying judicious methods. Each organization strove to get its ore to market and to be recognized as a shipping mine, and the competition for lake freights forced them to rates ruinous to the shippers. These rates also encouraged all-rail shipments, and the Gogebic range in 1887 increased its output 63·6 per cent over that of 1886, taking precedence of the Menominee range. But it is probable that in 1888 it will go behind its older rival, for the "bubble" which floated so many mining companies into prominence has collapsed and some Gogebic mines have suspended operation; the leases of others have reverted to the owners of the fee on account of defaults on royalties, and others which have been opened by imperfect methods must practically be developed anew. But the Gogebic range will continue as a very important factor in the lake Superior region, and will be a large producer of ores; in fact, under management which seeks to win ore cheaply and maintain the mines, the success of the district is more assured than when the operations were largely so regulated as to bolster the stock shares above their intrinsic value. The four large mines, which up to the close of 1887 had produced almost 70 per cent of the ore mined, give promise of continuing to add to the ore supply of the country and to maintain the Gogebic range as an important center of iron-ore mining.

The products of these four mines in 1887 are given as follows:

*Output of prominent mines in the Gogebic district in 1887.*

| | Quantity. |
|---|---|
| | *Long tons.* |
| Colby | 258,518 |
| Norrie | 217,251 |
| Ashland | 175,561 |
| Aurora | 159,252 |

Concerning the iron-ore deposits of the Gogebic range, Mr. Richard A. Parker, M. E., indorses the opinion that there are not two veins. He says of the ore-bearing strata confined by the red slates and jasper hanging wall that "there are not in any sense two veins; in twenty or more miles of development there are but three well established lenses of ore lying to the north of the strong foot-wall deposits, which have been called north veins, and their interrupted occurrence is so rare, compared to the continuity of more southerly deposits on the Laurentian schists, as to be scarcely sufficient to warrant the use of the significant term 'vein,' which was adopted and widely advertised by those interested in stock operations. As for manganese being made the basis of distinction between two veins, there may be instanced the continued occurrence of quite a regular percentage of it in the Kakagon and Bessemer mines, while the developed properties upon either side upon the same strike (Nimikon and Superior mines) are entirely free from it." . . .

Mr. Parker notes another point of interest in the frequency with which sheets of talcose matter, locally known as "soap rock," penetrate the ore bodies. At some period of development of all the large mines these sheets have been found, varying from 1 to 25 feet in thickness. One of the cleanest and most easily observed sheets is seen as the floor of the open pit at the Aurora mine. It has a pitch about the same as that of the ore lenses, but cuts across the deposit at right angles to the dip, ending when it reaches the foot-wall quartzite. It is soft, of smooth, even grain, and comparatively free from iron or iron stain. Where the ore came in contact with it the former was decomposed for a foot or so, and the analysis showed that it contained a higher percentage of phosphorus than usual (pp. 35–38).

Mr. Birkinbine by this time clearly sees that there is not in any sense two continuous veins of ore in the region, as is shown by his quotation from Mr. Richard A. Parker. In this the southerly deposits are explained as occurring on the Laurentian schists. This is in no case correct, the most southerly ore deposits always being found upon a fragmental quartzite which belongs to a group of rocks of which the iron-bearing member is one formation. What Mr. Parker says sbout the soapstone in the Aurora mine terminating when it reaches the foot-wall quartzite seems to me improbable. He does not give any evidence that it does not cut the foot-wall quartzite, and, considering that it is now known that these soapstones are dike-rocks and in many cases do not cut the foot-wall quartzite, it seems probable that the same thing occurs here.

BIRKINBINE (JOHN). The Resources of the Lake Superior Region. Transactions American Institute of Mining Engineers, vol. XVI, 1888, pp. 168–203.

This additional account by Mr. Birkinbine of the development of the range is accurate, and from it the following quotations are made:

If the development of the Vermilion iron-ore district is startling, that of the Gogebic iron range in Wisconsin and Michigan is even more so; for, although the existence of visible outcrops of ore was long known, and considerable amounts of money were expended by some of our large iron companies, no actual exploitation can be considered as having been made until the year 1885, when railroad connections were completed to Ashland and dock facilities provided. During 1884 1,022 gross tons were sent from what is now the Gogebic region, but in 1885 this amount was increased enormously, and the shipments amounted to 119,766 gross tons; and in 1886, 756,281 gross tons were sent to market. . . .

The development along the apparent strike of the ore covers nearly twenty miles in length, and active exploration is in progress for as great a distance both east and west of this territory, and also upon a parallel ridge 12 miles south, the latter being for magnetic ore. The center of the present developed iron-ore properties is near to the Montreal river, which forms the boundary between Wisconsin and Michigan; the largest producers up to the present time are, however, chiefly in the State of Michigan.

The ores in the Gogebic range differ from those of the Vermilion range in being softer, and therefore more easily mined, yielding less iron and also less phosphorus, but carrying a greater percentage of manganese, and more moisture. The dip of the Vermilion ore is nearly vertical; that of the Gogebic ores approximately 70°.

The ores of the Gogebic range evidently lie in a series of lenses, often connected or in echelon, and the region has attained considerable notoriety from the fact that ore indications or actual deposits have been found upon nearly every property along the apparent strike of the vein matter.

The general geology of the district is explained by Mr. J. Parke Channing, of Bessemer. He says: "The chief characteristic of the Gogebic range, and that which makes it so easy to explore, is the regularity and persistency of the formation and the strongly marked character of the footwall, which dips from 45 to 70 degrees to the north, being flattest near Sunday lake. The sinking of a shaft on the North Aurora, which it is thought will reach the continuation on the Aurora vein at a depth of about 1,200 feet, will illustrate the faith in its persistency.

"Their magnitude (aside from the occurrences of horses and fluctuations in their width) has been affected in at least one instance by a dike which cuts clear across the vein. In a few cases dikes of this description have been sunk through, and the ore found under them. Faults of the entire formation have been suspected in one or two localities, but are not directly proven." . . .

The Gogebic ores carry, on an average, about 60 per cent of iron when dry, some of the mining being above that figure. Carelessness in mining, particularly in open pits, is almost invariably followed by a decline in the iron-contents. Although the ore from a few mines is almost too high in phosphorus, the average product of the district is of Bessemer grade. The ore carries about 13 per cent of moisture in the winter, sometimes running as high as 15 per cent, while in the summer it is from 4 to 5 per cent less, averaging 7 to 10 per cent (pp. 184–187).

IRVING (R. D.). On the Classification of the Early Cambrian and pre-Cambrian Formations: A Brief Discussion of Principles, Illustrated by Examples Drawn Mainly from the Lake Superior Region. U. S. Geological Survey, J. W. Powell, Director. Seventh Annual Report, pp. 365–454.

In this paper Prof. Irving gives a full account of the "Unconformities of the Penokee-Gogebic region of northern Wisconsin and Michigan." The following is the first paragraph of the discussion:

No other so striking example of unconformity between a series of highly tilted but unfolded strata above the break, and a deeply folded series below, as that afforded by the Penokee region is known to the writer. Indeed, there are in this region two notable stratigraphical breaks: one between the iron-bearing series and the folded gneissic formation to the south of it; another between the unfolded but inclined iron-bearing series and the equally highly inclined Keweenaw series to the north. These breaks and the terranes which they separate are the counterparts of those just described as obtaining north of lake Superior (p. 423).

The proof of the positions here taken are not given, as the whole question is gone over in a subsequent chapter of this monograph.

WINCHELL (N. H.). The Gogebic Iron Region. In the Geological and Natural History Survey of Minnesota. Sixteenth Annual Report, for the year 1887. St. Paul, 1888, pp. 54–60.

A cursory examination was made of some of the mines in the Gogebic iron region, in order to be able to compare the features of the rocks and the manner of occurrence of the ore with the iron-bearing rocks of the Vermilion iron range, and some rock-samples were collected for future microscopic comparisons (p. 54).

At the Colby mine . . . there is apparent no hanging wall or footwall except the rock of the country, and that is a thin-bedded siliceous rock which itself is almost ore in some places, because of the high degree of ferruginization. This siliceous material is jasperoidal and distinctly bedded exactly like the bedding of sedimentation. The base of it all is apparently a fine "chalcedonic" silica, the same as that of the jaspilite, though in some, or many, of the beds it is a softer material, which may be earthy. . . . The south wall of the south Colby mine consists of a crumbling, coarsely granular, siliceous sandstone, the grains being subangular after disintegration. In some places it is firm and correctly bears the name of quartzite. It is stained, locally, with much or little iron, and with manganese. The "silicification" process seems here certainly to have produced fragmental silica, and subsequently, being interrupted, to have been followed by the process of ferruginization, which stained this sandstone with iron and manganese, sometimes almost constituting it an iron ore. It is not possible to say this ferruginization is a secondary, or rather a third, step, later than the general ferruginizing process, and that this quartzite has acquired the iron by reason of the accidental contiguity since, for the quartzite graduates into the rock of the mine, the acquired substances (iron and manganese) being the same as in the real ore. The general circumstances of the situation will not allow of such a separation.

About 250 feet farther north is an opening known as the North Colby. This is a long deep pit, where the iron has been worked out superficially, and timbered shafts are being prepared for deeper mining.

On the spur track from the Colby to the Valley mine is a short cut in siliceous greenish and yellowish slate, now largely ferruginous. This is sometimes earthy, like some seen at the Colby mine, but it is very siliceous with "chalcedonic" silica, some of it being almost wholly white, although the prevalence of hydro-mica and perhaps of other fine grained mineral particles intimately disseminated through the siliceous parts gives a greenish color to even the hardest and most quartzose parts of this rock. This dips so as to conform to the rock in the Colby mine, and probably lies under the foot wall of the South Colby. The full thickness of the bedding here involved, making allowance for the oblique direction in which the road goes across it, is about 250 feet (pp. 54–55).

At the Valley mine . . . in a ditch beside the railroad track at Bessemer, is a small exposure of the bottom conglomerate of the Cupriferous. It contains numerous pebbles of quartz and of fine porphyry like the copper-bearing conglomerate at the Calumet and Hecla mine. The dip can not be made out, as the exposure is small and the pebbles are rather evenly distributed throughout the whole. This conglomerate must lie in unconformity on the Gogebic iron-bearing rocks, and if it be the equivalent of the conglomerate at Negaunee (Cascade), as it appears to be, it indicates the greater age of the Huronian quartzite (the New York Potsdam sandstone) than the Cupriferous formation, i. e., than the greater part of the Cupriferous, since the Cupriferous strikes east and west near Bessemer, forming a conspicuous range of hills of eruptive rock but about a mile farther north, the dip being such as to cause it to overlie this conglomerate.

The Aurora mine, at Ironwood, has a sandstone or a soft quartzite, rather coarse, identical with that on the south wall of the South Colby mine, for its south or foot wall.

At the Aurora mine an interesting observation was made on the "granite" which forms a low hill range a short distance south of the mine, and its manner of contact with the rocks lying just north.

The low granite range, which has been mapped as Laurentian by the Wisconsin geologists, rises about 50 feet above the mine and lies south from the mine about 600 feet. The section of strata intervening between the mine and the granite range is made up about as follows, in southward (and descending) order:

1. Iron ore, soft hematite, 100 to 150 feet.
2. Sandstone (sometimes a quartzite), about 15 feet seen.
3. Gray and greenish slates and quartzites, in beds from half an inch to 4 and 6 inches; distinctly sedimentary, 580 feet.
4. Gray quartzite like that of No. 3.
5. Granite, hornblendic and massive.

The sandstone (No. 1) forms the south wall of the Aurora mine. The quartzites and slates (No. 2) are not all exposed at the mine, but at the Colby mine a section of 250 feet, in a connected exposure, can be seen along the spur track west of the mine. About 100 feet of similar strata are visible at the Aurora mine. It is partly assumed, therefore, that the whole interval of 580 feet consists of the same rock as seen at the northern and southern limits. It seems to be a part of the Animike slates and quartzites (pp. 55–56).

The hornblende-granite contains bowlder forms of different rock from the mass of the granite, some of them being of some dark-colored greenstone-like rock and others of some earlier granitic rock. The great mass of the granite is mainly homogeneous, and these bowlder forms appear most distinctly on the weathered surface of the bluff. When these bowlder masses were not originally of greenstone they are apparent by a blotched aspect which the granite presents, the blotches being caused by some patches of rounded outline, much finer grained than the rest, or by a marked difference in the relative amounts of feldspar and quartz compared to the same minerals in the most of the granite. The bowlder forms are, when distinguishable, from two or three inches in diameter to twelve inches. Their longer axes lie prevailingly in the same direction, but sometimes they have lost their first shape and have been drawn out into points in one or more directions or have been a little distorted by unequal pressure.[1]

This granite also has a uniform rift or grain, brought out by the constant or prevalent elongation of the hornblende crystals in the direction about east and west. The bowlders have their longer axes in the same position. It appears, therefore, that originally this granite was some conglomerate, which has been plastic or fluid-like.

At the most southerly of the three low bluffs of this granite, each of which faces

[1] Similar changes from conglomerates to gneiss are mentioned by Dr. E. Hitchcock in Vermont, in Am. Jour. Sci., 2d ser., vol. XXXI, p. 372.

toward the north, the granite can be seen, on the north side, to lie upon, or at least alongside of, a gray quartzite. There is an abrupt and simple contact line, with a sudden transition between them.

About 25 feet farther north is the second low northward-facing bluff of granite. It here looks as if the granite had been a molten rock and had flowed unconformably over the quartzite, the dip of which can not here be ascertained.

The third low outcrop of the granite is about 10 feet lower than the last and about 30 feet farther north. In the north face of this little bluff, not more than 6 feet high, is observable the contact seen in Fig. 2 of Fig. 8. Here the granite is unconformable on and embraces pieces and tongues and slabs of the gray quartzite and quartzite slates. This quartzite slate is fine grained, banded by sedimentation, and light greenish weathering. It is greenish gray within. At one point in this little bluff is a small area of granite surrounded by crumpled and broken portions of the slate. So at least it appears on the face of the bluff, but this isolated granite area is only superficial and doubtless was, and perhaps is still, united with the main granite mass.

These three little bluffs, running, so far as they have apparent extension, in the same direction, do not conform in their trend with the direction of strike of the bedded rocks that intervene between them and the Aurora mine. They vary from it about 20°, as illustrated in Fig. 1 of Fig. 8.

The interpretation of these facts and their bearing on the stratigraphic problems that relate to the horizon of the iron ore of the Gogebic range seem to warrant the following conclusions:

(1) The granite acts the rôle of an eruptive rock, but was originally a conglomerate. It was so far molten or plastic that it flowed over the adjoining sedimentary strata, but not so completely fused as to render the resultant granite entirely homogeneous.

(2) The accompanying beds of sedimentary rock being a perfect lithologic representative of the quartzites and slates of the lower part of the Animike, this conglomerate can be parallelized, stratigraphically, with the Ogishke conglomerate of Minnesota, in which have been seen (Fifteenth Annual Report and later in this report) similar semifused conditions, producing porphyries, syenite, and porphyritic conglomerates.

(3) The horizon of the ore of the Gogebic range is probably that of the Animike rocks.

(4) The granite is not of Laurentian age, but is younger in its present condition than the Animike slates, though originally a conglomerate older than those slates (pp. 56–59).

WINCHELL (ALEX.). The Gogebic Iron Belt. In the Geological and Natural History Survey of Minnesota; Sixteenth Annual Report, for the year 1887; St. Paul, 1888, pp. 185–195.

At the south vein of the Colby mine the ore is limited on the south by a compact hematitic slate, which is light-colored and sandstone-like in places. South of the mine is an outcrop of siliceous argillite, which is interbedded with quartzite-schist.

By the railroad near Bessemer, coming from the Valley mine, is an outcrop of conglomerate, with slight dip north. It is a small exposure, but in place, composed mostly of pebbles of dark red sandstone, hematite, granulite, and diabase. It appears like a conglomerate at the base of the Keweenian (p. 186).

The section at the Aurora mine, in descending order, is: Broken and mixed ore. Main deposit of ore dipping north at an angle of about 65°. Quartzite forming the foot wall in the Colby and Aurora mines. Siliceous argillite south of Colby mine—seen 250 feet; this perhaps occupies part of the concealed space south of the Aurora. Quartzite and syenite gneiss interbedded in the hill 633 feet south of the north face of the quartzite in the Aurora; thickness, 595 feet. Syenite gneiss (502) on the hill south of the Aurora.

This syenite is a heavy outcrop. It contains some fragments, mostly of greenstone, and only partly rounded. It reminds me of the Seagull and Saganaga regions, Minnesota. The rock weathers light colored. It is granular and porous, varying to compact. The feldspar is very pale pinkish, and the hornblende is grayish greenish. It presents all the characters of true syenite, showing no trace of bedding within the area subject to observation. But it is evidently a fragmental rock, since it contains many rolled fragments. It furnishes us ocular evidence that real syenite, with all its proper crystalline characters, may be a rock of sedimentary origin.

Looking around, we discover other evidence of its close affinity with products of sedimentary action. Close by, it overlies a true, fine-grained quartzite (503). The contact is apparent in several places. Four rods south of this syenite, a considerable mass of quartzite is imbedded in syenite. Down the hill a few rods farther, we find a vertical ledge of gneiss including warped and broken sheets of a siliceous schist (pp. 186–187).

The succession in the vicinity of Penokee gap is given. Here at the south is found hornblende-schist and similar rocks 988 feet in thickness, which dip to the south, and then the Penokee series with 3,480 feet of strata dipping to the north, including, from south to north, vitreous quartzite, siliceous slates, magnetitic slates, and argillites.

The firmly accepted conclusion of the Wisconsin geologists in reference to the equivalency of the magnetitic and carbonaceous slates of the Penokee gap makes them a continuation of the hematitic schists of the Gogebic range. That is, they hold the formation in both regions to be Huronian. That the Gogebic iron-bearing strata are not Huronian, I feel prepared to affirm. And I can not resist serious doubts of their equivalence with the Penokee strata, which strongly impress me as holding characters strikingly similiar to those of the Huronian slates of lake Huron and the Animike slates of Gunflint lake and Thunder bay. This resemblance impressed me from the beginning; but I feel reluctant to controvert the judgment of the Wisconsin geologists.

But while I hold the decision in abeyance, I take the liberty to offer a few points for consideration:

(1) We discover the strong lithological resemblance referred to.

(2) The lithological characters are unlike those of the ore-bearing strata of the Gogebic, Marquette, and Vermilion regions.

(3) The ore also is magnetic instead of hematitic.

(4) It is diffused through the laminated sheets of the formation, as at Gunflint lake, and not segregated in lodes, as in the other regions mentioned.

(5) A higher system of black slates, apparently unconformable on the hematitic schists, appears to exist in the Gogebic and Marquette regions, as it certainly does in the eastward prolongation of the Vermilion schists.

(6) At the distance of 15 to 18 miles in a direct line SSE. of the Gogebic range, is a well known line of magnetic attractions, such as are exerted by the magnetitic schists of Penokee gap.

(7) These lines of attraction, though as far as I know they lie too far south, may nevertheless, when more accurately located, be found in the strike of the Penokee schists, especially if the great exposure a mile north of Penokee station affords a reliable indication of the strike; for that is S. 67° E. But this is probably disturbed somewhat by the great fault.

Should the Penokee slates be identified with the Animike (true Huronian) then the Marquette or Kewatin system will be found underlying, and the juxtaposition of the Penokee slates with the (supposed) Laurentian schists on the south, may be due to an overslide accompanying the formation of the great fault. If the dislocation resulted from a horizontal movement, instead of an upthrow, then the strata on the east side must have slipped southward over 900 feet; and, if the movement was confined to the Penokee slates, they may thus have concealed a thin representation of the Kewatin which, on the identification assumed, is at present, wanting at this point (pp. 194–195).

Our own observations as to the occurrences of the rocks south of the Aurora mine differ radically from those of the Professors Winchell. The granite south of the Aurora, described by N. H. Winchell as consisting of three parallel knobs interstratified with quartzite, was found to be granite cut by fine grained dike-rocks. Winchell's quartzite-slate is then a dike which cuts the granite. These dikes are separated from the granite by perfectly sharp lines, and their intrusive character is unmistakable. The granite is described as at once an eruptive rock and a conglomerate. This description is doubtless due to the fact that in the granite are dark colored obscure roundish areas which have a pseudo-fragmental appearance. These areas, composed largely of dark-colored minerals, are very common in the ancient granites of the Northwest and may be either actual fragments of the more ancient crystalline schists which have been caught in the granite at the time of its eruption and only partially absorbed, or they may represent segregations. The north face of the granite ledge is brecciated to a certain degree and its joints are filled with cherty and siliceous slates belonging to the base of the Penokee series. The granite surface is plainly one of erosion, and there is absolutely no evidence that the granite has been plastic subsequent to the formation of the slate. The phenomena are precisely those that are always present when a fractured and jointed granite constitutes the surface upon which a fragmental slate formation begins to be deposited.

If the above observations are correct, Prof. N. H. Winchell's conclusions that the granite acts the role of an eruptive rock, but was originally a conglomerate which flowed over the sedimentary strata, and that the granite is not of Laurentian age but is younger than the Animikie slates, are erroneous.

VAN HISE (C. R.). The Iron Ores of the Penokee-Gogebic Series of Michigan and Wisconsin. Am. Jour. Sci., 3d series, 1889, vol. XXXVII, pp. 32-48.

This article is a condensed advance account of what is contained in the present volume with reference to the position of the ore-bodies in the Iron-bearing member and their genesis. As the subject is treated fully in a subsequent chapter, an abstract of this paper will not here be given.

# CHAPTER II.

BY C. R. VAN HISE.

## THE SOUTHERN COMPLEX.



*General.*—The rocks south of the Penokee series (Pl. II) are exceedingly complex, both as to their lithological character and structural relations. They comprise, first, unmistakable eruptives, fresh and in various stages of alteration, including diabases, syenites, gneissoid granites, granites; and, second, many different varieties of gneisses and schists. There are large areas which contain only massive rocks, and other large areas which contain only schistose rocks, except for infrequent cutting basic eruptives; but between the different areas are zones in which are found mingled massive and schistose kinds and apparent gradations between the two. The foliations of the schists vary widely in dip and strike. More often than otherwise they are in rough conformity with the members of the overlying Penokee series; but this is true only in a very general way, the strike frequently being almost or quite at right angles to the strikes of those rocks. Further, the strikes vary widely within short distances, presenting a strong contrast in this particular to the rocks to the north. If this variation in strike is noticeable, the variation in dip is still more remarkable, inclinations in opposite directions frequently occurring within a short distance of each other. These abrupt changes in strike and dip clearly indicate that the series is one which has been closely crumpled.

This report is not primarily designed to cover the complex basement series. What follows is therefore of an incomplete and somewhat general character. It is chiefly a lithological treatment, and even as such is but an outline, the only reason for entering into the subject at all being to give a basis for comparison with the rocks of the Penokee series. Beginning at the west, each of the areas is taken up in order and the rocks contained briefly described.

*Geographical distribution* (Pl. II).—In Sec. 20, T. 43 N., R. 7 W., Wisconsin, as discovered by Mr. Charles E. Wright, late state geologist of Michigan, the rocks of the Copper-bearing series and a gneissoid granite belonging to the complex system under consideration, are found upon opposite banks of the Numakagon river. To the west of this point no rocks, aside from these, are known for a considerable distance; so that it may be considered that here is the westernmost point at which exposures belonging to the Penokee series proper will be found. The next exposures in the Southern Complex east of this locality are in Secs. 21 and 22, T. 44 N., R. 5 W., Wisconsin, this rock being a gneissoid granite. From here eastward to Bad river, in Secs. 14 and 23, T. 44 N., R. 3 W., Wisconsin, occasional outcrops of gneissoid granites are found. The Western granite then is one which extends east and west for more than 25 miles, and north of which is found the Penokee series. It may be that within this area rocks other than the gneissoid granites occur; for the known exposures are comparatively few, and if within it softer schistose rocks were contained, it is probable that they would not be exposed.

At Bad river, very close to the Penokee series, is a schistose rock. The fine-grained crystalline schists which here first appear continue without a break, so far as known, to the West Branch of the Montreal river, in the northwest part of Sec. 35, T. 46 N., R. 2 E., Wisconsin, another stretch of more than 25 miles. As in the gneissoid granite area to the westward, the exposures are very few, but in at least two places, at the Potato river and the West Branch of the Montreal, the basement layer of the Penokee series is seen in contact with the schists to the south. How far the green schists of this area extend south of the Iron-bearing series is not known, but the traverses have in places extended as far as two miles. At Penokee gap and eastward for some distance, a little way south of the Iron-bearing series, the granites and schists are found in the immediate vicinity of each other, the line separating them gradually swinging away from the Penokee rocks, leaving a wedge of green schist between the latter and the gneissoid granites. The eastern end of this green schist area also runs to a sharp point, the granite being found south of it five or six miles west of the point at which it reaches the Penokee rocks. The distribution of the granite east and west of the schists suggests that the two areas are connected. If this is the case, the Western green schist is an isolated area bounded on the south by the granite and on the north by the Penokee series.

The second granitic area extends immediately south of the Penokee series, from Sec. 35, T. 46 N., R. 2 E., Wisconsin, to about the middle of T. 47 N., R. 46 W., Michigan. At the latter point the schists again appear, and like those to the westward, widen out in a wedge-shaped area, leaving the granite as the southernmost known rock for quite a distance south of the second schist area. This granite area has many exposures in such close proximity to those belonging to the Iron-bearing series for the distance mentioned as to leave no doubt that it is here the basement upon which the former rests. While it is called a granite area, it contains large masses of rock of a more basic character, including both syenites and altered gabbros, the relations of which to the granites will be referred to subsequently.

East of this Central granite follows another schist area, running from near the middle of T. 47 N., R. 46 W., Michigan, to within a mile and a half of the east side of T. 47 N., R. 43 W., Michigan. The schists are in places nearly three miles wide, but throughout the entire distance, with the exception of two or three miles in the east half of T. 46 N., R. 44 W., Michigan, granitic rocks are known to lie to the south.

East of this Eastern green schist again appear granites and gneissoid granites which south of the Penokee rocks extend to Gogebic lake. What has been said about the connection of the Central granite and Western granite applies even more strongly to the Central and Eastern granites, which would perhaps have been connected if the country had been traversed a little farther to the south. The boundaries between the Eastern green schist and the adjacent granites are of a most irregular nature, and quite often in the same exposure both granitic and schistose rocks are found. The significance of these facts will be discussed later.

*The Western granite.*—The granites and gneissoid granites of the western area are classed together, as they differ but little from each other. The gneissoid granites vary in character from those so coarsely schistose as to be with difficulty distinguished from the granites to those which are extremely contorted and quite finely foliated. Although the area is large, the rocks included within it are petrographically of essentially the same character. The massive phases are relatively infrequent, and are medium grained granites. Those phases which are most foliated are somewhat finer grained. The rocks of the area vary from almost white to quite a deep red, depending upon the coloration of the feldspar, which mineral is the preponderating constituent, the iron-bearing silicates and quartz being usually in subordinate quantities, but not infrequently plentiful enough to give the rocks a strongly mottled appearance or even a dark gray color. The normal rocks of the area (Pl. XIV, Fig. 1), when examined under the microscope, are seen to be composed very largely of alkaline feldspars, including the species orthoclase, microcline, and acid plagioclase. The feldspar is usually in individuals of nearly uniform size which show more or less perfect idiomorphic outlines. With most individuals the average greatest dimensions are less than ½ mm., although occasionally individuals are found which run up to 4 mm. Frequently the feldspars interlock with each other, in which case the crystal outlines are more or less broken, although the regular forms are to some extent maintained. The only important iron-bearing silicates present are biotite and chlorite. These minerals occur at times included within the feldspars, but more frequently are found in the spaces between them. The chlorite often occurs in well defined blades having a rectangular extinction, and appears at times to be secondary to biotite, although often it is in part secondary to feldspar. Occasionally a little muscovite is found included within the feldspar. Quartz has been the last mineral to crystallize and has filled up the spaces left by those previously mentioned. It occurs in small roundish or irregular areas between the feldspars, giving the rock a completely interlocking crystalline character. In one or two cases the quartz and adjacent feldspar have a pegmatitic structure. This may signify that the quartz and feldspar in the final stages of crystallization were forming simultaneously, or that this is secondary saturating quartz. If the latter is true it becomes not impossible, although hardly probable, that the independent quartz in the interstices of the feldspar is a secondary material, in which case the original rock would have been a syenite.

All of the minerals are more or less altered. A kaolinitic decomposition has widely affected the feldspar. Less frequently chlorite and mica have developed within it, and the chlorite has further partly changed to epidote. But the most interesting decomposition shown by the feldspar is an alteration into quartz and biotite. This alteration has occurred to some extent in quite a number of the rocks, and is very clearly shown by the gneiss a short distance west of the south quarter post of Sec. 23, T. 44 N., R. 5 W., Wisconsin (Pl. XIV, Fig. 2) on Marengo river. Here the large individuals of feldspar have each decomposed in a great measure to the more basic mineral biotite, the excess of silica apparently separating as finely crystalline quartz, so that a single feldspar contains many score folia of biotite and grains of quartz. In certain parts of the section this decomposition has gone on until little or no feldspar remains, the result being a finely crystalline interlocking aggregate of quartz and biotite in place of a single grain of feldspar. In other words, a somewhat coarsely crystalline strongly feldspathic rock—the normal phase of granite—has changed to a finely crystalline gneissoid biotitic quartz rock. It is interesting to note in this connection that these are the identical changes which have, in the upper belt of the Penokee series, changed a feldspathic fragmental rock to a crystalline mica-schist.

*The Western green schist.*—The exposures within this area are comparatively few in number, particularly in its western half. The rocks are quite finely laminated, dark colored, fine grained, crystalline schists. They are, then, in strong contrast to the coarse grained granites and gneissoid granites to the westward. In different parts of the area they have very different characters, so that they can not be described together.

At Bad river the schistose rocks are technically all gneisses. They have a strike which is nearly conformable to the strike of the overlying Penokee series; but their dip is south instead of north, and hence they are not in conformity with that series.[1] The chief constituents of the gneisses are feldspar, quartz, hornblende, biotite and quite frequently magnetite, epidote being an accessory. In certain of the specimens biotite is absent and in others hornblende. The relations of the minerals are those ordinarily found in typical crystalline schists, which give little or no indication of their original condition. Some of the gneisses, however, show that the biotite has in a large measure been derived from feldspar. The alteration of each grain of the latter mineral to many folia of mica, with the simultaneous separation of quartz, presents exactly the appearance subsequently described (chapter VI) as characteristic of the fragmental feldspar rocks of the Upper slate belt, which there carried to the extreme has resulted in forming from a fragmental rock a completely crystalline mica-schist. There is this difference, however: In the Upper slate the crystalline schist was traced back into an unmistakable fragmental rock, while here the origin of the rock is unknown. In these gneisses much of the quartz and feldspar has a general roundish appearance, which suggests a fragmental origin. The hornblende-gneisses, upon the other hand, associated with these biotite-gneisses contain comparatively little or no quartz, a good deal of hornblende, and plentiful magnetite. The last are, then, rocks which are presumably schistose eruptives.[2]

Between Bad river and Potato river the country south of the Penokee series is low, swampy, and almost without exposure, so that little is known of the character of the rocks. One exposure of an obscure chlorite-gneiss is found in Sec. 5, T. 44 N., R. 1 W., Wisconsin, the only noticeable thing about which is the occurrence of a considerable quantity of tourmaline, a rather uncommon accessory in the crystalline schists of this district.

At Potato river, in contact with and just south of the Penokee rocks, large exposures of the underlying schistose rocks are found. They are here fine grained; some of them are nearly massive and others highly schistose. They are seen to contain, microscopically, many small grains or crystals of feldspar, roundish areas of chlorite, and sometimes large areas

[1] For detailed descriptions of the exposures here see Geol. Wis., 1880, vol. III, pp. 93-96, and p. 224.

[2] A. Geikie: Recent work of the Geological Survey in the Northwest Highlands of Scotland. Quart. Jour. Geol. Soc. London, vol. XLIV, 1888, pp. 387-399.

of calcite. They are of a mottled dark green color, and are more highly altered near the junction with the overlying rocks than farther to the southward. They can hardly be said to have any true strike and dip, but the fibers of the schist abut almost perpendicularly against the slates of the Penokee series, which here as usual dip northward. In thin sections these rocks are much altered, but they can perhaps best be named chloritic and hornblendic gneisses. A groundmass is always present, which consists of finely crystalline quartz, partly decomposed tabular crystals of feldspar, and areas of chlorite, with kaolin, epidote, sericite, and hornblende. Contained in this groundmass are larger complex and simple areas of quartz, many crystals of feldspar, including both orthoclase and plagioclase. Some of the latter are of large size. They often have roundish outlines, and include near their exteriors chlorite and magnetite. Magnetite in numerous crystals of small size, and calcite in large areas are contained as late formed secondary minerals, particularly in that part of the exposure near the overlying series. The appearance of these rocks is such as to suggest highly altered silicified porphyritic basic eruptives; but if they were porphyrites, the series of alterations through which they have gone has been of a very complicated character.

The exposures between these last described and the West Branch of the Montreal, although sparse, are more numerous than anywhere else in the area. They are essentially all of one class of rock—crystalline hornblende-gneisses, although in one or two specimens the feldspar is scant and these rocks might technically be called schists. Macroscopically the rocks are all dark green, fine grained, compact, yet finely schistose rocks. Their schistose structure is so close that in the field no proper strike or dip is in general obtainable. When examined in thin section they are seen to be as completely crystalline schists as any rock can possibly be. Their backgrounds are generally in about equal quantity finely crystalline quartz and feldspar, although each in certain sections becomes preponderant. The two minerals intricately interlock, both with each other and with themselves. In a majority of the sections in the background are larger grains of quartz and feldspar which have a roundish appearance. This feature is particularly characteristic of the quartz, although in each case the exteriors of the grains are minutely angular. A general oval form is also very marked with some of the feldspars (Pl. XIV, Fig. 3). The larger feldspars in the coarser phases of the rock are about $1^{mm}$ in greatest length. They are nearly all striated and have the appearance of this mineral in ordinary basic eruptives. Included in the feldspars are blades of hornblende and grains of quartz, the latter in some cases averaging not more than $\frac{1}{50}$mm in diameter. Manifestly either the feldspar has crystallized subsequently to the quartz and hornblende, or, and this is perhaps more probable, the decomposition of the feldspar has formed the hornblende and quartz. The appearance of the hornblende individuals both within and without the feldspars is such as to suggest that they are now in the process of growth (Plate XIV, Fig. 4). In general the feldspar is badly altered, so that it not only includes hornblende and quartz, but a gray decomposition product taken to be kaolin. When the alteration of a large feldspar has proceeded far, the area may consist of many detached particles of feldspar, included in which are large hornblendes and numerous quartzes. Unless examined closely this peculiar relation would not be noticed and the area would be concluded to be an intricately interlocking one in which the particles of feldspar are independent, as they are recognized only as a skeleton of a single feldspar when closely examined in polarized light. The hornblende is of the pale green variety; it has normal pleochroism and extinction. The individuals do not have well defined outlines, but fray out in every direction in ragged stringers (Pl. XIV, Fig. 4). This is especially noticeable in sections cut parallel to the vertical axes, but is also distinctly seen in transverse sections. If this mineral was the first to crystallize, as must be the case if all those individuals now present are original crystallizations, the exceedingly ragged forms are inexplicable. If, upon the other hand, the hornblende is a product which has formed subsequently to the feldspar, these are precisely the forms which would be expected. It thus seems probable that these rocks are much altered ones which originally contained much more feldspar than at present; perhaps those containing hardly any feldspar being as feldspathic as those of the gneiss which contains a large amount of this mineral. In some of the sections biotite is as abundant as the hornblende. It is intimately associated with that mineral and bears the same relation to the feldspar that the hornblende does. Magnetite in small areas and crystals is plentiful in some of the sections. It is scattered quite uniformly throughout all the minerals as though it were the earliest present. The secondary minerals—epidote, sericite and chlorite—are at times in quantity. The character of these hornblende-schists and gneisses gives no certain clew as to their origin. With almost equal plausibility, taking the rocks of this area alone, a case could be made out for their derivation from fragmental sediments or from eruptive rocks.

At the West Branch of the Montreal a somewhat peculiar rock occurs. In thin section chlorite in an almost solid mass composes a large part of the sections. Calcite and quartz, with a little magnetite, are included in this chlorite as subordinate constituents. Actinolite is the only remaining mineral of importance. When cut perpendicular to the vertical axis or approximately so, it shows crystal outlines, in which case its prismatic cleavage is nicely developed. When cut parallel to the vertical axis each individual of actinolite terminates in many long needle-like points, which penetrate deeply into the chlorite. Sometimes the actinolite blades are clustered into sheath-like forms. The perfect freshness of this mineral and its deep penetration of the chlorite indicate that the actinolite is of a secondary character.

*The Central granite.*—The granitic area east and west of the Montreal river is a large one, but it has not been sufficiently traversed to find a great number of exposures. The rocks are always coarse grained and are sometimes massive, although more often they have the structure of granitoid gneisses or coarse gneisses with a well developed foliation. The rocks here included vary greatly in their chemical composition, running from granites to gabbros. The three chief types of rock are the granites (including one micrognanite), the syenites, and the gabbros.

The granites have their large development east of the Montreal river. They vary in exposure from massive granites to granitoid gneisses; in texture they are always moderately coarse and evenly granular; in color they vary from almost white to deep flesh color. Feldspar is usually the preponderating constituent, although both quartz and the iron-bearing silicates are often abundant. (Pl. xv, Fig. 1.) Under the microscope these rocks are found to be in almost every particular like those of the Western granite already described, except that hornblende takes the place of biotite, so that this mineral and chlorite are the chief constituents aside from the quartz and feldspar. The hornblende of the ordinary variety is found in large well developed blades and crystals. It is at times included within the feldspar, but in general it is between different individuals of that mineral, although even here the relations are such as to show that the feldspar has accommodated itself to the hornblende. This must mean that if the hornblende is an original mineral it was the first one to crystallize. Its pleochroism is: $\mathfrak{c}$, dark bluish green; $\mathfrak{b}$, dark yellowish green; $\mathfrak{a}$, light yellow; absorption, $\mathfrak{c}$ about equal to $\mathfrak{b} > \mathfrak{a}$. The chlorite of the rocks, where it is found instead of the hornblende, bears the same relation to the feldspar that the hornblende does. In some of the sections the chlorite is in part secondary to hornblende and it may all be of this derivation.

Constituting an exception to the granites just described is an exposure of microgranite found in the NE. $\frac{1}{4}$ of Sec. 27, T. 47 N., R. 47 W., Michigan. Macroscopically it has an aphanitic background which contains simple and complex areas of varying sizes, consisting of coarse individuals of feldspar, a dark colored mineral, and quartz. In other words the background includes many areas which have a true granitic texture. These complex areas of greatly varying sizes are included in the most irregular fashion. More abundant than these are single porphyritic crystals. In thin section the background is very fine grained, and apparently consists of intricately interlocking quartz and feldspar. As indicated by the hand specimen it contains numerous roundish areas consisting of large individuals of quartz and feldspar, with quite a quantity of chlorite, each mineral occurring separately and together in complex, intricately interlocking areas. Quite a number of the single individuals of quartz show plainly an interrupted growth, which gives each grain an appearance like that of enlarged quartzes met with in fragmental rocks. Here this doubtless means that the cores belong to a first generation and the enlargements to a second generation of crystals. The porphyritic feldspars include orthoclase, microcline, and plagioclase. This rock differs from any which I remember to have seen. In most cases in which crystallization has thus occurred in two generations only detached porphyritic crystals are contained in a finer grained matrix. Here, however, large and small complex areas having the appearance both macroscopically and microscopically of an ordinary granite are contained in a matrix of exceedingly finely crystallized material. If this difference in the character of the coarse and fine parts is taken to mean that the coarser part crystallized at depth and the latter after a change of condition and near the surface, the conclusion would be that the crystallization had proceeded much further than usual in porphyries before the change in condition occurred. And, if this is so, the specimen throws some light upon the manner of crystallization of granites. In the development of the minerals in massive igneous rocks, it is usually assumed that the crystallization of the different species is in the main successive, although to some extent simultaneous. It would appear that in this rock, while this may be to a small degree true, it is certain that before the change of condition occurred all of the minerals found in a granite had begun to develop, and in such a fashion as to make small masses of perfect granite. These masses of granite, associated with simple individuals of quartz and feldspar, were separated from each other by the liquid magma in which they were contained. After the change of conditions the magma rapidly crystallized, thus preserving the individuals and clusters of individuals which had before formed. If the growth had continued without a change of conditions, the simple and complex areas would probably have formed larger and larger masses of granite until the whole space was occupied. This implies that in the outward growth of each mass all of the minerals which go to make up a granite separate from a magma in which these same minerals have before developed in such relations to each other as to have for short distances the typical structure of a deep seated crystalline rock. This manner of growth differs radically from that first mentioned as the ordinary conception of the crystallization of igneous rocks.

The exposures west of the Montreal river, and a few of those a short distance east of it, are of a more basic character than the granites. The rocks here included are syenites and gabbros, the latter being much altered. The granites east of the Montreal differ in acidity. In content of quartz they vary from a normal rock to one in which the quartz is distinctly subordinate to the other constituents, and which might with equal propriety be classed as a granite or a syenite. The syenites west of the Montreal river are even more basic than this rock (Pl. xv, Fig. 2), containing little or no quartz They have a well developed, coarse foliation, and were regarded in the field as coarse gneisses rather than syenite-schists. The specimens vary from mottled red and black to black, depending upon the quantity of the iron-bearing silicates present and the color of the feldspar. When examined in thin section, they are found to be very much coarser grained than would have been suspected from the hand specimens. They contain as a background large—upon an average, 2 mm. in diameter—closely fitting and interlocked individuals of alkaline feldspar comprising the three species, orthoclase, microcline, and plagioclase. So far as seen, the schistose structure of the rock does not in any measure affect these feldspars. In the centers of some of the larger orthoclases, in irregular areas, the microcline twinning is developed. This peculiar appearance indicates either that one of them may alter into the other or that in their growth one has enveloped the other. In most of the syenites the abundant mineral, aside from the quartz, is hornblende accompanied with a considerable quantity of biotite and chlorite. The hornblende is in well defined blades and crystals and the biotite in its usual broad leaflets. Sometimes transverse sections of hornblende show almost perfect crystals which exhibit the prismatic faces or these combined with the orthopinacoids. If these minerals are original crystallizations, they must have formed before the feldspars. If they are secondary, they must have developed within the feldspars. The strongly marked schistose structure characteristic of the rock is wholly due to the arrangement of the hornblende and biotite minerals, the larger blades usually having their greater lengths in a common direction. In places they are massed together in large areas so as to wholly exclude the feldspar. At times a single blade of biotite or hornblende cuts through several individuals of feldspar. The hornblende of these rocks is somewhat abnormal in its optical character. It has strong relief and gives very brilliant interference colors. The angles $c : \mathfrak{c}$ run as high as 21°. Its pleochroism is: $\mathfrak{c}$, bluish-green; $\mathfrak{b}$, yellowish-green; $\mathfrak{a}$, pale honey yellow; $\mathfrak{b} \geqq \mathfrak{c} > \mathfrak{a}$. Differing from these hornblende-syenites is a mica-pyroxene-syenite, the pyroxene in this case replacing for the most part the hornblende. This rock is like the other syenites in all other points, and the relations of the mica and pyroxene to the feldspar are the same as those of the hornblende and biotite in the mica-hornblende-syenites. This rock also carries some hornblende, but in subordinate quantity. In some cases the biotite seems to be forming as a secondary product from it. The pyroxene is colorless, strongly doubly refracting, and from its optical properties is taken to be malacolite. It is generally in roundish granules in cross-section, and in blades several times longer than broad in longitudinal section. Many of the biotite blades are much distorted. All of the syenites contain very numerous, large, well formed crystals of apatite, which are included in all of the other minerals.

Not very far in basicity from these syenites are coarse, altered gabbros, which in large exposures are closely associated with them. In the field and in hand specimen they do not differ greatly in appearance from some of the syenites just described. Their feldspars have a reddish cast, as in them, and their structure is much the same. However, when they are examined in thin section they are seen at once to be altered basic eruptive rocks of the ordinary type. The chief original constituents are plagioclase, magnetite, and diallage, which have relations characteristic in a rock intermediate in structure between a diabase and a gabbro. The plagioclase has altered very extensively to chlorite and kaolin, and is in many places replaced to some extent by saturating quartz. The magnetite occurs in well defined areas and crystals, which give no evidence of alteration, it being the only mineral within the rock which is unaffected. The pyroxene has very largely decomposed, the resultant products being hornblende, biotite, and chlorite, more largely the first. It is a very noticeable thing that the secondary hornblende is not paramorphic but several or many blades have formed which are in crystallographic position independent of the original augites, and much of this hornblende in its forms is like the hornblende contained in the syenites just described. As a result of the complete decomposition of the diallage, hornblende and biotite are formed with their axes arranged quite often in a common direction. In this case these minerals, in their appearance and relations, are much like those of the same minerals in the associated syenites. It is further noticeable that these rocks also contain numerous large, well formed crystals of apatite. Considering all of the foregoing facts, it is quite probable that the gabbros, syenites, syenite-schists, and possibly the granites are parts of the same continuous rock-mass.

*The Eastern green schist.*—The shape of this area will be seen by examining Pl. II. The exposures contained are very numerous, and the rocks within a certain narrow range have great variety. While quite large subareas contain only a single phase of rock, they grade into other areas containing rocks of a different character, and even a single exposure frequently contains quite dissimilar rocks. This confusion is so great that no attempt will be made to subdivide the area into smaller ones, each containing a definite phase of rock, nor will any attempt be made to explain the field relations of the different phases. The rocks here included may all be technically classed under one general term—gneiss—although perhaps some of them might better be called syenitic schists and most are fine grained green crystalline schists. In these gneisses, aside from the quartz and feldspar, any one of the minerals hornblende, biotite, chlorite, sericite, or epidote may be the additional chief constituent, while often two or more are equally abundant. Consequently the area contains hornblende-gneiss, biotite-gneiss, sericite-gneiss, chlorite-gneiss, epidote-gneiss, and various intermediate phases. The rocks vary greatly in coarseness, running from those that are so exceedingly fine grained that it is with extreme difficulty that the minerals are determined, to rocks which approach a granitoid gneiss. It is noticeable that the coarser grained phases are mostly found near the granitoid gneiss areas. In fact the line forming the boundary between this schist area and the surrounding granite and gneissoid granite areas is arbitrarily drawn. As the granite area is neared the schists become coarser and coarser, grading into a coarse gneiss. The change is so gradual at the east end of the area that the boundary between the gneisses and granites would probably not be put by another observer in the same place as mapped. The principle followed in our mapping is to include within the schist area all rocks which in hand specimen do not have a strong granitic appearance. While there is this change, it is not a passage which is made out in any case by actually tracing a finely schistose rock-mass in continuous exposure into a granite, but the various phases are presented by numerous detached exposures. Aside from this apparent passage, the fine grained schists adjacent to the granite area not unfrequently contain massive granite. This granite is sometimes found as a boss upon which the schist rests, but more often constitutes one part of an exposure, the schists cut by it composing the other part (Fig. 3). In some places the manner in which


FIG. 3.—Schist cut by massive granite, NW. ¼, Sec. 4, T. 46 N., R. 2 E., Wisconsin.

the granites cut the schists is such as to leave no doubt of the eruptive character of the latter (Fig. 4).


FIG. 4.—Schist cut by granite, NE. cor. Sec. 28, T. 47 N., R. 45 W., Michigan.

Macroscopically the gneisses of the area are light gray to very dark green. They vary in coarseness from aphanitic to the texture of a gneissoid granite. In all of the rocks a schistose structure is very strongly developed. In the coarser gneisses the foliation is marked in hand specimen and in exposure, but in the finer grained varieties it is often only exhibited by a readier cleavage in one direction. The different phases described under the microscope differ from each other but little macroscopically. Some of the syenite-schists are an exception to this statement in that they approach in structure to a basic eruptive.

One of the most characteristic and abundant phases of schist, as seen in thin section (Pl. xv, Fig. 3), is that which has a white granular background composed of quartz and feldspar. The proportions of these two minerals vary widely in the different specimens, running from those in which quartz is preponderant to those in which the feldspar almost entirely excludes that mineral. The individuals of each of these minerals in this background are approximately of uniform size in each section, although varying widely in different sections; in general they have roundish or oval forms. The particles of the two minerals fit each other very closely, but do not intricately interlock. The effect of this even grained background composed of roundish particles is to suggest a fragmental origin, but nowhere is there any conclusive evidence that any of the material is of fragmental character. If the grains represent fragments they could not have thus perfectly fitted each other as originally deposited, and nowhere is there any proof of enlargement in either the quartz or feldspars, and there is no space between them for a fine grained interstitial material; so this granular structure can not be taken as proof of fragmental origin.

The feldspar is very largely of the species orthoclase, although microcline and plagioclase are often abundantly present. It has usually largely altered, the resultant products being kaolin, sericite, chlorite, epidote, and at times biotite and hornblende. This alteration is sometimes certainly, and probably often, attended with the simultaneous separation of quartz. This decomposition in the cases when it has extended far enough results in producing in the place of a feldspar a complex interlocking mass of finely crystalline material. In a few cases in which the gneiss was originally strongly feldspathic the alterations have caused it to closely resemble some of the feldspathic graywackes of the Upper slate member of the Penokee series (chapter VI). As mentioned in the case of a similar occurrence in the Western granite there is, however, the great difference that no evidence can here be found that the original feldspathic rock was of a fragmental character.

The abundant iron-bearing minerals of the gneiss are hornblende, biotite, and chlorite. Less frequently epidote, sericite, and calcite occur. In a single section any one of these minerals may be predominant; two or more, or all of them may occur together. There seems to be absolutely no regularity as to their occurrence, either in the field or in the sections themselves. Hornblende is, however, the preponderant mineral in many sections, although chlorite and biotite are hardly less frequently so. In the coarser grained gneisses (Pl. XV, Fig. 4) the hornblende often occurs in large, well defined crystals, which in transverse sections show either the planes of the prism or the planes of the prism combined with the macropinacoids. The terminal planes are not often well developed. The pleochroism of the hornblende is very uniform; $\mathfrak{c}$ dark greenish blue, $\mathfrak{b}$ dark green, $\mathfrak{a}$ honey yellow. The absorption is: $\mathfrak{b} \geq \mathfrak{c} > \mathfrak{a}$; $c : \mathfrak{c}$ varies from 13° to 15°. The hornblende individuals always include many grains of the other minerals present, usually more quartz and feldspar than of chlorite and biotite. It apparently shows by its inclusions, combined with its idiomorphic forms, that it was the last mineral to crystallize. Its growth within these gneisses may be compared to the growth of crystals of garnet and staurolite in staurolitic and garnetiferous mica-schists, which frequently include large quantities of foreign materials. In its development, if a late mineral, it took within itself such material as it could not force aside. More often in the gneisses the hornblende is in small blades free from inclusions, located between the particles of quartz and feldspar or else penetrating them

The biotite and chlorite occur in well developed folia, and in small fibers and irregular areas. Each of these minerals is in turn in quite a number of the exposures the chief constituent aside from the quartz and teldspar. Each frequently contains numerous smaller particles of what is taken to be oxide of iron, which are arranged within their parts in the same regular manner. A portion of the chlorite and biotite is certainly secondary to feldspar and hornblende. This is particularly true of the chlorite. However, there is no evidence that their abundant, well defined blades are secondary. The epidote, so plentifully present at times, is found alike in the feldspar, chlorite, hornblende, and biotite, although most common in the first two. It occurs in numerous small granules and large irregular areas. A large part of it is certainly derived from feldspar, chlorite often being an intermediate stage in its formation. It also has formed from hornblende. In some of the rocks the epidote is with quartz the chief constituent and the rock consequently is an epidosite. There is here no evidence of the derivation of the epidote from feldspar, hornblende, and chlorite, but it may be true that the rocks in which the origin of the epidote is plain is an intermediate phase in the formation of the epidosite. The other accessories most frequently present in the gneisses are pyrite and iron oxide; tourmaline is rarely found.

In general the hornblende, biotite, and chlorite are largely in the spaces between the quartz and feldspar, but they also are extensively included within them, a single individual of one of these minerals perhaps penetrating several particles of quartz or feldspar, or both. Usually the chlorite, biotite, and hornblende are arranged with their axes more or less regularly in a common direction. Sometimes this arrangement is but imperfect, while in other cases the parallelism is remarkable, the fibers of the many individuals lying almost exactly parallel with each other. When this parallelism is so marked it is sometimes the case that the quartz and feldspar particles are elongated in the same direction. This elongation of all of the minerals in such a case doubtless indicates that the rocks have been subject to great dynamic forces.

Within these evenly granular gneisses are quite often larger grains of quartz and feldspar, which have very distinct oval outlines. This is particularly true with reference to the large quartz grains (Pl. xv, Fig. 3), although when examined closely they are seen to be minutely angular. As in the roundish grains of the quartzose background, no proof has been found that the quartzes are of a fragmental character.

By a gradual lessening of the quartz in the hornblende-gneisses they pass into a rock in which the chief constituents are hornblende and an alkaline feldspar. These rocks might perhaps better be named syenite-schists. In the cases of some of them the hornblende is very abundant; the feldspar closely interlocks, and they contain many areas of black iron oxide, which is doubtless menaccanite, as it is generally surrounded by a brilliantly polarizing reactionary ring supposed to be titanite. These feldspar-hornblende-menaccanite rocks in their mineralogical character are identical with the syenites.

They have not, it is true, in any case been traced in continuous exposure to a rock which has the genuine syenitic texture, but considering the fact that it has been proved that this class of rocks is in certain cases derived from basic eruptives, it becomes possible that these syenitic schists are of this origin.

A second phase of hornblende-gneiss found abundantly in this area is exactly like the hornblende-gneisses already described and illustrated (Pl.

XIV, Figs. 3 and 4) between the Potato river and the West Branch of the Montreal (pp. 109–111).

They will, then, not be described in detail here again. It will be remembered that they contain numerous large plagioclase feldspars, within which are blades of hornblende and particles of quartz. In case the feldspars are large and the alteration has proceeded far, within a single individual may be found many grains of quartz and blades of hornblende. It will also be remembered that the hornblendes have peculiar jagged terminations, which are shown in a marked degree when the sections are longitudinal, but are also observable in transverse sections. It was noted that they might, with almost equal plausibility, be regarded as of eruptive or sedimentary origin. In the Eastern green schist these rocks have, however, been traced step by step into those which are almost certainly of an eruptive origin. This rock in hand specimen in one case is massive, and has strongly the appearance of a massive basic eruptive. Within the same exposure are other phases of rock which have the distinct foliation of the hornblende-gneisses of the region. These rocks and others within the locality under consideration have almost no quartz, the background being composed of large areas of feldspar, which intricately interlock. Between these feldspars and in them are many hornblendes of varying sizes, individuals frequently being large. They have the same jagged outlines which are characteristic of the hornblende already alluded to. The sections also contain much comparatively fresh magnetite. There can be little doubt that this massive rock is a modified eruptive, or that the schistose one from the same exposure is of the same character. As there is every phase of gradation between this massive rock and those schistose ones in which there is a large amount of quartz present, it is exceedingly probable that all of this class of hornblende-schist is eruptive, although, as before, I would guard myself by saying that we have no absolute proof of this.

Between the two main kinds of rock above described there are all intermediate phases.

Besides these phases of rock there are many subordinate varieties. It is worthy of remark that in one of the fine grained schists which is found in large exposures a background of very finely crystalline quartz and chlorite contains minute tabular crystals of feldspar. In this matrix are found large, much altered crystals of the same mineral. Menaccanite and leucoxene are also abundant in small granules. These rocks would be regarded ordinarily as modified porphyrites, although in the field and in hand specimen there is the strongest possible foliation. In character they are allied to some of the various finely crystalline quartzose gneisses which stand intermediate between the two main phases described.

*The Eastern granite.*—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.

Included in each of the foregoing areas are here and there exposures of fresh diabases. These rocks in every particular are like the diabases so abundantly contained as dikes in the Penokee series, and no doubt were contemporaneous if not actually continuous with them. The description of these rocks is given in Chapter VII.

*Summary.*—The kinds of rock mentioned in the Southern Complex are not necessarily all which may there exist, for the traverses were not frequent enough to find more than a fraction of the exposures. The narrow range in the lithological character of the granite is very noticeable. Three large areas of rock, in which the easternmost exposures are fully 90 miles from the westernmost ones, are alike in every important particular. This likeness of character suggests, as does also their distribution, as seen in Pl. II, that these areas are really connected. It is also suggestive that a like condition of affairs prevailed for a very considerable distance at the time of the formation of these rocks.

A summary of the more important characters of the granites and granitoid gneisses is here given. An alkaline feldspar is always the chief constituent, while in the majority of cases it composes three-fourths or more of the rocks. Moreover, a very large proportion of this feldspar is of the species orthoclase, although microcline and acid plagioclase are always present and often plentifully. There is a very marked tendency in these feldspars to idiomorphic forms. In some cases in which the feldspar is predominant this tendency is so strong that the rock might be described as panidiomorphic. This characteristic of the granites and syenites is shown both in hand specimen and in thin section. Quartz varies in quantity to an amount about equal to that of the feldspar. When the quartz is not plentiful it is in part so arranged with reference to the feldspar as to suggest that it might be of secondary origin. This suggestion is reinforced by the fact that occasionally the feldspars near their exteriors contain saturating quartz. This pegmatitic structure may be due, however, to the simultaneous crystallization of quartz in the final stages of the formation of the feldspar.

Further, it does not appear probable that all the quartz found in these rocks is a secondary product, for in the most acid of them the feldspar and quartz interlock in the irregular fashion characteristic of ordinary granites. In the massive granites the only other important constituents are hornblende, biotite, and chlorite. The hornblende quite often occurs in well defined crystals. The chlorite frequently imitates the forms of the hornblende. The biotite is in well developed, sharply outlined blades. These minerals are ordinarily between the feldspars, but bear such relation to them as to suggest that the feldspars have adapted their forms to these minerals rather than the reverse. Not infrequently each of them is included in large blades or crystals in the feldspar. It follows from these relations that the hornblende and biotite were earlier than the feldspar, or else that these minerals have developed subsequently to the consolidation of the rock.

The most important fact developed by the study of the Southern Complex is the apparent gradual change between the massive rocks and the schistose ones. These gradations have already been alluded to. It will, then, here only be necessary to remember that the lines separating the granites and the gneissoid granites from the fine grained gneisses and schists are more or less arbitrary. In the field the massive granite, gneissoid granite, granitoid gneiss, coarse gneiss, and fine grained gneiss are sometimes found in order in passing from a granite into a schist area. This change has not been found in continuous exposure, but in detached ones. More frequently a different relation is found, the fine grained crystalline schists being cut by massive granites in such a manner as to leave no doubt of the eruptive nature of the latter. In passing from a schist to a granite area, there first appears cutting the schists rare small veins and stringers of granite; then the granite is found in dike-like forms or in masses and bosses within the schist. Next, the granite becomes predominant, and finally the schists altogether disappear as we get wholly within a granite or gneissoid granite area.[1] The old interpretation placed on such apparent transitions from finely schistose to massive rocks has been that metamorphic agencies have transformed the crystalline schists into the massive granites. It has been taken for granted that the strongly schistose, finely laminated phases must be of sedimentary origin. This being the case, their gradation into massive rocks was taken as proof of the derivation of the latter from the former by metamorphosing agencies; that is, moisture, heat, and pressure have recrystallized the rock, giving it a coarsely crystalline granitic structure in place of the finely crystalline schistose one. This interpretation is based upon the assumption that the strongly foliated schistose rocks are of sedimentary origin. If this is unprovable the conclusion is valueless. At the present time this derivation of massive syenites and granites from schistose rocks by metamorphosing agencies is greatly discredited. It is almost universally believed that massive granites, syenites, and gabbros are of eruptive origin. If this is assumed, there seems to be no escape from the conclusion that a large proportion of the crystalline schists and gneisses of the area were originally eruptives.

[1] These relations are similar to those described by Dr. Andrew C. Lawson, of the Canadian Geological Survey, as occurring between the Keewatin and Coutchiching series, and the associated Laurentian granites and gneisses. Report on the Geology of the Rainy Lake Region, Andrew C. Lawson, Annual Report of the Geological and Natural History Survey of Canada for 1887, Alfred R. C. Selwyn, director; part F, pp. 1–182. In this paper Dr. Lawson maintains that the granite which is associated with and cuts the schist has been produced by the fusion of the schists, thus changing them to truly igneous rocks.

Still further, it has been seen that the syenites in the same exposure vary into syenite-schists; it has been seen that the granites vary into granitoid gneisses; and the nature of the mineral changes which explain this variation has been given. The coarser grained syenite-schists are found, by examining them in thin section, to have a background composed of closely interlocking feldspar precisely like the massive syenites. The foliation of these rocks is due to the biotite and hornblende. The large blades of these minerals, arranged with their axes in a common direction, are within the feldspars, many blades often being included within a single individual of that mineral. The relation is such in many cases as to make it almost certain that these minerals have developed within the feldspar as secondary products. The pressure to which the rocks were doubtless subject during the time of the growth of these minerals probably influenced their arrangement. The alteration of a massive feldspathic rock has produced a foliated micaceous or hornblendic one. When this alteration of the acid feldspar to the more basic minerals, biotite and hornblende, has been accompanied by the simultaneous separation of quartz, the result is a crystalline gneiss. Phases of strongly foliated rocks are found, from those which contain no quartz—that is, a syenite-schist—to those in which quartz is as abundant as the feldspar, when the rock is a gneiss. In the fine grained syenites and schists, in which the feldspar occurs in small roundish grains, there must have been a recrystallization of the feldspar itself if these rocks are transformed massive eruptives, which is by no means certain.

The question as to whether any of the crystalline schists and gneisses of the region are of fragmental origin can not be answered. The roundish, evenly granular appearance of the quartz and feldspar in many of them strongly suggests upon casual examination a clastic origin. However, the more closely they are examined the more clearly it is apparent that this is not sufficient evidence of a fragmental character. It has been noted that in the gneisses of this class the individuals fit each other perfectly. The grains as fragmental ones could not possibly have thus been deposited. If fragmental, either they must have recrystallized or else have been enlarged until they interlocked. Each of these processes and both combined are now known to transform fragmental rocks into crystalline ones; but in order to prove that such a transformation has occurred, it is necessary to show that the rock in which they have been found to occur was a fragmental one. The rounded cores in a quartzite are sufficient to show this, but in the case of a recrystallization of feldspar it is necessary actually to trace the crystalline rock back to its fragmental state. The modified fragmental rocks of these kinds in the Penokee series reveal themselves as such with little difficulty. Upon succeeding pages it is remarked that whenever quartz is present in them as a fragmental constituent, even if associated with quartz not of this origin, it is easily discovered. Its original outlines are so strongly marked by particles of gas, iron oxide, and other inclusions that all subsequent changes seem inadequate to obliterate them. While this is the case with these known fragmental rocks, the complete absence of anything which suggests that there have been cores in any case in the sections of the crystalline schists loses largely its force as negative evidence against a fragmental origin; because the fragmental rocks mentioned are nowhere foliated, while the schists are strongly foliated. Fragmental rocks in other districts which have been subject to dynamic forces, and have therefore become foliated, have rapidly lost evidence of their original fragmental character.

To conclude, if the massive, coarsely crystalline rocks are assumed to be of eruptive origin, it necessarily follows that a large number of the schistose ones are certainly derived from them; also, it has not been possible to trace any of these crystalline schists back to a fragmental rock.

# CHAPTER III.

By R. D. Irving and C. R. Van Hise.

## THE CHERTY LIMESTONE.

Relation of the limestone and chert. Geographical distribution. Possible former greater continuity. Thickness. Petrographical character of the limestone. Petrographical character of the chert. Change to the overlying Quartz-slate. Tabulation of petrographical observations. Prominent exposures. Origin of the limestone and chert. Summary.

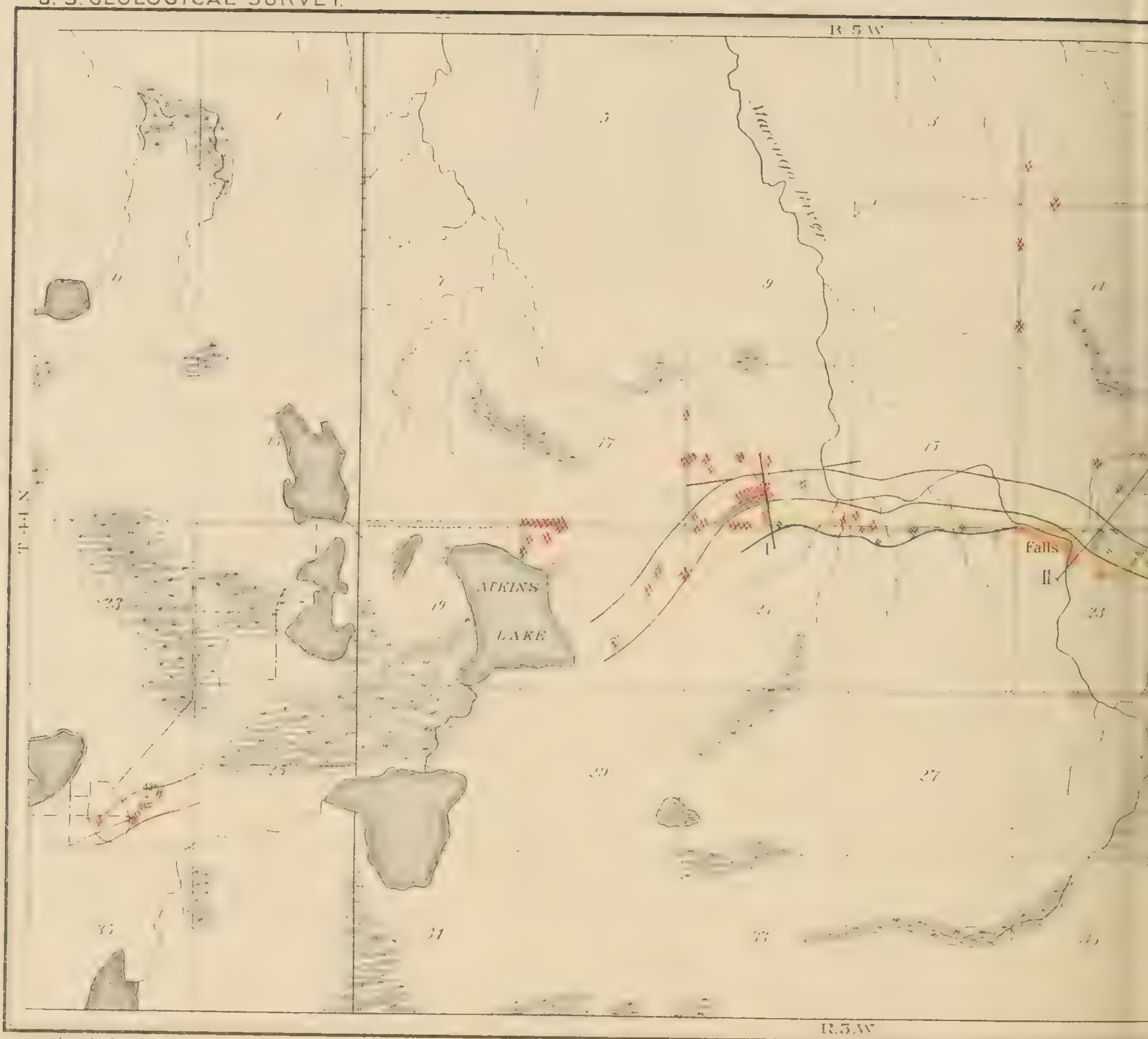
*Relation of the limestone and chert.*—In the third volume of the Geology of Wisconsin (pp. 104, 106-108), and on Pls. XXIII to XXVI of the atlas accompanying that volume, the lowest member of the Iron-bearing series of the Penokee district is represented as being a tremolitic crystalline limestone, with an average thickness of 90 feet, above which is said to succeed a peculiar white quartzite, with an average thickness of 40 feet. These two layers, though occasionally wanting altogether, as indicated on the maps referred to, are represented as having a considerable longitudinal extent and as being separate from one another; that is to say, all of the white quartz is taken as lying above all of the limestone.[1] That this is the case was concluded particularly from the exposures seen at Penokee gap, where such a succession is very manifestly the true one, as indicated on Pl. XXVI of the Wisconsin atlas. Our later investigations, and more particularly our experience on the Michigan side of the Montreal river, have shown us, however, that in fact these two rocks form portions of one and the same layer; that is to say, that the white quartz, or chert, as we now think it should more properly be called, occurs as a rule interstratified and thinly interlaminated with the limestone. Taken together, these two ma-

[1] However, a doubt was expressed (Geol. of Wis., vol. III, 1880, p. 110) as to whether the limestone exposures in the western part of the Penokee district might not represent both limestone and chert as seen at Penokee gap.

terials constitute a well marked belt, which is sharply separated, not only from the granites and schists to the south of it, but also from the fragmental slates immediately above, from which it differs in being almost free from an intermixture of fragmental material.

*Geographical distribution.*—It is difficult to define very accurately the geographical distribution of the limestone member. Certainly in a number of places it is entirely wanting, since the strongly marked slate belonging immediately above it is found directly in contact with the granites and schists which belong below it. When the atlas sheets of the Geology of Wisconsin were drawn, this belt was represented as having a greater degree of continuity than is indicated on the maps that accompany the present volume, exposures distant from one another having been relied on to indicate a continuity, so that, substantially, this member was represented as continuous except where it was certainly known to be wanting. Our later experience having taught us that this member may thin out and disappear quite suddenly, and that it is lacking more often than was formerly supposed, we have pursued just the opposite course in mapping it; that is to say, we have mapped it as occuring only in those places where exposures demonstrate its existence.

The detailed maps of Pls. V, VI, VIII, X, XII, and XIII of the present volume, which show the exact positions of all of the exposures belonging to the various belts of the Penokee series, will serve to indicate to the reader the exact facts which we have had at command in deciding as to the degree of continuity possessed by this member. This member then is indicated on our maps as appearing in six detached portions in the distance between Atkins lake, T. 44 N., R. 5 W., Wisconsin, and the Little Presque Isle river, T. 47 N., R. 44 W., Michigan. Beginning with the westernmost of these areas, it is to be said that, so far as our knowledge goes, it may extend some miles farther west than the maps indicate, since we are without exposures to prove either its continuity or its absence. The eastern end of this westernmost area, however, is sharply defined by actual exposures, as indicated on Pl. V, the granite and siliceous slate member of the iron series coming directly into contact with one another along the course of the Marengo river, in the SW. ¼ of Sec. 15, and NW. ¼ Sec. 23, T. 44 N.,





KEWEENAW SERIES.

Exposures of eruptives.
South limit.

PENOKE

Upper Slate Member.

North limit.
South limit.

Iron-bearing Member.

Exposures of ferruginous schist.
Limits of surface distribution.

Quartz-S

Sl. Exposur
Q. Exposure
South limi

Exposures showing strike and dip. Exposures showing no structure.

Scale of Map 1 inch = 1 mile.

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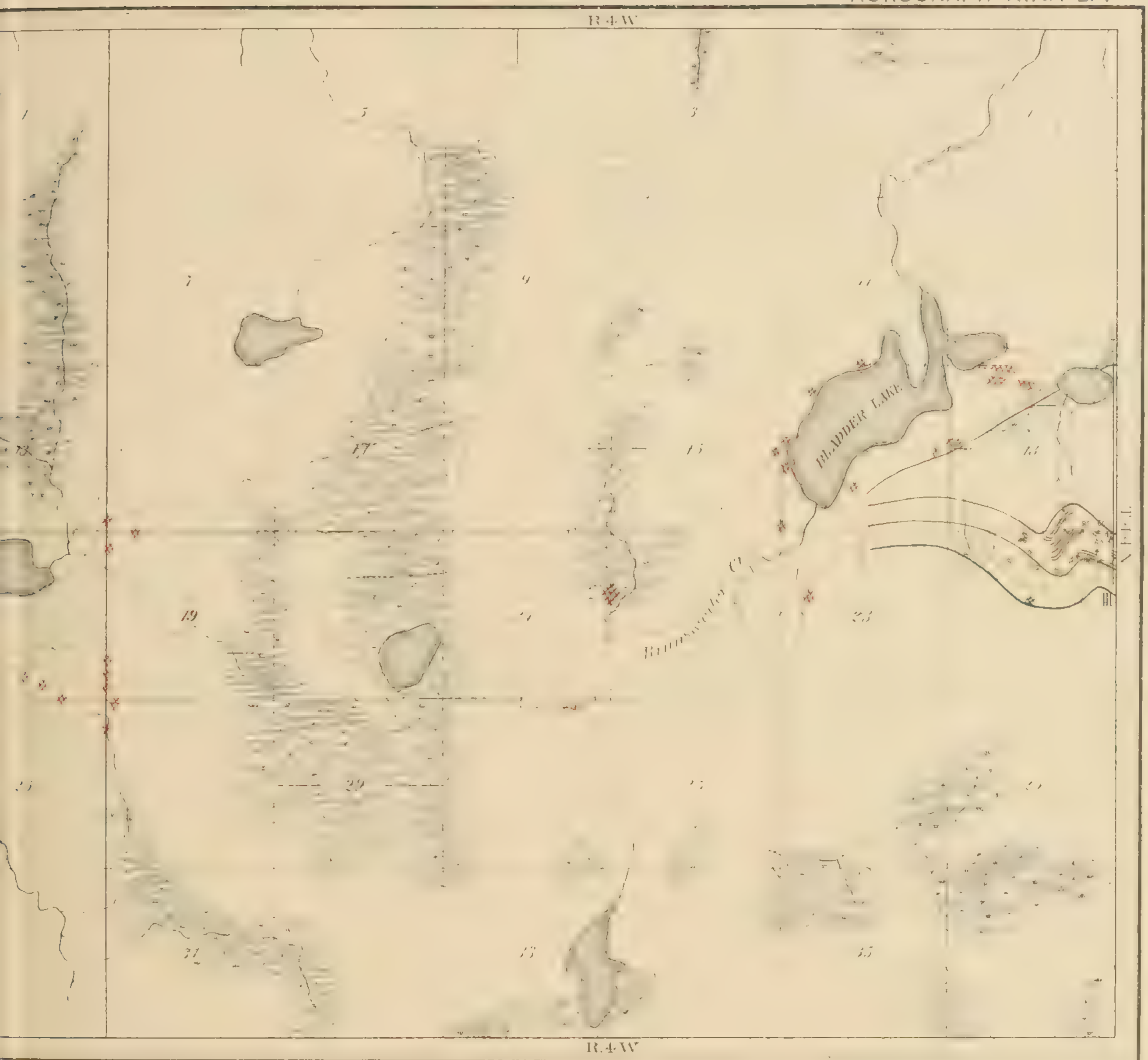



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SOUTHERN COMPLEX.

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Cherty Limestone Member.

Exposures of limestone and chert.
South limit.

Eruptives.

Exposures of greenstones

Exposures of granite

exploration by U.S Geol. Survey. Lines of exploration by Wis Geol. Survey.

Sections 1 inch = 1320 feet.

EE DISTRICT, SHEET I.


KEWEENAW SERIES. PENOKEE SERIES. SOUTHERN COMPLEX.

| KEWEENAW SERIES. | Upper Slate Member. | Iron-bearing Member. | Quartz-Slate Member. | Cherty Limestone Member. | Eruptives. | SOUTHERN COMPLEX. |
|---|---|---|---|---|---|---|
| Exposures of eruptives. South limit. | North limit. South limit. | Exposures of ferruginous schist. Limits of surface distribution. | Sl. Exposures of slaty phases. Q. Exposures of quartzitic phases. South limit. | Exposures of limestone and chert. South limit. | Exposures of greenstones. | Exposures of granite. |

Exposures showing strike and dip. Exposures showing no structure. ------ Lines of exploration by U.S. Geol. Survey. —·— Lines of exploration by Wis. Geol. Survey.

Scale of Map 1 inch = 1 mile. Scale of Sections 1 inch = 1320 feet.

DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET I.

R. 5 W., Wisconsin. Farther east we do not meet with any exposures of the limestone until Sec. 24, T. 44 N., R. 4 W., Wisconsin, southeastward from Bladder lake, is reached. In the interval the only known rock is a great mass of gabbro. Whether any of the members of the iron series are here continuous is an open question. The limestone exposure just referred to, which exposure, however, indicates an unusual thickness for the belt, is the only fact we have for the area indicated on the general map as extending through Secs. 23 and 24 of T. 44 N., R. 4 W., Wisconsin, and Sec. 19 of T. 44 N., R. 3 W., Wisconsin. So far as exposures go, however, there is nothing to indicate that this area can not be continuous with that long one which begins about a mile west of Bad river, in Sec. 15, T. 44 N., R. 3 W., Wisconsin. The eastward continuation of the latter area is indicated by several exposures in R. 2 W., and it is possible that there is a connection with the area which is represented as occurring in the vicinity of Tylers fork, in the southerly part of T. 45 N., R. 1 W., Wisconsin. There is, however, certainly a break in the continuity before the Potato river is reached, for here the Quartz-slate member of the iron-bearing series lies with a marked unconformity directly upon a chloritic schist of the older series. To the east of Potato river only small exposures of the member are met with—one in the middle of T. 45 N., R. 1 E., Wisconsin, and two in T. 47 N., R. 46 W., Michigan—until a point some 2 miles east of Sunday lake in Michigan is reached. Through some of this distance the Limestone member must certainly be absent, since the exposures of the Quartz-slate member and of the lower rocks come into direct contact with one another, as on the West Branch of the Montreal, T. 46 N., R. 2 E., Wisconsin, or so close to one another as to leave no room for the limestone belt. The easternmost of these limestone areas, that in the eastern part of T. 47 N., R. 45 W., Michigan, and western part of T. 47 N., R. 44 W., Michigan, is one of the most extensive and best exposed in the series.

*Possible former greater continuity.*—The occurrence of cherty fragments in the lower portion of the Quartz-slate member of the iron series in places where the limestone with this chert are themselves entirely wanting is strongly suggestive of a former greater continuity for the Limestone member than it now possesses. This occurrence of cherty fragments is frequent at the base of the slate. It is shown below that whatever may be the origin of the chert of the limestone belt, it had plainly in the main reached its present condition before the beginning of those processes of mechanical sedimentation by which the Quartz-slate member was accumulated, since fragments of the chert are commonly included within the slate. It is more than probable that the forces of erosion which accumulated the fragmental slate may have in places completely swept away the underlying limestone and chert.

*Thickness.*—The thicknesses of this member, noted at different points, vary between somewhat wide limits. At Penokee gap the entire surface width of the chert and limestone together is 125 feet, which corresponds to a thickness of about 113 feet. On the other hand, in the SE. ¼ of Sec. 18, T. 47 N., R. 44 W., Michigan, there is a continuous surface exposure of limestone and chert of such width that the thickness of the member in this place must be at least 300 feet. This is the greatest thickness that has anywhere been observed, but there are indications that in some places the member may at times be much thinner than is indicated by the Penokee gap section, as would be expected, since it is at times wanting altogether.

*Petrographical character of the limestone.*—Externally the limestones of this belt vary very considerably in appearances, the variation being due mainly to a varying coarseness of grain, which is at times so small that the rock is not far different in appearance from any compact earthy limestone of the fossiliferous series. On the other hand, it at times presents a very distinct and somewhat coarsely crystalline aspect, though the more compact kinds predominate.

The color generally ranges from white to gray, iron-stained portions being rather unusual. Thin blades of white tremolite may occasionally be seen on the surface of a specimen. Analyses of the soluble portions of these limestones indicate that they are always strongly magnesian; indeed, as shown by the following analyses by Mr. W. F. Hillebrand, of the U. S. Geological Survey, they have so much magnesia as to justify the application to them of the name dolomite. No. 1 is from near Sunday lake, (specimen 9405) SE. ¼ Sec. 18, T. 47 N., R. 44 W., Michigan; No. 2 (specimen 9677) is from the NW. ¼ Sec. 22, T. 44 N., R. 5 W., Wisconsin.


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KEWEENAW SERIES.

Exposures of eruptives
South limit.

PENOK

Upper-Slate Member.

M S. Mica-slate exposures
Bl. Sl Black slate exposures.
Q Quartzite exposures
Gw Graywacke exposures.

Iron-bearing Member.

Exposures of ferruginous schist.
Limits of surface distribution

Quartz

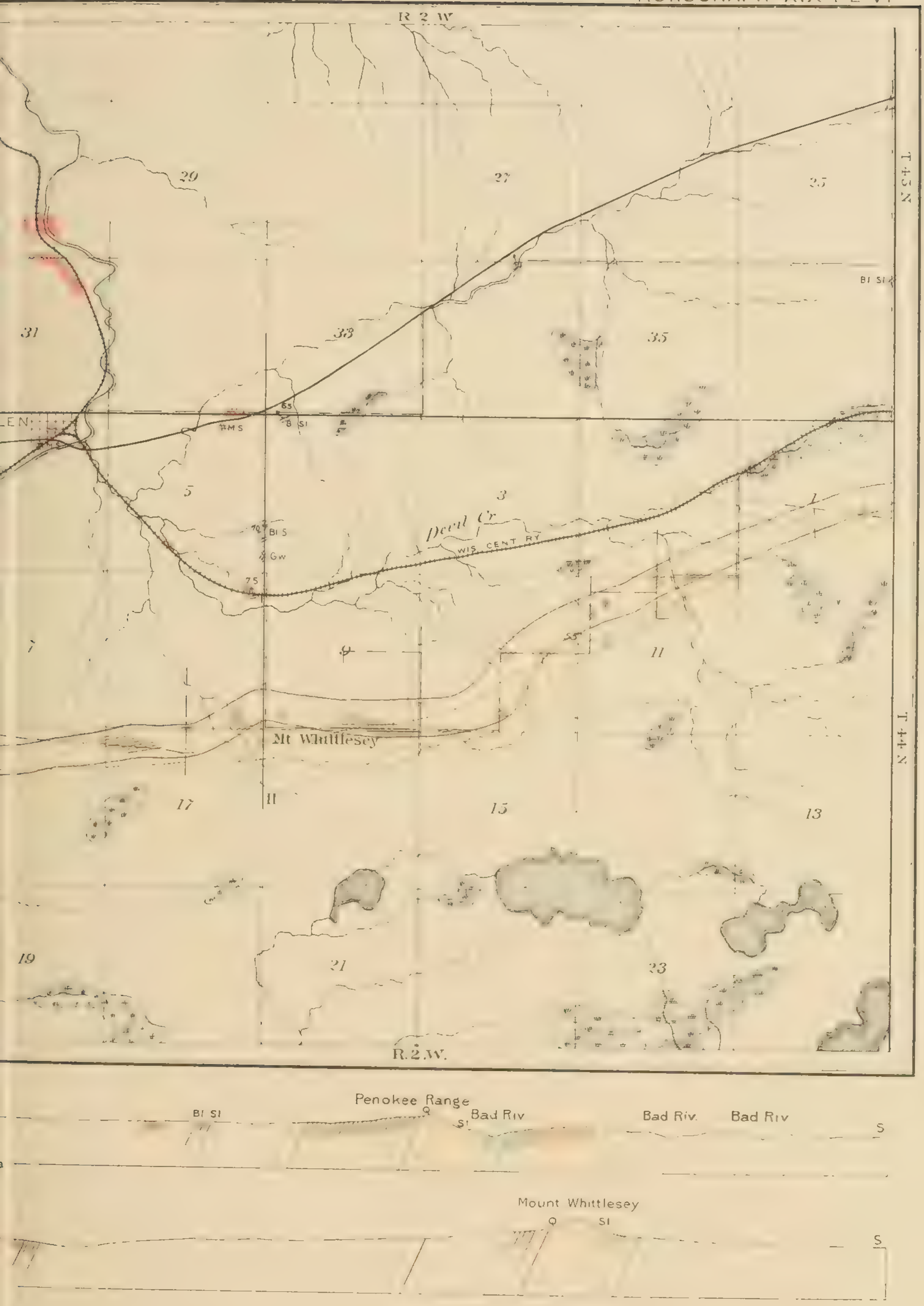
Sl. Expo
Q. Expos
South

Exposures showing strike and dip. Exposures show

Lines of exploration by Wis. Geo

Scale of Secti

DETAILED GEOLOGY OF THE

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Cherty Limestone Member.
Exposures of limestone and chert.
South limit.

Eruptives.
Exposures of greenstones.

SOUTHERN COMPLEX.
Exposures of hornblende-schist.
Exposures of granite

ucture. ------Lines of exploration by U.S. Geol. Survey.

Scale of Map 1 inch=1 mile.

=1320 feet.

KEE DISTRICT, SHEET 2.


DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET 2.

*Analyses of limestones.*

| | No. 1. | No. 2. |
|---|---|---|
| $SiO_2$ | 3·07 | 0·63 |
| $TiO_2$ | ......... | ......... |
| $Al_2O_3$ | ......... | ......... |
| $Fe_2O_3$ | 0·09 | 0·03 |
| FeO | 0·86 | 0·75 |
| MnO | 0·15 | 0·08 |
| CaO | 29·72 | 30·94 |
| MgO | 19·95 | 20·68 |
| $H_2O$ | 0·30 | 0·27 |
| $CO_2$ | 45·31 | 46·27 |
| $P_2O_5$ | ......... | ......... |
| $SO_3$ | ......... | ......... |
| Cl | Trace. | Trace. |
| $FeS_2$ | ......... | ......... |
| Organic matter | ......... | ......... |
| | 99·45 | 99·65 |

Dolomite and calcite are not readily distinguished in the thin section. So far, however, as appearances go, the carbonate entering into the composition of these rocks seems to be always the same, and, judging from the content of magnesium carbonate, it is rather to be counted as dolomite than as a mixture of dolomite and calcite or as a magnesian calcite, though the assertion that calcite is always absent is not ventured. Under the microscope the dolomite individuals, which constitute the larger part of each section, present the usual appearance met with in sections of crystalline limestone, being without crystal outlines, but fitting together closely along irregular curved lines. The interlocking of the grains is however, usually somewhat greater than in the case of statuary marble.

In addition to the carbonate, most of the sections show more or less tremolite, which varies greatly in quantity. Occasionally only a few minute flakes are discoverable, while in other cases broad single blades of radiating clusters make up a large portion of the thin section. The tremolite blades often penetrate the carbonate in every direction, and in the case of the larger blades the dolomite appears to be included within the tremolite. In yet other cases the tremolite in aggregated blades appears to make up the whole of certain narrow belts in the thin section. The tremolite is known to be such by its usual microscopical characters, which need not be here enumerated. Fig. 1 of Pl. XVI is from a section of one of these limestones magnified sixty diameters, in which there is shown one of the larger tremolite blades, through which in places are dimly seen the outlines of the dolomite individuals.

Many of the sections of these limestones show more or less of a siliceous ingredient, which is found in varying quantities up to an amount which very largely predominates over that of the carbonate. In fact, these siliceous varieties furnish us with a complete gradation into the chert rock, which, as already indicated, at times excludes the limestone completely. Now and then there are apparent in the thin sections of these siliceous limestones a few grains of quartz, whose fragmental nature is demonstrated by their rounded contours and by the secondary enlargements they have occasionally received. But these fragmental particles are relatively sparse and unimportant, the most of the silica having plainly solidified in situ. Of the latter silica there may be distinguished two varieties, which, however, grade into one another. The first of these presents itself in the shape of an interlocking mass of quartz individuals of finer or coarser grain. As these become finer and finer, there is found intermingled with them more or less of a fine spotty and chalcedonic silica with the characteristic aggregate polarization and radiating structure; and finally they pass into kinds containing a good deal of a completely amorphous opaline material. In Fig. 2 of Pl. XVI the thin section of one of the more siliceous varieties of limestone is represented as seen in polarized light and magnified sixty diameters. In the middle band of this figure the dolomite predominates greatly over the silica. On the upper right-hand side of the figure is a band composed of the finely crystalline silica, and at the lower left-hand corner is an area of the more coarsely crystalline quartz.

*Petrographical character of the chert.*—As already indicated, the cherty material of this limestone belt is often in layers of considerable thickness, at times apparently making up the greater part of the whole belt. At Penokee gap, for instance, it has a thickness of some 45 feet. In other cases it is scattered through or is interstratified with the limestone in narrow seams. As in the case of the siliceous material just described as occurring


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TOPOGRAPHY OF THE PENOKEE DISTRICT, SHEET 3.

at times closely intermingled with the dolomite, so also in the case of this chert rock the silica presents itself in completely crystalline, half crystalline, and amorphous conditions, these several phases occurring at times intermingled with one another. In some cases, however, as for instance in the rock at Penokee gap, all of the silica is completely individualized, and the individuals furnished more or less thoroughly with crystal outlines. As seen microscopically, this peculiar quartz rock is perfectly white, studded with minute crystal facets, and of a saccharoidal texture, being often so crumbly as to be readily mistaken for a fine grained sandstone. This impression is confirmed by the crystal facets, which one takes at once to be in the nature of the enlargements of quartz fragments commonly met with in sandstone, but the examination of the thin section fails to substantiate the impression, since the outlines of the original grains are not perceptible. On the whole, then, on account of the gradation varieties between this peculiar rock and those phases in which there is more or less chalcedonic and amorphous silica, we conclude that here also the whole of the silica has separated out in situ.

The accessory constituents in this chert are few and unimportant in quantity. They include sericite, brown iron oxide, and occasionally magnetite and dolomite. The usual snow white color of the rock is due to the general absence or sparseness of the iron oxide ingredient. Only rarely is the iron oxide present in sufficient quantity thoroughly to redden the rock. In these rare cases, however, the chert resembles a jasper.

In Pl. XVI, Fig. 3, we have represented one of the finer grained phases of chert as seen in polarized light. The concretionary and semichalcedonic arrangement of the silica is plain, the finer grained portions tending to form the centers of areas the outer portions of which and the interspaces between which are composed of the coarser grained quartz. Pl. XVI, Fig. 4, shows a section of the chert in which a band of the coarser grained quartz is seen adjacent to one of finer, but still completely crystalline, material. Our photographs of these sections of the chert and limestone containing the finest grained and amorphous silica have not proved sufficiently successful for reproduction, largely on account of the confused appearance of the objects themselves.

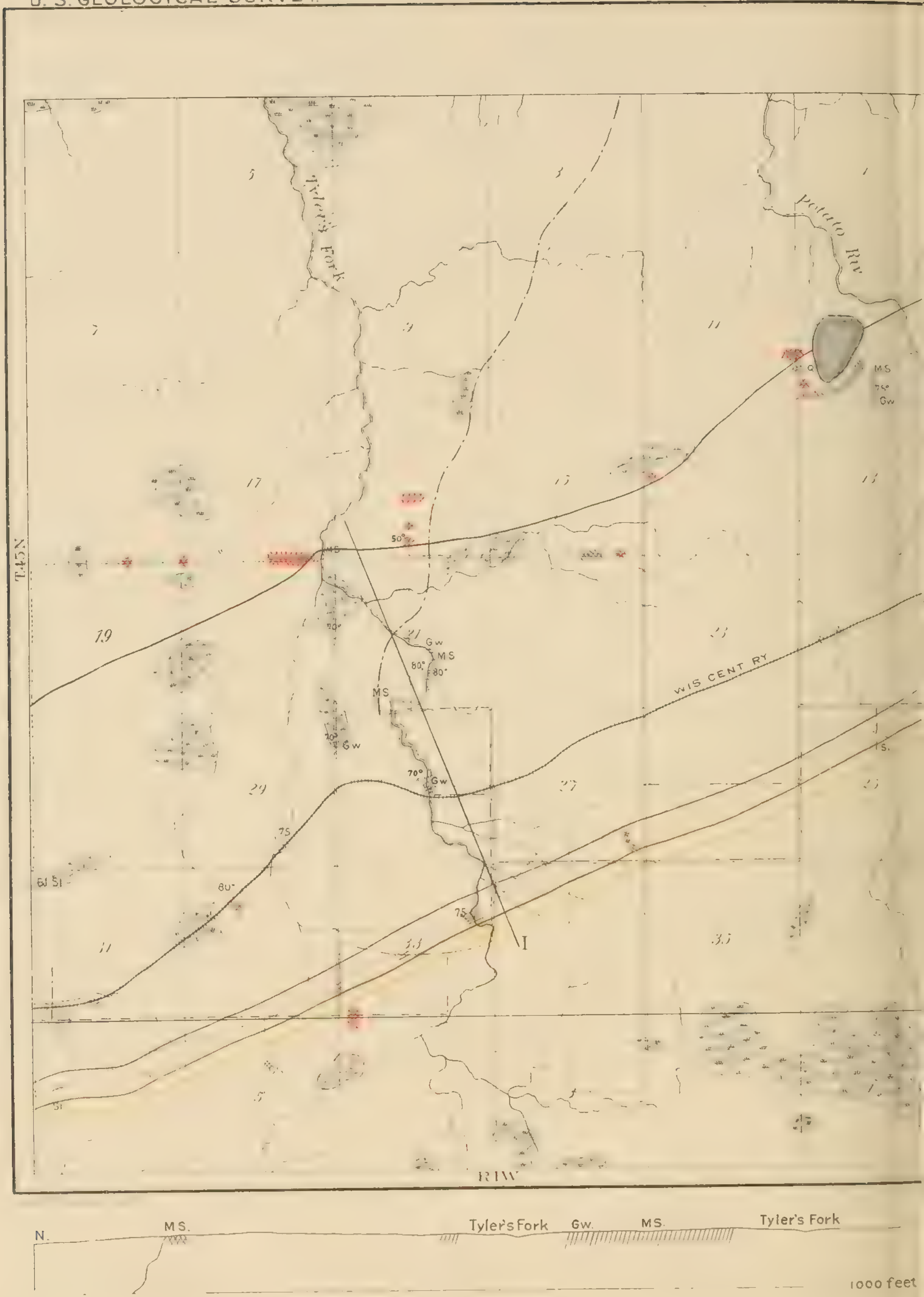
One of the most notable peculiarities of this cherty rock is its tendency to assume a brecciated form, in which angular pieces of the chert, ranging from microscopic sizes to fragments two or three inches across, are buried in a chert of a character wholly similar to that of the fragments or differing from them only in carrying a small quantity of other ingredients, such as magnetite and chlorite. These brecciated phases occur at times wholly within the horizon of the Cherty limestone member itself, and in other cases are very near to its junction to the overlying slate, when it is not always easy to draw the line between the two members.

*Change to the overlying Quartz-slate.*—As already indicated and subsequently further explained, the limestone or basal member of the sedimentary series is directly overlain by a very considerable thickness of completely fragmental rocks, whose main constituent is quartz, which mineral is, however, accompanied by a large proportion of feldspar fragments and by various alteration derivatives from the feldspars. The change from the limestone member to this quartz-slate is very sharp, the fragmental rock often carrying at its base pieces from the cherty material belonging directly beneath it. As this detritus in the quartz-slate is precisely like the material of the cherty limestone as it now exists, there must have been a considerable lapse of time between the deposition of the two formations.

*Tabulation of petrographical observations.*—Although, in the present development of the knowledge of petrography, it is rather unusual to include a description of individual sections in a volume like this, it is given in this and succeeding chapters because the essential unity and continuity of each formation, as well as the contrast between it and the following one, thus appear with a clearness which can be enforced in no other way.

This detailed observation is desirable for the further reason that, as explained in the Preface, the Penokee district is dealt with in greater detail than is intended with any subsequent iron-bearing district, the reason for the great elaboration being that this is the first of the iron-producing areas of lake Superior in which the geology has been fully worked out.

The numbers of specimens and slides are usually those of the collection of the lake Superior division. Specimens with Wr. after the numbers are from the collection of the late Mr. Chas. E. Wright. Specimens with




KEWEENAW SERIES.

Exposures of eruptives.
South limit.

PENOK

Upper Slate Member.

M.S. Mica-slate exposures.
Bl. Sl Black slate exposures.
Q Quartzite exposures
Gw. Graywacke exposures

Iron-bearing Member.

Exposures of ferruginous schist.
Limits of surface distribution

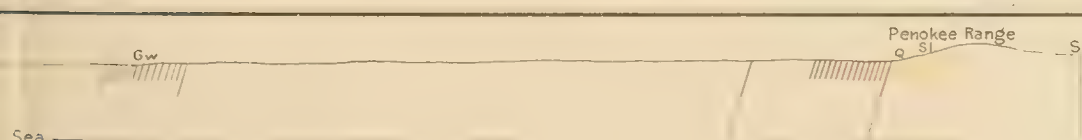
Quartz-

Sl. Exposu
Q. Exposur
South lin

Exposures showing strike and dip. Exposures showing no structure.

Scale of Map 1 inch=1 mile. S

DETAILED GEOLOGY OF THE


ES.

SOUTHERN COMPLEX.

ber. Cherty limestone Member. Eruptives.

phases Exposures of limestone and chert. Exposures of greenstones.

ic phases South limit.

Hb.S Exposures of hornblende-schist.

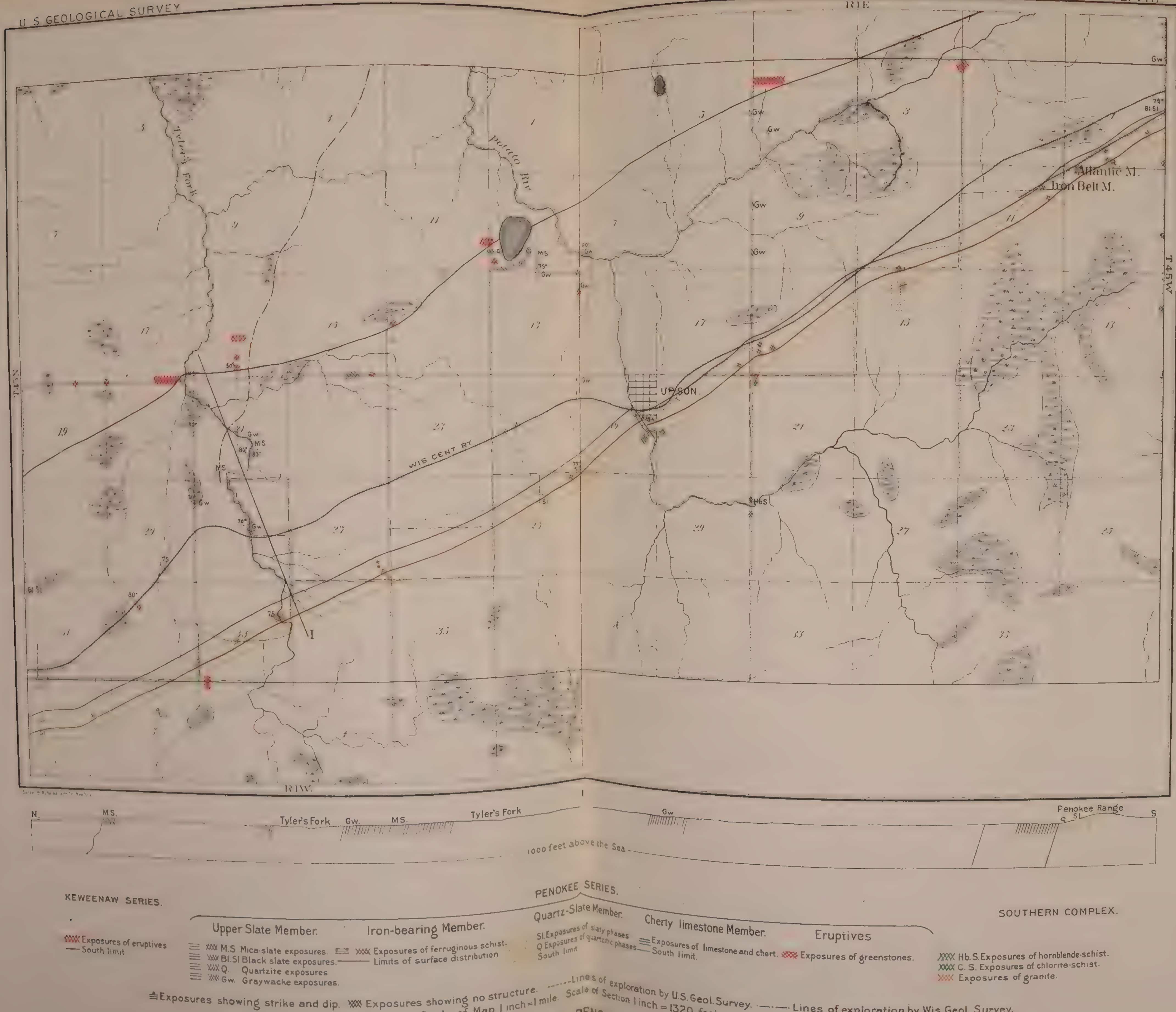
C.S. Exposures of chlorite-schist.

Exposures of granite

exploration by U.S. Geol. Survey. Lines of exploration by Wis. Geol. Survey.

ection 1 inch = 1320 feet.

KEE DISTRICT, SHEET 3.




DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET 3.

Wis. after the numbers are from the collection of the Wisconsin Geological Survey. Locations are given from southeast corner of the section, in steps of 2,000 per mile.

1. Tremolitic dolomite. Specimen 9678 (slide 3165). From 1850 N., 1675 W., Sec. 22, T. 44 N., R. 5 W., Wis.

A uniformly granular, grayish white limestone; in appearance very close to marble.

The thin section is composed chiefly of interlocking grains of dolomite, which often show the characteristic cleavage and twinning. Mingled with the dolomite are quite large blades of tremolite, which in many places are more or less decomposed (Pl. XVI, Fig. 1).

2. Tremolitic dolomite. Specimen 189 Wr. From 0 N., 1900 W., Sec. 15, T. 44 N., R. 5 W., Wis.

The mass of this rock is like 1, except that it is of a dark gray color. Cutting through it are veins of tremolite in very coarse, radiating blades.

The greater part of the section is like that of 1, but a portion of it is cut from the vein of tremolite, which material occurs in radiating clusters of quite large sized brilliantly polarizing blades.

3. Quartz rock. Specimen 9676 (slide 3163). From 1900 N., 1300 W., Sec. 22, T. 44 N., R. 5 W., Wis.

A finely granular, very friable, snow-white quartz rock, which in the sunlight exhibits innumerable glittering crystal facets.

The thin section is composed of a minutely crystalline mass of quartz. The quartz individuals are in large part crystal outlined, and appear to fit against each other perfectly, face to face, with little or no interlocking. There are usually no vacant spaces between the crystals, but the fragility and pseudo-arenaceous texture of the rock are explained by its peculiar make-up. No amorphous silica is present, nor is there any evidence that the crystals have been produced by the enlargement of quartz fragments, as in ordinary quartzites.

4. Tremolitic dolomite. Specimen 9654 (slide 3161). From 1400 N., 1000 W., Sec. 24, T. 44 N., R. 4 W., Wis.

This rock differs from 1 in that a portion of it is of a decided greenish color.

The section differs from that of 1 in that the tremolite is almost as abundant as the dolomite.

5. Dolomite. Specimen 9653 (slide 3160). From 1300 N., 1000 W., Sec. 24, T. 44 N., R. 4 W., Wis.

The rock is fine grained, uniformly granular, and of a gray color.

The thin section is composed wholly of a finely and evenly granular aggregation of dolomite individuals.

6. Tremolitic dolomite. Specimens 9531 (slide 3138), 1421 Wis. (slide 251). From 1440 N., 1200 W., Sec. 14, T. 44 N., R. 3 W., Wis.

A finely granular, uniformly textured, light gray rock, containing quite numerous small grains and crystals of pyrite. The rock contains: calcium carbonate, 50·52; magnesium carbonate, 33·41; iron, 1·19; insoluble ingredients, 13·85; undetermined 1·03=100.[1]

The sections are composed almost wholly of small, closely fitting particles of dolomite. Scattered through them are quite a good many blades of tremolite. Quartz and pyrite are sparse accessories. A small portion of the dolomite exhibits the characteristic cleavage and twin lamellation.

7. Sericitic quartz rock. Specimen 9533 (slide 3139). From 1460 N., 1200 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

A rock much like 3, but of a coarser grain.

The thin section is composed of fine grains of quartz, which include many minute flakes of sericite. The individuals of quartz are coarser than in 3, and while occasionally showing the crystal outlines, the greater number of particles form junctions which are more or less irregularly curved. The sericite is equally distributed throughout the section, being included in each of the quartz grains. Often a single flake of sericite is seen to penetrate two or more grains of the quartz. No evidence of enlargement of the quartz can be detected.

8. Quartz rock. Specimens 4526 (slide 1112), 4520 (slide 1110). From 1460 N., 1200 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

The thin section differs from that of 7 in being coarser grained, in not having the quartz particles very thoroughly interlocked, and in containing relatively little sericite. Chlorite also occurs as a sparse accessory.

9. Sericitic quartz rock. Specimen 4534 (slide 1465). From the extreme NE. ¼ of Sec. 16, T. 44 N., R. 2 W., Wisconsin.

The thin section resembles closely that of 7, the only difference of importance being the occurrence in it of magnetite in a few small crystals.

10. Flinty cherts. Specimens 7511 (slide 2056). From 1925 N., 1934 W.; 9430 (slide 3129), from 1900 N., 1900 W.; 9434 (slide 3131), from 1923 N., 1940 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

A fine grained to aphanitic, light gray or pinkish gray chert with a conchoidal fracture.

The sections are composed essentially of a minutely crystalline silica, the particles of which, however, vary a good deal in size; some portions looking as though the rock might be in part amorphous. In other parts one sees that there is a vague concentric arrangement, the amorphous and more minutely crystalline silica tending to lie in the middle portions of certain areas whose exterior portions are made up of more coarsely crystalline particles. This is an arrangement which approaches to the texture of true chalcedony, the resemblance to which mineral is also very evident in

[1] Wisconsin Geol. Survey, vol. III, p. 107.




TOPOGRAPHY OF THE PENOKEE DISTRICT, SHEET 4.

the hand specimen of these rocks. In places a very small quantity of brown iron oxide is present in minute particles. (Pl. XVI, Fig. 3.)

11. Chert. Specimens 9423 (slide 3063), 9424 (slide 3064). From 1740 N., 1075 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

A fine grained, pinkish saccharoidal chert.

The thin sections are like those last described, except that the silica is more coarsely crystalline. (Pl. XVI, Fig. 4.)

12. Dolomites. Specimens 7486 (slide 1935). From 550 N., 0 W.; 9405 (slide 3049). From 450 N., 330 W., Sec. 18, T. 47 N., R. 44 W., Michigan.

Rocks almost exactly like 6.

In thin section, as in 6, dolomite is the only mineral of importance, and the general appearance is the same as in that slide. A little tremolite is present.

13. Cherts and dolomites. Specimens 7485 (slide 1934). From 550 N., 300 W.; 9407 (slide 3124). From 450 N., 330 W., Sec. 18, T. 47 N., R. 44 W., Michigan.

Consist of interstratified fine grained, gray limestone and milky white flinty chert.

The sections include portions of both chert and limestone. The dolomite is like that of 12; the chert like that of slides 2056 and 3131 in 10. In section 3124 the line of separation between the chert and limestone is seen to be perfectly sharp. (Pl. XVI, Fig. 2.)

14. Chloritic dolomite. Specimen 9404 (slide 3270). From 600 N., 40 W., Sec. 18, T. 47 N., R. 44 W., Michigan.

This rock differs from most of the previously described limestones in being of a pale green color.

The thin section is composed chiefly of finely crystalline dolomite, mingled with which is a subordinate quantity of pale green nonpolarizing chlorite.

15. Dolomite. Specimen 9408 (slide 3050). From 525 N., 1925 W., Sec 17, T. 47 N., R. 44 W., Michigan.

A coarser grained rock than any of the preceding limestones; of a bright flesh color, with pale green spots and bands.

The thin section differs from 3138 in 6 only in being coarser grained, and in containing a minute quantity of ferrite, to the presence of which mineral the pinkish color of the rock is due.

16. Chloritic dolomite. Specimen 9387 (slide 3041). From 350 N., 1550 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

This rock differs from 6 only in containing streaks of a greenish material and in being of a pinkish gray color.

The thin section is like that of 14 except that some ferrite is contained.

17. Flinty chert. Specimens 9413 (slide 3054), 9414 (slide 3055), 9415 (slide 3056), all from 250 N., 1350 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

These specimens closely resemble 9430 and 9434 in 10. Immediately overlying them comes the fragmental slate that forms the first member of the overlying series.

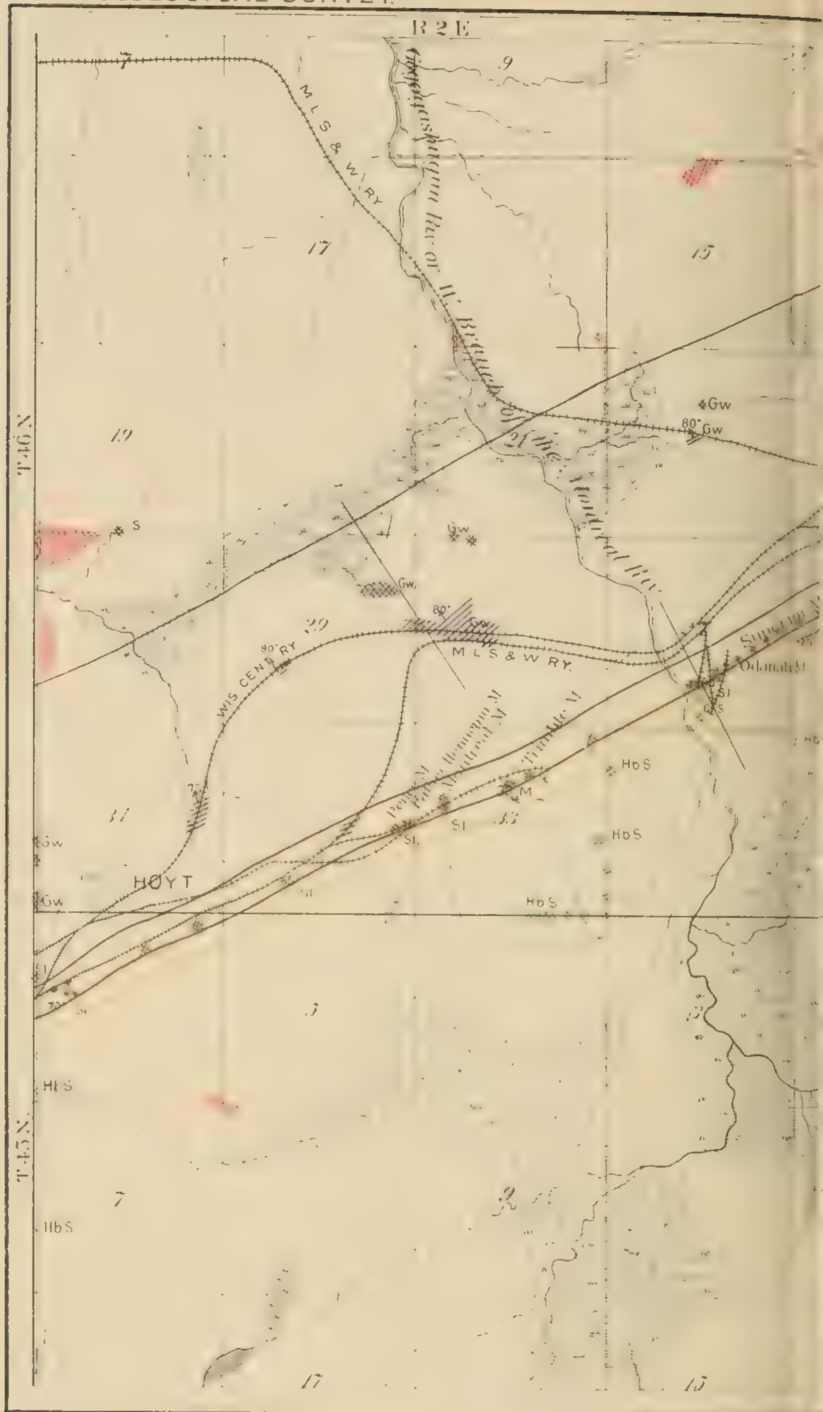
The sections of these specimens show in part numerous quartz fragments buried in a matrix of minutely crystalline silica, each quartz fragment having about it a halo of added material. Other portions are without any fragmental quartz, being made up of minutely crystalline silica in all respects like that of 2056 and 3131 in 10. In still other places, however, are areas of very coarse grained quartz, the individuals of which interlock intricately and present an appearance of true vein quartz. These areas and bands seem hardly to be vein quartz in the sense that they have been introduced wholly subsequently to the remainder of the silica.

*Prominent exposures.*—The various exposures upon which the existence of this member as a distinctive horizon is based are located carefully on the accompanying detailed maps (Pls. v to xiii) so that it will not be desirable here to give a description of each of them. A few words, however, with regard to the greater exposures, and particularly with regard to those which illustrate best the general nature of this member, may be of advantage.

Beginning at the west, we may note first the several exposures of limestone running along the south line of Secs. 15 and 16, T. 44 N., R. 5 W., Wisconsin, in the vicinity of Marengo river. These exposures show relatively little of the cherty material, being mainly made up of an unusually coarse crystalline white or greenish white limestone, which is often exceedingly tremolitic; bands occurring in the rock which are composed entirely of interlocking blades of tremolite. The large exposure indicated on Plate v as occurring not far north of the middle of Sec. 24, T. 44 N., R. 4 W., Wisconsin, shows a coarsely crystalline limestone very similar to that just described, containing but little chert, but seams and bunches of greenish white tremolite are particularly prominent. The extent of this exposure appears to indicate that we have here a considerable thickness for the limestone member. In the vicinity of Penokee gap the exposures of this member are those immediately under the railroad bridge across Bad river on the south side of the gap, in the SE. ¼ of the NW. ¼, Sec. 14, T. 44 N., R. 3 W., Wisconsin.[1] Bad river here runs with an easterly course through a narrow

[1] Geol. of Wis., vol. iii, 1880, p. 106. Also Atlas to the Geol. of Wis., Pl. xxiii.

U. S. GEOLOGICAL SURVEY.

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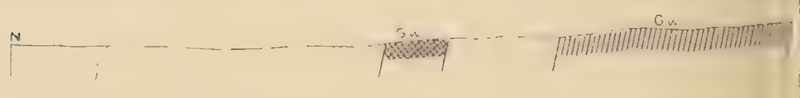


KEWEENAW SERIES.

Exposures of eruptives.
S. Sandstone.
South limit.

PENO

Upper Slate Member.

Sl. Black slate exposures
Gw. Graywacke exposures.

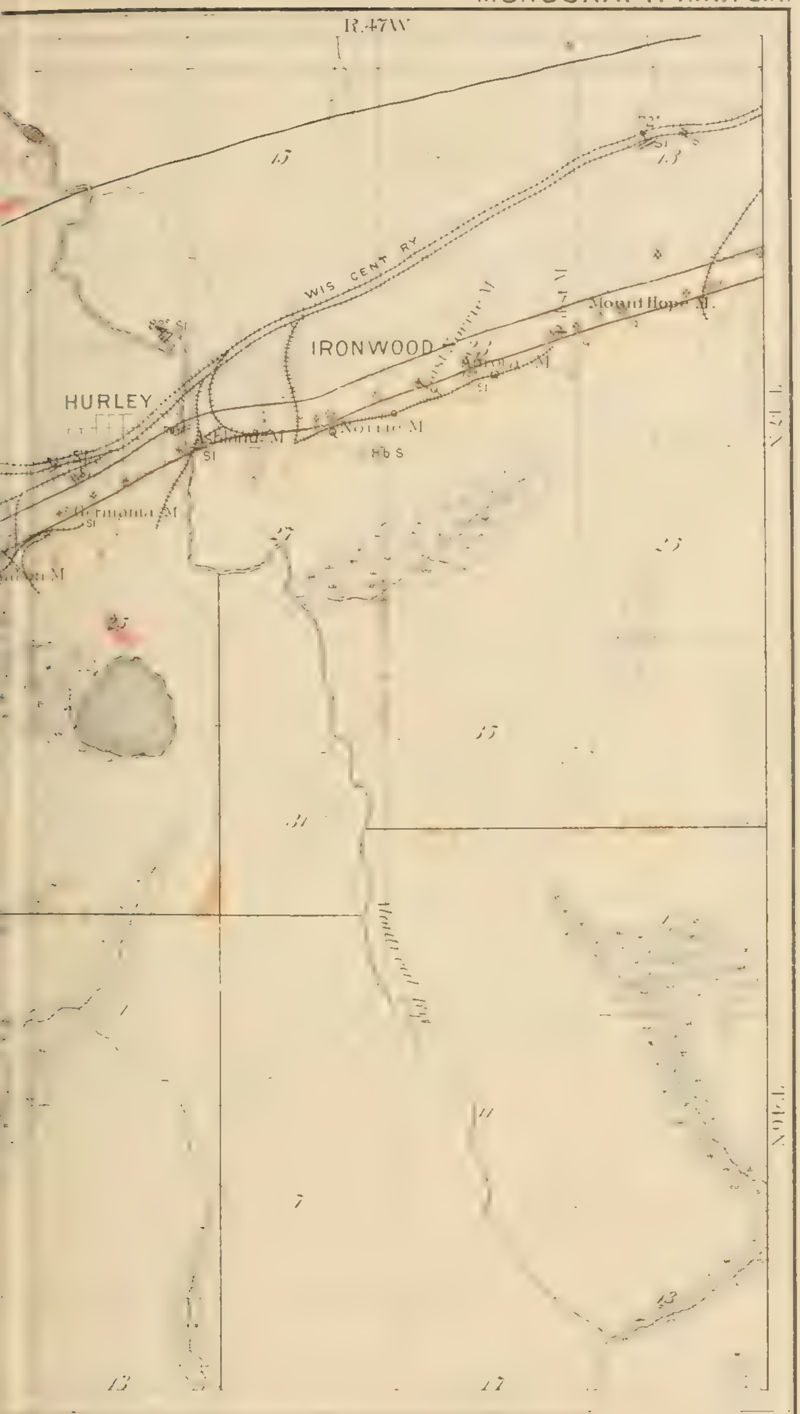
Iron-b

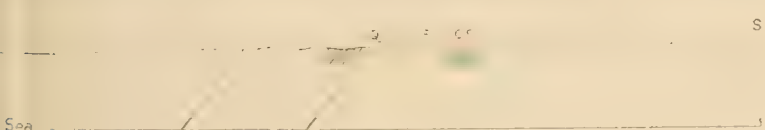
Exposur
Limits c

Exposures showing strike and dip. Exposures showing no structure.

Scale of Map 1 inch=1 mile.

DETAILED GEOLOGY OF THI




:S.

ber.

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Quartz-Slate Member.

SI. Exposures of slaty phases
Q. Exposures of quartzitic phases
South limit

SOUTHERN COMPLEX.

Hb.S Exposures of hornblende-schist
C. S. Exposures of chlorite-schist
Exposures of granite
Exposures of greenstone

exploration by U.S. Geol Survey. —·— Lines of exploration by Wis. Geol. Survey
ection 1 inch = 1320 feet.

KEE DISTRICT, SHEET 4.


PENOKEE SERIES.

KEWEENAW SERIES.

Sandstone

South limit

Iron-bearing Member.

Upper Slate Member

Sl. Black slate exposures

Gw Graywacke exposures

Quartz-Slate Member

Sl. Exposures of slaty phases

Q. Exposures of quartzitic phases

South limit

SOUTHERN COMPLEX.

Hb S Exposures of hornblende-schist.

C. S. Exposures of chlorite-schist.

Exposures of granite

Exposures showing strike and dip. Exposures showing no structure. Lines of exploration by U S Geol Survey. Lines of exploration by Wis. Geol. Survey.

Scale of Map 1 inch = 1 mile. Section 1 inch = 1320 feet.

DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET 4.

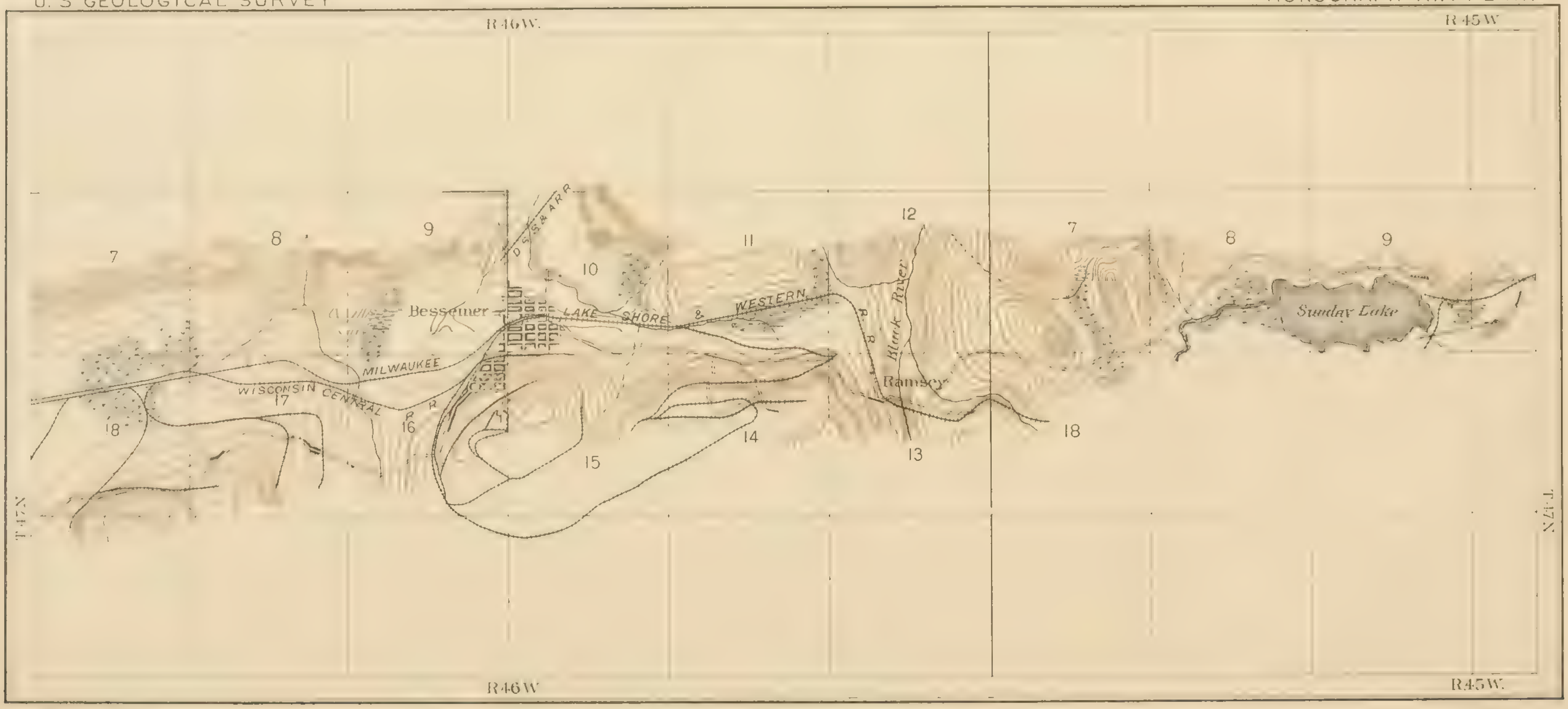
gorge, the northern side of which is composed of a snow-white chert, while the southern side is made up of a tremolitic minutely crystalline light gray limestone. The limestone and chert appear here then to be separated into two distinct layers, all of the chert overlying all of the limestone. The chert at this place has a thickness something like 40 or 50 feet. Less than a dozen steps south of the limestone are exposures of a Laurentian schistose gneiss.

The next exposures worthy of note are those lying to the east of Sunday lake, in the northwestern part of Sec. 15, T. 47 N., R. 45 W., Michigan. Here are extensive exposures of the siliceous slate member, immediately to the south of which a number of test pits have uncovered chert and chert breccia belonging to the Cherty limestone member. The principal point of interest to be noted here is the abundant occurrence of rounded fragments of yellowish white chert in the basal layers (8 to 10 feet in thickness) of the slate series, the rock being a chert conglomerate. The fine grained cementing material, as well as the pebbles and bowlders, is largely chert; so that the lower layer of the slate has derived most of its detritus from the Cherty limestone member. In passing upward the amount of cherty material becomes rapidly less and the rock soon passes into the ordinary feldspathic quartz slate. In the northern part of Section 14 is a long east and west exposure of the chert rock, immediately to the north of which is seen recomposed material similar to that just described. Here, however, the matrix of the chert conglomerate at the basement of the Quartz-slate member is largely of ordinary detrital material. On the SE. ¼ of Sec. 18 and in the adjoining part of Sec. 17, T. 47 N., R. 44 W., Michigan, are the most extensive exposures of limestone to be met with anywhere in the district. There is here a bluff some 200 feet in height, running nearly half a mile in a direction somewhat south of east. The extent of the rock here exposed is so great as to indicate a total thickness of something more than 300 feet. This limestone is mostly quite fine grained and massive, and of a gray color. Throughout the limestone there is contained much cherty silica. This silica is not only intimately mingled with the carbonate, as shown by the thin section, but occurs in nearly pure layers interlaminated with the limestone. The peculiar ridgy weathering all over this exposure is due to the presence of these layers of chert. The easternmost point at which any rock has been seen that can be with certainty referred to the limestone member is near the northeast corner of Sec. 20, T. 47 N., R. 44 W., Michigan, where chert and chert breccia are struck in a test pit a few feet south of exposures of the siliceous slate.

*Origin of the limestone and chert.*—From the statement already made, it is apparent that no facts have been obtained going to show that the limestone and the major portion of the chert of this belt are other than original water deposited sediments. Whether the carbonates are of chemical or organic origin we have no definite proof. Early in the study of these rocks it was thought that they were chemical sediments, as we had then little or no evidence of life independent of the nature of the rocks themselves and the iron carbonates at higher horizons. Later, as other proofs of life accumulated, the assumed chemical deposition of these carbonates became more and more doubtful. Many geologists hold that such carbonates are evidence of and could have been produced only by life agencies. Where there are no fossils, as in these carbonates, it is at best a matter of opinion as to their origin; but in making up a judgment upon this point, the organic beds of chert of later times associated with limestones, and the beds of iron carbonate and carbonaceous material in higher horizons of the series, are facts to be taken into account.

The vein-like character of a part of the chert implies that the silica has been rearranged to some extent, or partially introduced subsequently to the deposition of the main body of the belt. The deposition of similar cherty carbonates of great thickness is definitely known to occur in the Carboniferous and Permian periods.[1] The chert is here probably all of organic origin. Whether the chert in the limestones under discussion is an organic or a chemical substance it is impossible to say; but it is certain that in later time we have the exact analogue of the deposits described which are def-

[1] On the Organic Origin of the Chert in the Carboniferous Limestone Series of Ireland, and its Similarity to that in the Corresponding Strata in North Wales and Yorkshire. George Jennings Hinde. Geol. Mag., London, New Series., decade III., vol. IV, pp. 435–446. On the Chert and Siliceous Schists of the Permo-Carboniferous Strata of Spitzbergen, and on the Characters of the Sponges therefrom, which have been described by Dr. R. von Dunikowski. Dr. Hinde, ibid, vol. V, pp. 241–251.




TOPOGRAPHY OF THE PENOKEE DISTRICT, SHEET 5.

initely known to be organic deposits. The origin of similar cherty deposits in the Iron-bearing formation is discussed, in chapter v, section 2. What is said there with reference to the "original rock" applies equally well here.

It appears that the chert of the limestone belt, whether original or secondary, had in the main reached its present condition before the accumulation of the immediately overlying Quartz-slate formation, since, as already stated, very numerous fragments of this chert are found included within the slate at its base, and even in its middle and upper parts, and if the concentration of this material in layers is due to secondary causes, there must have been sufficient time between the deposition of the Cherty limestone and the Quartz-slate to accomplish this. That the chert has been rearranged to a greater or less extent since its deposition, and that in the cracks infiltrating solutions have brought additional silica, is more than probable. At the time of this subsequent rearrangement and introduction of silica, doubtless the tremolite was formed, although even this mineral may have developed very early. In the formation of the tremolite, the silica in solution had but to unite with a portion of the bases present, calcium and magnesium. The origin of actinolite from an analogous rock, except that it bore iron, is discussed in chapter v. What is there said applies equally well to the tremolite in the Cherty limestone.

*Summary.*—The cherts and limestones are placed together because as a rule the chert occurs interstratified and thinly interlaminated with the limestone.

This member, instead of being continuous, often thins out and disappears quite suddenly, so that it is mapped as occurring only where actually found. It is probable that the Cherty limestone member had a much greater former continuity than at present. This is particularly probable because fragments of it are abundantly contained in the overlying Quartz-slate member.

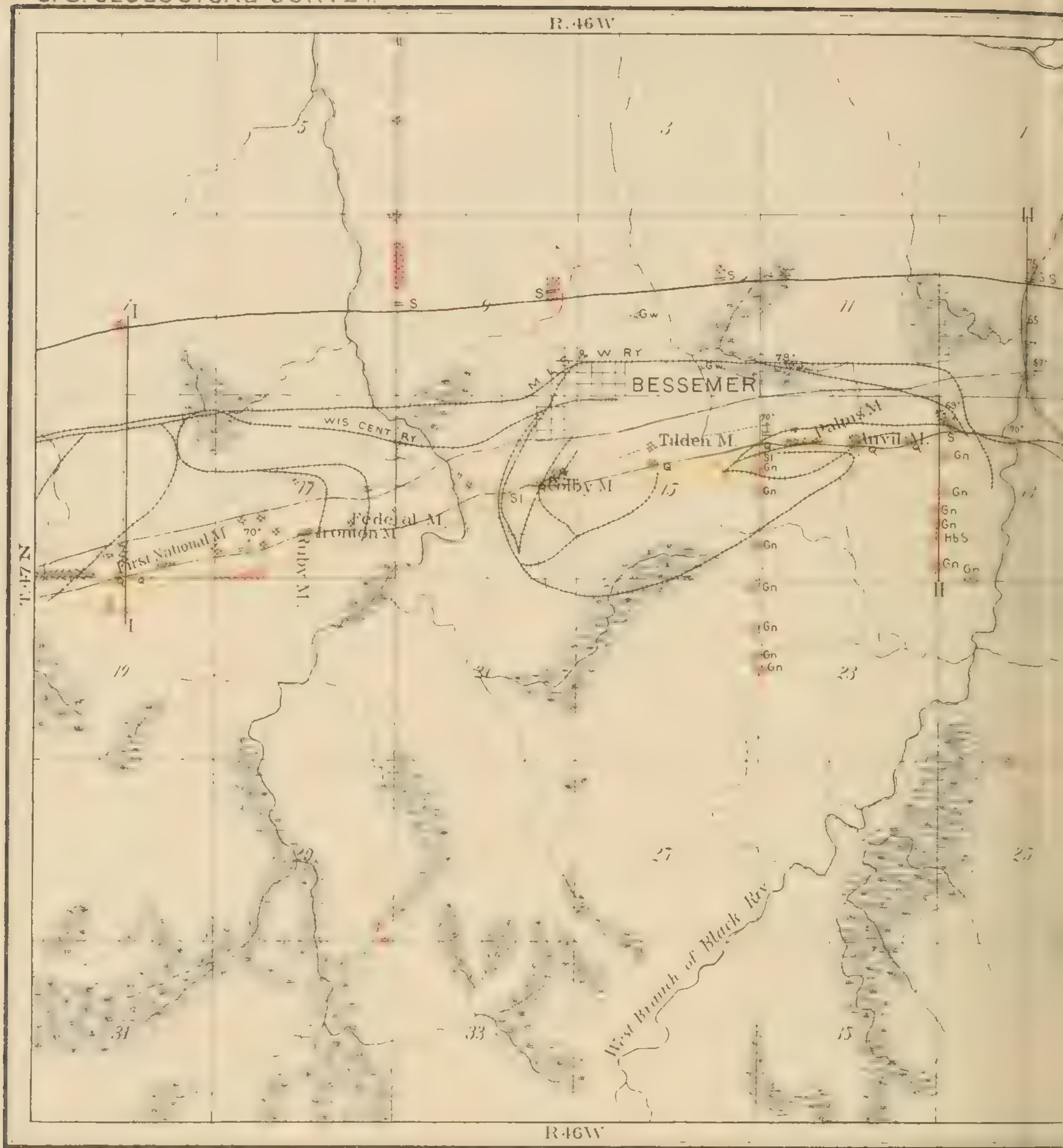
Its maximum thickness is 300 feet, and from this it varies to nothing.

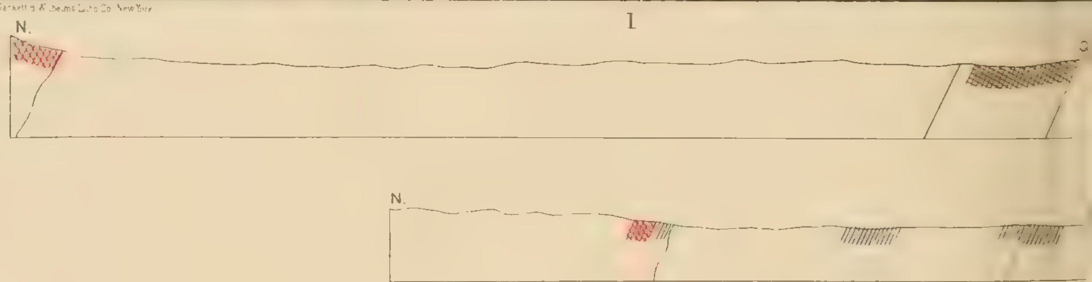
In petrographical character the limestone is close to a dolomite which is frequently tremolitic.

Chert occurs in the dolomite from minute particles through thin layers, which protrude on the weathered surface in leaf-like forms, up to belts which are 45 or 50 feet thick.

The change from the Cherty limestone to the overlying Quartz-slate member is usually abrupt, while in many places between the two there is certain evidence of an erosion interval.

The chert and limestone are water-deposited sediments. Whether chemical or organic is uncertain, but it is not improbable that they are partly or wholly the latter. However, if this is the case, the silica has subsequently changed to the mineral form and has been extensively rearranged, while the limestone has become dolomitized.




KEWEENAW SERIES.

PENO[...]

Upper Slate Member. Iron-bearing Member. Quartz[...]

Exposures of eruptives. S. Sandstone. South limit.

Gw. Graywacke exposures.

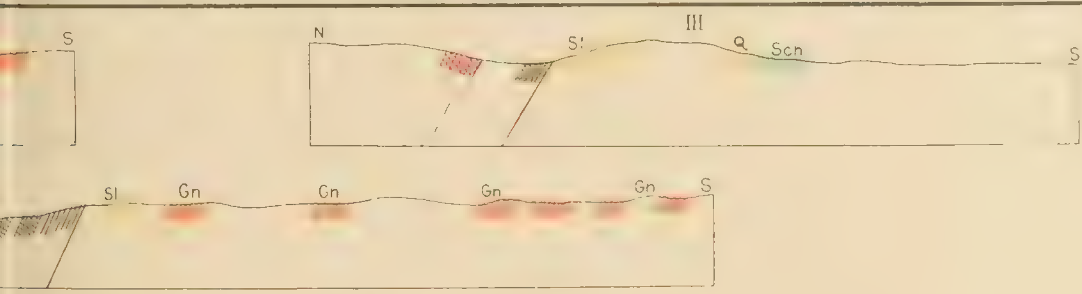
Exposures of ferruginous schist. Limits of surface distribution.

Sl. Expos[...] Q. Expos[...] South [...]

Exposures showing strike and dip. Exposures showing no structure.

Scale of Map 1 inch = 1 mile.

DETAILED GEOLOGY OF THE[...]


...ES.

SOUTHERN COMPLEX.

...ber.

Cherty Limestone Member.

Eruptives.

...ases
...ic phases.

South limit

Exposures of greenstone

Hb S Exposures of hornblende-schist.
M S Exposures of mica-schist.
C. S. Exposures of chlorite-schist.
Gn. Exposures of granitoid gneiss
Exposures of granite
Exposures of greenstone.

...exploration by U.S. Geol. Survey.
...ections 1 inch=1320 feet.

...EE DISTRICT, SHEET 5.


DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET 5.

# CHAPTER IV.

By R. D. Irving and C. R. Van Hise.

## THE QUARTZ-SLATE MEMBER.



*Applicability of the name.*—Resting directly upon the limestone or white chert of the formation described in the last chapter, or, in the absence of that formation, directly upon the gneiss, schist, or granite of the Southern Complex, follows a set of slaty layers, which, though for the most part less than 500 feet in total thickness, constitute a singularly well marked horizon, traceable throughout the entire extent of the area occupied by the Iron-bearing series of the district. The principal ingredients of these layers are quartz and feldspar, which fact has led to our selection of the name Quartz-slate for the entire member; although, as shown subsequently, very many varieties deserving of distinct lithological names occur within it. In the Wisconsin State Reports[1] the term siliceous slate is made use of for this member of the series, but this term has been so widely applied, particularly in its German form of Kieselschiefer, to a rock which is cherty or nonfragmental in its nature, that it appears inapplicable in the present case where a fragmental texture is the most prominent characteristic. The possession

[1] Vol. III, p. 111.

of this fragmental texture puts the formation in strong contrast with the chert and limestone of the limestone member immediately underlying it, and with the various ferruginous and cherty rocks of the immediately overlying Iron-bearing member, all of which rocks are entirely without the fragmental texture, and whatever their mode of deposition, are certainly not in the nature of mechanical sediments.

*Geographical extent.*—From the western end of the Penokee range, on the south line of Sec. 14, T. 44 N., R. 4 W., Wisconsin, to the southeast corner of Sec. 17, T. 47 N., R. 43 W., Michigan, a total distance of 52 miles, the outcropping edge of the Quartz-slate formation forms a continuous belt. West of the western end of the Penokee range, as shown on the maps herewith, all of the rocks of the Iron-bearing series disappear from sight, but in T. 44 N., R. 5 W., Wisconsin, they appear again, and here the same quartz-slate may be traced for a distance of something more than 3 miles. Whether the horizon is recognizable farther to the east than the easternmost point in Michigan above mentioned is, however, in some doubt. This question is considered separately in a subsequent chapter.

From the western end of the Penokee range eastward to the vicinity of Sunday lake, the width of the outcrop of these slates, which dip nearly always at a high angle to the northward, presents only very slight variations. To the east of Sunday lake, however, there is a somewhat rapid expansion. In the northern part of Sec. 24, T. 44 N., R. 4 W., Wisconsin, the width is 600 feet; at Penokee gap, on Bad river, it is 450 feet; at mount Whittlesey, near the northwest corner of Sec. 16, T. 44 N., R. 2 W., Wisconsin, it is 450 feet; at the gorge of the Potato river, Sec. 19, T. 45 N., R. 1 E., Wisconsin, it is 475 feet; at the passage of the West branch of the Montreal river, Sec. 27, T. 46 N., R. 2 E., Wisconsin, it is 450 feet; at the Aurora mine, NE. $\frac{1}{4}$ Sec. 24, T. 47 N., R. 47 W., Michigan, its possible maximum is 580 feet; on the west side of Sec. 13, T. 47 N., R. 46 W., Michigan, its possible maximum is 600 feet; and in the southern part of Sec. 10, T. 47 N., R. 45 W., Michigan, the width is 1,000 feet, this great increase in width being due in part to a flattening in the northward dip, and in part to an actual increase in thickness.


PEN...

Iron-bearing Member.

...xposures of ferruginous schist.
...imits of surface distribution

Quartz-Slate Member.

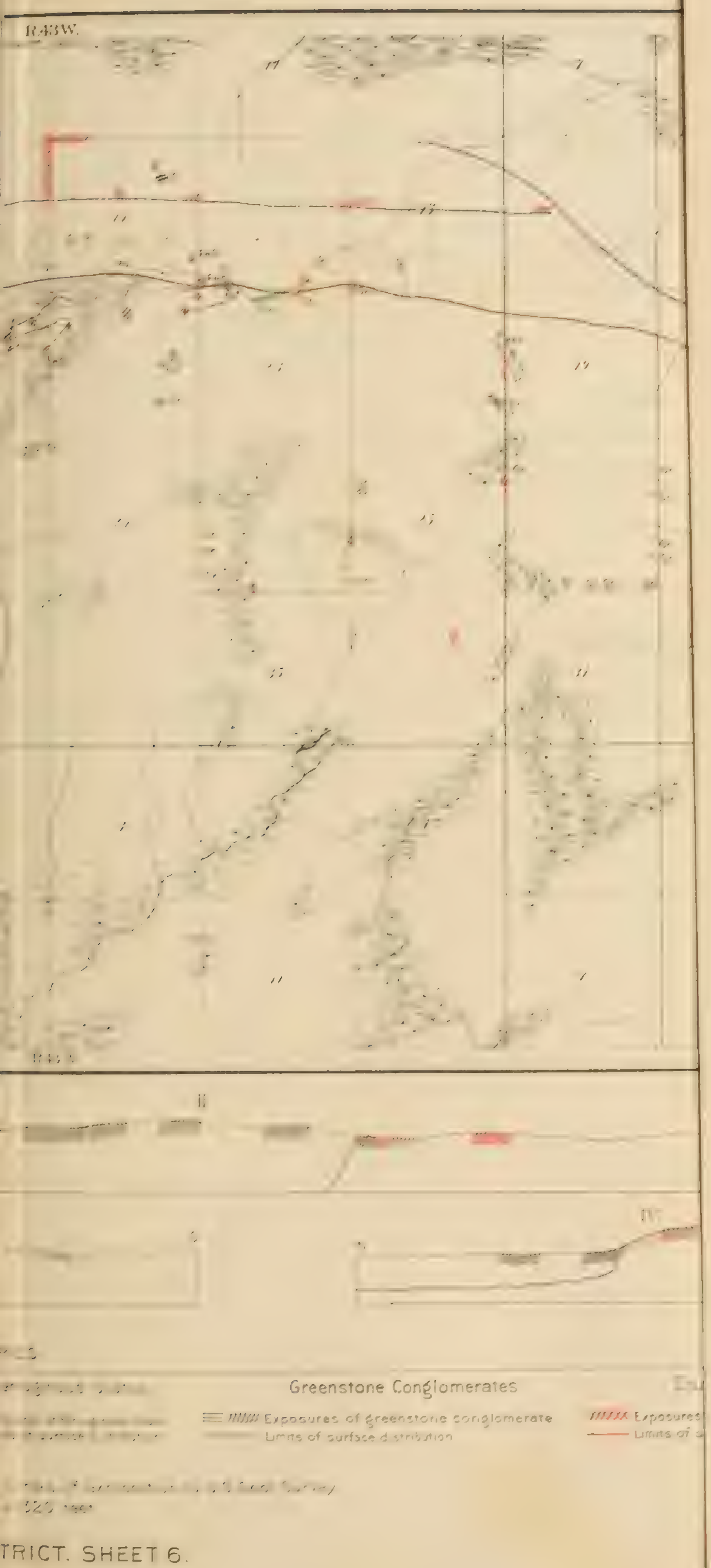
Sl. Exposures of slaty phases
Q Exposures of quartzitic phases
South limit

Cherty Limestone Member.

Exposures of limestone and chert
South limit

Exposures showing strike and dip. Exposures showing no structu...
Scale of Map 1 inch = 1 mile. Scale of Sect...

DETAILED GEOLOGY OF THE PENOK...


R.43W.
Greenstone Conglomerates
Exposures of greenstone conglomerate
Limits of surface distribution
Exposures
Limits of
TRICT. SHEET 6.


EASTERN SANDSTONE.

Exposures of sandstone and conglomerate
South limit.

KEWEENAW SERIES.

Exposures of eruptives
S Sandstone
South limit

PENOKEE SERIES.

Iron-bearing Member.

Exposures of ferruginous schist
Limits of surface distribution

Quartz-Slate Member

Sl Exposures of slaty phases
Q Exposures of quartzitic phases
South limit

Cherty Limestone Member

Exposures of limestone and chert
South limit

Ferruginous Slates

Fe Sl Exposures of ferruginous slate
Limits of surface distribution

Greenstone Conglomerates

Exposures of greenstone conglomerate
Limits of surface distribution

Eruptives.

Exposures of greenstone
Limits of surface distribution

SOUTHERN COMPLEX.

Hb S Exposures of hornblende schist.
C S Exposures of chlorite-schist.
M S Exposures of mica-schist.
Gn Exposures of gneiss
Gn Exposures of granitoid gneiss

Exposures showing strike and dip. Exposures showing no structure. ......Lines of exploration by U S Geol Survey

Scale of Map 1 inch = 1 mile. Scale of Section 1 inch = 1320 feet.

DETAILED GEOLOGY OF THE PENOKEE DISTRICT, SHEET 6.

*Topographical features.*—At the western end of the Penokee range the layers of the Quartz-slate member form the base of the southern slope of the range. From here eastward, however, the slate rises higher and higher on this slope, forming frequent bold and even precipitous south-facing exposures. At Bad river the slate reaches nearly, and at mount Whittlesey, Sec. 16, T. 44 N., R. 2 W., Wisconsin, quite, to the top of the ridge. Still farther east it forms more and more of the bulk of the range; while to the east of Tyler's fork the whole width of the outcrop lies on the northern slope of the range, the summit here lying within the Southern Complex. The same is very noticeably true in the Gogebic country, east of the state boundary, the slate as far as the vicinity of the West branch of Black river forming the northern slope of a bold ridge whose summit lies within the granite. To the east of the West branch of Black river another change in this respect takes place, the ridge itself lying within the jaspery iron belt north of the quartz-slate, which now lies in the lower ground to the southward; while beyond Sunday lake and as far east as the East branch of Black river, the quartz-slate again appears in bold exposures, and now forms the principal ridge, with low ground north and south of it. This varying position of the crest of the ridge with regard to the different rock belts is plainly a result of the varying relations between the several belts as to power of resisting erosion. At the west the Quartz-slate member contains an unusually large amount of soft chloritic slates and relatively little of highly quartzose portions, whilst at the same time the iron belt immediately north of it is exceedingly quartzose and resistant. Farther east the quartz-slate becomes more and more highly quartzose, and hence resistant, and now goes along with the iron belt itself to make up the bulk of the ridge. After Tyler's fork is passed, however, the iron belt begins to undergo a change whereby its resisting power becomes less and less, and, as the Montreal river is neared, the granite to the south becomes the most resistant rock, and the crest of the ridge is on it. In the same way a connection between the different degrees of resisting power of the various rocks, and the position of the crest of the range, may be shown to hold for that portion of the distance east of the West branch of Black river.

*Thickness.*—In several places the full surface width of the Quartz-slate member is continuously exposed, while in other places exposures of the rocks north and south of it limit its possible width in such a manner that we can tell very closely the true thickness. This surface width, while of course primarily dependent upon the thickness of the layer itself, is also dependent largely upon the degree of its inclination to the north, which varies from 40° as a minimum, to 75° as a maximum, although the extremes are rarely reached, the usual figures lying between 55° and 65°. The following are the approximate thicknesses observed at various points, beginning on the west: In the northern part of Sec. 24, T. 44. N., R. 4 W., Wisconsin, 400 feet; at the passage of Bad river, Sec. 14, T. 44 N., R. 3 W., Wisconsin, 410 feet; at mount Whittlesey, near the northwest corner of Sec. 16, T. 44 N., R. 2 W., Wisconsin, 400 feet; at the passage of the Potato river, Sec. 19, T. 45 N., R. 1 E., Wisconsin, 425 feet; at the passage of the West branch of the Montreal river, Sec. 27, T. 46 N., R. 2 E., Wisconsin, 467 feet. At the Aurora mine, NE. ¼ Sec. 24, T. 47 N., R. 47 W., Michigan, the observed thickness is 300 feet, but the entire thickness is not exposed, the greatest possible thickness between the granite on the south and the Iron-bearing member on the north being 545 feet. Similarly on the west side of Sec. 13, T. 47 N., R. 46 W., Michigan, the greatest possible thickness is 564 feet. Farther east the formation thickens somewhat rapidly, particularly east of Sunday lake. In the northern part of Sec. 10, T. 47 N., R. 45 W., Michigan, there is a continuous exposure about 1,000 feet wide, which, with the dip of 55°, corresponds to a thickness of at least 800 feet. Thus it appears that from the western end of the Penokee range to the passage of the Potato river there is an almost constant thickness of 400 feet; that east of Potato river there is a very gradual increase in thickness, which, at the passage of the West branch of the Montreal, is nearly 500 feet; and that this gradual increase continues until the vicinity of Sunday lake is reached, when a more rapid increase occurs, the maximum of 800 feet being reached about 2 miles east of that lake.

*General petrographical character and stratigraphy.*—The rocks of this formation have in common, with the exception of its uppermost horizon, a strong slaty tendency and light colored weathering; the slaty structure lying, however, parallel to the bedding, and not being in the nature of the ordinary slaty cleavage. These two characters serve to mark this formation so strongly that after once having become familiar with them one is never at a loss to refer its exposures to their true horizon; but while there is this general similarity of appearance, there are at the same time a great many subordinate phases presented. As macroscopically distinguished, the two most prominent phases are: (1) A thinly slaty, rather soft, usually very fine grained, dark colored kind, having often a distinct tendency toward a greenish tint; and (2) a kind shading into the last, but differing from it in being harder, and in tending to a paler or even light gray color, often showing mica flakes on the slaty surface, but as often presenting a nearly aphanitic appearance. From the first of these phases there are gradations into (3) a very thinly laminated, highly chloritic, and very soft kind; while from the second phase there are gradations in one direction into (4) a genuine vitreous quartzite; in another into (5) a slightly indurated sandstone; and in a third into (6) a light gray novaculite. Besides these there are certain phases of relatively rare occurrence. These are (7) red, green, and purple clay-shales or clay-slates; (8) a conglomerate in which fragments of white chert are imbedded in a greenish chloritic matrix; (9) a magnetitic conglomerate, like the last, but containing a large proportion of magnetite (these last two occur where the formation is in contact with the cherty limestone); and (10) a peculiar greenish conglomerate-slate found only on the Potato and West branch of the Montreal rivers, immediately at the contact with an unconformably underlying greenish schist. These distinctions are based entirely upon the macroscopic appearances, which appearances, however, are quite well borne out by the study of the thin sections. The second phase mentioned includes kinds which prove to have, in addition to the predominant quartz, a considerable proportion of a fragmental feldspathic ingredient, to whose presence the characteristic whitish to straw-colored weathering is undoubtedly due. The gradations from this phase towards vitreous quartzite arise from a lessening in the amount of the feldspathic constituent; those towards novaculite from an increase in the proportion of this feldspathic constituent, accompanied by a great decrease in coarseness of grain. The rocks of the first phase prove microscopically to differ from those of the second in containing a relatively large proportion of fine micaceous particles, these ingredients, including biotite, chlorite, and sericite, occurring either singly or together. A still further increase in these ingredients, accompanied by an increasing fineness in grain, gives rise to the third phase; while a still greater increase in fineness of grain, along with an increase in the amount of clayey material from the decomposition of the feldspar, leads to the argillaceous slates or shales of the seventh variety. The microscopical study shows further that the difference between these several phases, so far as they are not the result of unusual conditions, as in the case of the cherty and magnetitic breccias above mentioned, are almost entirely dependent upon the original proportions and degrees of fineness of the two main fragmental constituents; that is, the quartz and feldspar. Some of these micaceous ingredients are taken to be of fragmental origin. This is particularly true of some of the large flaked sericite or muscovite, but in the main these materials, including also kaolinite, appear to have resulted from a decomposition of the feldspathic particles. This decomposition was accompanied by the separation of a secondary silica, which is now apparent in most of the thin sections in the shape of a minutely crystalline quartz.

Disregarding the special and rarer phases, the important kinds may be microscopically listed under the following heads: *Chloritic and biotitic quartz-slates; feldspathic quartz-slates; vitreous quartzite; sandstone; novaculite; argillaceous slates.* These are variously interstratified with one another. However, the vitreous quartzite layer is a persistent element in the stratigraphy, composing the uppermost part of the formation wherever it is exposed. The conglomerates referred to (Nos. 8, 9, and 10,) lie always at or near the base of the formation, their peculiarities having been caused by proximity to the underlying rocks; but exposures of this kind are not sufficiently numerous to demonstrate that such rocks are a persistent element in the stratigraphy, although this is quite probable. At one place a vitreous quartzite is at or near the base of the series. However, while no further definite subordinate arrangement is observable in the cross-section, a change in character is to be noted as the belt is followed from west to east, the biotitic phase (Nos. 1 and 3,) predominating in the western portion of this belt, though steadily lessening in relative amount as one moves eastward. East of Sec. 34, T. 45 N., R. 1 W., Wisconsin, although the uppermost quartzite continues well marked, the cross section becomes varied, feldspathic quartzites, feldspathic quartz-slates, sandstones, and clay-shales alternating with one another.

*Microscopical character of the feldspathic quartz-slates* (Phase 2, see Pl. XVIII, Figs. 1, 2, 3, 4).—In thin sections, from the typical specimens of this phase, which is the prevailing rock of all that portion of the quartz-slate belt to the east of Sec. 34, T. 45 N., R. 1 W., Wisconsin, a single glance through the microscope generally suffices to show that it is composed of two parts, a coarser plainly fragmental portion and a finer interstitial material. The relative proportions of these materials vary greatly, the coarser portion at times sinking to quite a subordinate position, and again nearly excluding the matrix. Between the finer and coarser portions there is often a material of an intermediate fineness, and the whole appearance suggests that the two portions are in large measure only finer and coarser particles of the same minerals.

The coarser portion in these sections always comprises fragments of both quartz and feldspar. With these is very often more or less rather coarse grained mica, which appears also in a finer condition in the interstitial material. This coarser grained mica is taken to be in the main fragmental also, although, as will be seen subsequently, secondary micaceous minerals are plentifully developed in the rocks of this member. These coarser grained micas are the ones which appear as brilliant flakes to the naked eye on the surfaces of the laminæ. There is considerable variation in size among the coarser pieces, which, as already said, grade downward into the matrix material itself. This mingling of coarser and finer material, since it is made up of fragments of different minerals, is taken to indicate that the detritus of which this rock is composed had received relatively little sorting before deposition.

The fragments of quartz are for the most part portions of single individuals, but not unfrequently they are minutely complex, having been derived from some cherty or flinty rock. These particles vary greatly as to the degree of rounding which they have received. In general the amount of rounding appears to be in a direct relation to the size of the particles, the more minute pieces having remained quite angular. In speaking of these pieces as rounded, however, we refer always to the original fragments, whose outlines for the most part still remain distinct; but as they now stand, a large proportion of them are built out by secondary enlargement; the added portions varying greatly in width, but often extending beyond the original fragments a distance equal to a fifth or sixth of their diameters. These enlargements are, as usual, optically continuous with the original fragments, and have frequently interlocked with one another in such a fashion as to produce very irregular outlines. It is noticed that these secondary enlargements are narrowest in those sections which have a considerable quantity of brown iron oxide among the interstitial materials. The outlines of the original quartz fragments where they have received enlargements are emphasized, as is usual in such cases, by particles of brown iron oxide, and by the presence of minute cavities. In a few cases, mingled with this brown iron oxide, and at times almost excluding it, are films of a greenish chlorite.

The feldspar fragments include three distinct kinds. The most abundant is unstriated, and its appearance is, in every respect that of the ordinary orthoclase of the granitic rocks, and there can be no reasonable doubt that it is of this nature. The difficulty of separating these supposed orthoclase particles from the other ingredients of the rock, particularly from the microcline, would be so great that it is not thought worth while to make the determination any more certain than this. A second variety is the ordinary cross twinned microcline, and the third is a striated plagioclase. On making many measurements of the extinction angles of the last named variety by Pumpelly's method, we fail to find any angles which would suggest the presence of a plagioclase more basic than one belonging in the oligoclase series. We may therefore, with some confidence, say that the feldspar particles of these rocks include pieces of orthoclase, microcline, and albite or oligoclase, or both, an association which is that of the ordinary granites. Often these feldspar fragments are very fresh, but in other cases many of them are much altered or decomposed, a gradation in this respect being found to obtain between those kinds in which the particles are still very fresh and the chloritic slates or the argillaceous shales; the most plentiful products of the decomposition of the feldspars being chlorite and kaolinite. In the decomposition of the feldspars to chlorite, the particles of the latter mineral are found to form in the first place in the neighborhood of the edges of the feldspar fragments, the alteration having progressed regularly from the outsides of the grains; in the case of the kaolinitic alteration, the kaolinite particles appear as usual in numerous minute flakes throughout the entire feldspar grains.

The large particles of white mica which are supposed to be of a fragmental nature are taken to be an altered muscovite.

The fine interstitial material in these rocks, aside from the minute grains of quartz and feldspar, is a mixture of a minutely divided silica, flakes of kaolinite, chlorite, and a fine mica, which is taken to be sericite and muscovite, in proportions which vary between very wide limits, although in nearly every case all of these minerals appear to be present in the matrix, except perhaps the sericite. The siliceous portion of this matrix is at times completely though very minutely crystalline, but in other cases it takes on a chalcedonic or even an amorphous form. While some of the larger particles of the quartz in the matrix are doubtless of a fragmental nature, much of this interstitial silica is evidently an original crystallization. The kaolinite and chlorite are in minute flakes intimately mingled with the fine silica; the brown iron oxide occurs in irregular brown patches, being usually in a rather minute quantity, though at times deeply staining the entire matrix. The sericite particles of the matrix are usually of somewhat larger size than the particles of the other minerals, on which account it is perhaps a question whether this sericite should not rather be regarded as belonging with the larger mica flakes which we have already mentioned as of a fragmental nature. All of these interstitial minerals are ones which, as is known, result from the alteration of feldspars and micas, and it is supposed that they are the result of metasomatic changes carried out particularly in the finer detrital material subsequently to the original deposition of the rock.

*Microscopical character of the biotitic and chloritic quartz-slates.*—(Phases 1 and 3, see Pl. XIX, Fig. 1.) The thin sections of these slates, which are, as a whole, much finer grained than the slates just described and which do not show the same separation into a coarser fragmental portion and a finer interstitial portion, show a background which is composed mainly of quartz, but also contains usually more or less feldspar. In some sections the feldspar particles are quite abundant, while in others they are almost, or quite, wanting. Scattered through this background in varying quantities in the different sections are green flakes of chlorite and brown ones of biotite, the chlorite predominating in some sections, the biotite in others.

The quartz particles as now constituted are minutely angular. However, many of the larger have very plainly marked fragmental cores whose outlines are emphasized by films made up of minute flakes of chlorite and biotite. It is exceedingly difficult to say how much of the finer grained quartz is of a fragmental origin. Judging from the sections of the coarser grained varieties of phase 2, described immediately above, we conclude that part of this finer silica is fragmental, but that part of it is also an original crystallization.

The flakes of chlorite and biotite are usually quite small, but very well defined, though occasionally large sized scales of uniaxial chlorite are seen. It is taken as probable that all of these two minerals, along with the nonfragmental silica, have resulted from the decomposition of a detrital feldspathic material. At all events, in some sections all three of the minerals occur within the outlines of a single original feldspar fragment in such a manner as to show their derivation from the feldspar. This is a process of alteration, particularly as regards the biotite, which, as shown on a subsequent page, has been carried out in a very striking manner among the slates of certain portions of the Upper slate member of this district, fragmental feldspathic rocks having been thus altered to rocks that would ordinarily be taken as crystalline mica-schists. If this is also the origin of the micaceous ingredients of the rocks now especially under consideration, we should expect feldspar fragments, recognizable as such, to be present in an abundance standing in an inverse ratio to the amount of chlorite and biotite present. The thin sections show that this is actually the case. In the most highly chloritic and biotitic varieties there is recognizable little or no feldspar.

However this may be, that all of these rocks are of a fragmental origin is rendered sufficiently evident by the gradation of those kinds in which the fragmental texture is lost into those phases in which it still remains distinct. It should be said that these gradations occur constantly within short distances, and that those portions in which no distinct trace of fragmental origin is now perceptible are all relatively of very small extent and rare occurrence. It is a noticeable coincidence that the most thoroughly changed varieties met with in this slate belt occur in its more western portions, this being at the same time true of the uppermost member of the series. A reason for this coincidence is later suggested.

*Microscopical character of the vitreous quartzite.*—(Phase 4, Pl. xx, Figs. 1, 2, 3, 4.) The vitreous quartzites[1] prove, as one would expect from their macroscopic appearance, to be composed almost entirely of relatively large sized quartz fragments, each one of which has received an enlargement, the several secondary enlargements interlocking with one another in a more or less intricate manner. Feldspathic quartzites are interstratified in thin seams at various horizons in the quartz-slate formations, particularly so in the more eastern portion of the belt; but the only occurrence of pure quartzite in this formation, as already noted, is that persistent band which forms throughout the entire extent of the formation its uppermost horizon. The specimens brought from this particular layer furnish some of the handsomest illustrations which we have ever met with of a transformation of a sandstone to a vitreous quartzite by the enlargement process.[2] The outlines of the original fragments of these rocks are in many cases emphasized by a brown iron oxide, in which case the rock has usually a more or less distinctly brownish tinge; but in many cases the emphasizing mineral is chlorite in minute flakes. In the latter case the rock is either of a light gray color, or, if the chlorite is

[1] As used in this memoir, the word "quartzite" is restricted to rocks which have been derived from fragmentals. The fundamental difference which exists between rocks of this kind and those in which the quartz is an original crystallization, we believe, is in this volume for the first time fully recognized. However quartzite-like the nonfragmental quartzose rocks of the Iron-bearing and Cherty limestone members are, they are always designated by some other name than quartzite.

[2] For a more complete explanation of this enlargement process, with illustrations drawn from very many localities and from different geological horizons, see Bull. U. S. Geol. Survey No. 8, by R. D. Irving and C. R. Van Hise.

somewhat plentiful, of a distinct greenish tinge. The entire, or nearly entire, absence of particles of any other mineral than quartz in these rocks is taken to indicate a greater amount of sorting than has been received by materials which have composed the other phases of this formation. This conclusion is borne out by the generally uniform size of the quartz fragments of the vitreous quartzites, the sorting having been carried so far as to remove not only the particles of other minerals, but the smaller particles of quartz.

*Microscopical character of the sandstone, novaculite, and argillaceous slates.*—(Phases 5, 6, and 7.) These phases of the Quartz-slate member, because of their relatively small importance, may be more rapidly dismissed. The sandstone phase (Pl. XIX, Fig. 3) is an unusual one, having been so far observed only in three localities, viz: In the vicinity of the Ashland mine, Sec. 27, T. 47 N., R. 47 W., Michigan; in the vicinity of the Aurora mine, Sec. 23, T. 47 N., R. 47 W., Michigan, and at a point about three-fourths of a mile east of Sunday lake, Sec. 10, T. 47 N., R. 45 W., Michigan. In the first two localities it occurs at a high horizon immediately beneath the overlying vitreous quartzite; but in the last place the sandstone occurs on the contrary at a low horizon. Macroscopically these sandstones are of a rather fine grained arenaceous texture and from red to white in color, these colors being often very irregularly blotched. An examination of the hand specimens, without reference to their source, would certainly suggest that they came from some modern sandstone formation rather than from so ancient a terrane as that we are now concerned with. Microscopical examinations show, however, that they are merely less consolidated phases of the quartzites or feldspathic quartz-slates above described, these rocks being in fact no whit less fragmental in texture than the sandstones themselves.

The novaculite or whetstone-like phase (Pl. XVIII, Fig. 4) of the Quartz-slate member occurs here and there in thin seams in the eastern half of the belt. One of the most noteworthy localities for this phase is the gorge of Tyler's fork where the novaculite shows on the west bank of the river at about 200 paces north of the quarter post on the east line of Sec. 33, T. 45 N., R. 1 W., Wisconsin. This novaculite is nothing more than a very fine and even grained variety of the feldspathic quartz-slates, above described.

The argillaceous slates (Pl. XIX, Fig. 4) occur in a number of places, but nearly always in relatively thin seams, interstratified with the coarser varieties into which they grade. These slates appear to differ from the feldspathic quartz-slates merely in having the coarser fragmental portion almost, although not quite, excluded; that is to say, they are of the same nature as the matrix portion of the feldspathic quartz-slates, with perhaps an unusual amount of kaolinitic material from the alteration of feldspar detritus.

*Tabulation of petrographical observations.*—The following tabulation exhibits a series of observations made on specimens from this formation. As in the case of the limestone formation, these observations are tabulated in the first place in geographical order, proceeding from the west to the east. In the second place in stratigraphical order for each cross-section examined, beginning with the lower horizons in each case and proceeding to the higher.

*From the section in Sec. 24, T. 44 N., R. 4 W., Wisconsin.*

1. Chloritic and biotitic slate, from a middle horizon. Specimens 9645 (slide 3155), 9646 (slide 3156).[1] From 1500 N., 0 W., Sec. 24, T. 44 N., R. 4 W., Wisconsin.

A finely granular, dark gray, uniformly textured material, of almost quartzitic compactness, is interbanded with a finely laminated material of a greenish gray color, which upon the surface of the laminæ shows the sheen of mica.

The sections consist chiefly of quartz, feldspar, kaolin, chlorite, and biotite, the first two minerals being fragmental. In the more quartzitic phases the quartz in rather small uniform sized fragments, some of which have received a secondary enlargement, constitutes two-thirds of the mass of the rock. The feldspar fragments include both orthoclase and plagioclase. Scattered through the mixture of quartz and feldspar, and composing the greater part of the remaining third, are small flakes of chlorite and biotite, the former the more abundant of the two. The chlorite is in well defined flakes which extinguish rectangularly. The schistose part of the rock contains a greater proportion of feldspar, kaolin, and biotite than the more quartzitic portion. The biotite and chlorite both appear to be secondary developments from the feldspar fragments. Magnetite is an unimportant accessory.

2. Hornblendic and chloritic quartzites, from the uppermost layers, above 9645 and 9646, and immediately underneath the Iron-bearing member. Specimens 9647 (slide

[1] The numbers of specimens and slides are usually those of the collection of the lake Superior division. Specimens with Wr. after the numbers are from the collection of the late Mr. Charles E. Wright. Specimens with Wis. after the numbers are from the collection of the Wisconsin Geological Survey. Locations are given from the southeast corner of the sections, in steps of 2,000 per mile.

3157), from 1575 N., 0 W., 9648; (slide 3158) from 1635 N., 0 W., Sec. 24, T. 44 N., R. 4 W., Wisconsin.

A medium grained, massive, semi-vitreous quartzite, mottled light gray and dark green.

Fragments of a very limpid quartz compose three-fourths of the thin sections. These fragments are often partly or wholly separated from each other by an interstitial material, composed mainly of chlorite in aggregates of pale green flakes, and hornblende in small greenish needles and blades. However, over the greater part of the sections the quartz grains fit closely, or even interlock, and at times the original outlines of the fragments are quite obliterated. Here and there a little interstitial carbonate is seen.

*From the section in Sec. 17, T. 44 N., R. 3 W., Wisconsin.*

3. Chloritic quartzite. Specimen 4521 (slide 1402). From SW. ¼, Sec. 17, T. 44 N., R. 3 W., Wisconsin.

Rather large interlocking quartz grains compose the greater part of the section. These are believed to be enlarged fragments of quartz, mainly because in most of the similar rocks of this belt they are manifestly so; but taking this section alone, the proof of the fragmental origin is not conclusive. In masses and films between the grains are aggregates of chlorite, the section as a whole being closely allied to those of 2.

4. Biotitic slate. Specimen 9644 (slide 3154). From near the center of Sec. 17, T. 44 N., R. 3 W., Wisconsin.

This is for the most part a finely laminated slate, but occasionally bands of greater width and coarser grain occur. It is of a greenish gray color and shows strongly the sheen of mica.

The thin section is composed mainly of very fine grained quartz and mica, the two minerals being about equally abundant and evenly mingled. The fragmental character of this fine matrix is not entirely plain, but a coarser band running across the section shows the usual large fragments of quartz, each with a wide secondary enlargement, while occasional quartz grains of the same character are scattered through the fine grained groundmass. The line of demarkation between these quartz fragments and the enlargements is commonly marked by minute flakes of mica. There are also occasionally present large flakes of a rectangularly extinguishing chlorite, and some fragments of feldspar. It is not improbable that much of the fine grained quartz has developed from the alteration of the feldspar. (Pl. XIX, Figs. 1 and 2.)

5. Chloritic quartzite. Specimen 164 Wr. From 1000 N., 1000 W., Sec. 17, T. 44 N., R. 3 W., Wisconsin.

This is a medium grained, gray, vitreous quartzite, which resembles closely 2, but differs in lacking the peculiar mottling shown by those rocks.

Intricately interlocking clear quartz grains compose nearly the whole section, the only other minerals present being chlorite and ferrite, unless some of the greenish interstitial mineral be amphibole. Most of the quartz individuals have plainly been enlarged, and the rock is certainly an ordinary fragmental quartzite. In the case of a few of the large quartz individuals the outlines of the original fragmental cores are not visible; but these areas are so completely like the others, in which the cores are perceptible, that all must be taken as of the same nature. Both enlargements and original cores are composed of a singularly pure limpid quartz; whence the occasional invisibility of the outlines of the cores. This section, then, furnishes us abundant proof of the possibility, under favorable circumstances, of the development, from an ordinary sandstone by enlargement of the quartz fragments, of a quartzite whose fragmental character would never be suspected from the thin section. In this same connection reference should be made to 2 and 3, above described, whose fragmental origin is less clear than in the section now under consideration.

*From the section in Sec. 16, T. 44 N., R. 3 W., Wisconsin.*

6. Hornblendic and chloritic quartzite, from the uppermost layers and immediately beneath the Iron-bearing member. Specimen 9613 (slide 3153). From 1850 N., 1050 W., Sec. 16, T. 44 N., R. 3 W., Wisconsin.

A rock similar to 2, both macroscopically and microscopically.

*From the Penokee gap section.*

7. Magnetitic chert-breccias, from the base of the Quartz-slate member. Specimens 9534 (slide 3140), 9535 (slide 3141), 1424, Wis. (slide 252). From 1470 N., 1200 W.; 1455 Wis. (slide 265). From 1500 N., 1635 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

In these peculiar rocks a greenish to black schistose matrix contains numerous angular pieces of white chert, and fewer smaller ones of clear quartz.

The groundmass of the thin sections consists mainly of a minutely crystalline silica of nonfragmental appearance. This is explained by the fact that this rock rests directly upon the friable quartz rock (Nos. 7 and 8, p. 136) of the cherty limestone and has derived most of its material from this underlying formation. It approaches closely to a recomposed quartz rock, the particles of which are separate grains. With the quartz are mingled more or less chlorite and actinolite, some brown and red iron oxide, and a large quantity of magnetite. In 3140 and 3141 this magnetite plays a very subordinate part. In 252, however, it is very abundant, while in 265 it predominates over the silica of the cement, occurring in most beautifully outlined crystals, often of a very considerable size. There is little at first sight in the matrix of any of these rocks to suggest a fragmental origin. However, there are contained in it, in quantity sufficient to compose from one-third to three-fourths of the area of the thin sections, fragments of quartz and of a minutely crystalline silica or chert. The quartz fragments are well rounded, and the pieces of chert are only partly so, being often quite angular. The chert pieces reach as much as a quarter of an inch in diameter. The quartz fragments are both simple and complex, and have often received secondary enlargements. The most notable thing about these rocks is the fact that the crystals of magnetite, and also numerous minute needles of actinolite, besides being contained in the matrix, are included abundantly in the enlargements of the fragmental grains of quartz. These minerals have developed in situ. These very singular rocks come from a belt lying above the chert, which at Penokee gap forms all of the upper part of the limestone member, and the fragmental slates of the member now under consideration. (Pl. XVII, Figs. 1 and 2.)

8. Biotitic and chloritic slates, from low horizons. Specimens 9562 (slide 3143), 9563 (slide 3097), from 1480 N., 1700 W.; 9564 (slides 3144, 3145), 9565 (slide 3098), from 1530 N., 1160 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

These are fine grained, thinly laminated rocks, breaking at times with a subconchoidal fracture across the planes of lamination. In color they range from dark brown or black, through gray, to various shades of green.

The thin sections present a groundmass which is always chiefly quartzose, the grains being of small but uniform size and generally of roundish or oval shapes. In detail, however, the outlines of the grains are angular, and the projections of the different particles commonly interlock. In many of these minute particles the outlines of the original cores are perceptible, the enlargements being narrow and producing the angular projections referred to. The line of division between the enlargement and the original core is generally emphasized by secondary developments of particles of chlorite and biotite. Many more quartz particles, however, do not show any traces of the original cores, and it is not certain that a portion of them may not have crystallized in situ. Small fragments of feldspar make up a part of the groundmass, scattered through which are particles and clusters of particles of chlorite and biotite. The single flakes of these two minerals are larger than the particles of the groundmass itself, but are still very minute. In some slides the biotite almost excludes the chlorite, while in others the reverse of this is true. A considerable portion of these two minerals seems plainly to be due to the decomposition of the feldspar fragments. Accessory constituents are sericite, kaolin, tourmaline, and magnetite.

9. Quartzite, from the uppermost part of the slate, and immediately beneath the Iron-bearing member. Specimens 9560 (slide 3192), 9561 (slide 3193). From 1675 N., 1280 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

A fine grained, quite grayish quartzite, having a conchoidal fracture.

Quartz in rather small but uniform sized particles composes three-fourths of the sections. The particles of this mineral, although they very often closely fit and interlock, are plainly in the main of a fragmental nature. Biotite in 3192 and chlorite in 3193 occur sparingly between the quartz particles. Numerous fragments of feldspar, flakes of sericite, and a few particles of limonite are seen. The sections are closely allied to those of 8.

10. Chloritic and biotitic slate. Specimen 4532 (slide 1405). From NE. ¼ Sec. 17, T. 44 N., R. 2 W., Wisconsin.

The thin section is composed of exceedingly fine particles of quartz, feldspar, biotite, chlorite, and sericite. The general appearance is a fragmental one, but the grain is so minute that it would be difficult to prove a fragmental nature from this section alone.

*From the Tylers fork section.*

11. Chloritic and biotitic slate. Specimen 9615 (slide 3099). From 1135 N., 1980 W., Sec. 34, T. 45 N., R. 1 W., Wisconsin.

A fine grained, slaty rock, breaking with conchoidal fracture across the lamination. Upon cleaved surfaces are seen numerous flakes of white mica of a light gray color.

The chief constituents of the thin section are quartz and feldspar in plainly fragmental particles, the former being very plentiful, and having the fragments ordinarily enlarged. Between the grains of quartz and feldspar, and also included in the feldspar fragments as secondary products, are numerous small folia of chlorite, biotite, and sericite.

*From the Potato river section.*

12. Magnetitic quartz-slate and conglomerate, from the base of the Quartz-slate member. Specimens 9094 (slide 3297), 9096 (slide 2895), 9175 (slides 2994, 2995). All from 888 N., 35 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

The lowest portion of the Quartz-slate member on Potato river, at and near the junction with the underlying green schists, differs from the body of the member above described only in the presence of much magnetite, along with numerous pebbles and bowlders derived from the lower schists, also fewer small fragments of jasper and chert.

The background of the sections differs from the slates before described only in that they contain a very considerable quantity of magnetite in well defined crystals, and aggregates of crystals, these being at times so large and numerous as to make up most of the sections. As indicated in the macroscopic description, these rocks contain pebbles and bowlders derived from the green schist immediately below, and also fewer of quartz, chert, and jasper. In sections 2994 and 2995 is seen a large cherty area in which are numerous magnetite particles. The occurrence in these rocks of numerous fragments of cherty and jaspery material, associated with an abundance of magnetite, calls to mind the peculiar magnetitic breccia which lies at this same horizon on Bad river, where, however, there lies between it and the lower schists a thickness of some 90 feet of limestone and white chert. The Cherty limestone member is entirely lacking at Potato river, but the occurrence just described suggests that it and a jasper formation may have formerly been here. (Pl. XVII, Fig. 4.)

13. Feldspathic quartzites, or graywackes, chloritic quartz-slates, and graywacke-slates, from middle and lower horizons. Specimens 9083 (slide 2781), from 950 N., 180

W.; 9084 (slide 2782), from 970 N., 200 W.; 9086 (slide 2783), from 960 N., 185 W.; 9088 (slide 2784), from 960 N., 185 W.; 9089 (slide 2785), from 910 N., 105 W.; 9099 (slide 2788), from 888 N., 36 W.; 9100 (slide 2896), from 889 N., 37 W.; 9101 (slide 2897), from 890 N., 38 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

Except at the extreme north, where the quartzite 14 is found, the exposures of the Quartz-slate member on Potato river consist of interstratifications of thinly bedded pale pinkish quartzitic layers, and greenish (chloritic) gray and brown argillaceous slates. These grade into one another and are all described here together.

The thin sections from the more quartzitic portions of the Potato river exposures show fragments of quartz as the predominant ingredient, but mingled with the quartz fragments are plentiful ones of feldspar, including orthoclase, microcline, and plagioclase. The quartz fragments have nearly always received enlargements which have produced an interlocking of the quartz areas. The feldspar fragments on the whole are singularly fresh. Chlorite, ferrite, and calcite are present as accessories in some of the sections, occurring as narrow films and areas between the fragmental particles. From the quartzitic phases there is found a gradation to those varieties which are entirely aphanitic in the hand specimens, and are so exceedingly fine grained and clayey that in the thin section little is to be made out save that minute particles of quartz and feldspar are scattered through the clayey background, which is taken to be composed of pulverized and kaolinized feldspar, mingled with chlorite, sericite, etc. Slide 2788 is at the extreme as to fineness of grain and small number of recognizable quartz and feldspar particles. In the intermediate varieties half or more than half of each section is composed of minute but still distinctly recognizable fragments of quartz and feldspar, the quartz grains being almost always provided with plainly visible enlargements, even when widely separated from one another by the intermediate clayey matrix. This matrix in many sections, in addition to the minerals mentioned above (namely, chlorite, sericite, kaolin, and ferrite), contains calcite and occasionally crystals of magnetite, which last mineral is particularly met with in sections from specimens which come from not very far from the underlying green schists.

14. Quartzite, from the uppermost horizon of the Quartz-slate member, immediately beneath the Iron-bearing member. Specimen 9082 (slide 2780). From 1000 N., 210 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

A coarse grained, vitreous quartzite, of a pale pink color.

The section is almost wholly composed of clear quartz in large intricately interlocking areas. Each one of these areas, however, is furnished with a very distinctly outlined fragmental core, and occasionally the secondary enlargement has received crystal outlines. The cores and enlargements are separated from one another by films of ferritic material. This section furnishes one of the very finest illustrations that we have met with of the production of a vitreous quartzite from a completely fragmental sandstone by the enlargement process. (Pl. XX, Figs. 1 and 2.)

*From the section in Sec. 6, T. 45 N., R. 2 E., Wisconsin.*

15. Chloritic slate, from a low horizon underlying 9145 (16). Specimen 9133 (slide 3300). From 1000 N., 1600 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

A fine grained, thinly cleavable, grayish green slate.

Minute fragments of quartz and feldspar, the former enlarged in the usual manner, are mingled with a finer material composed of kaolin, sericite, and ferrite.

16. Chloritic quartzite, from the uppermost horizon. Specimen 9145 (slide 2800). From 1090 N., 1535 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

A fine grained, vitreous, greenish gray quartzite.

The thin section is composed mainly of rather small quartz fragments, which are provided, however, with wide and deeply interlocking enlargements. Chloritic flakes with a little ferrite occur in the interstices of the grains.

*From the West branch of the Montreal section.*

17. Chloritic slate and conglomerate, from the basal portion of the Quartz-slate member, and in contact with the underlying green schist. Specimens 9149 (slide 2912), 9171 (slide 2914). From 175 N., 1035 W., Sec. 27, T. 46 N., R. 2 E., Wisconsin.

Specimen 9171 contains large pebbles of green schist, cemented by a dark green, uniform grained matrix, in which are recognizable numerous grains of quartz, feldspar, and calcite. Specimen 9149 is like the matrix of 9171. They are both from the junction with the underlying greenish schists.

The slides are like those described in 12, except that they carry numerous fragments of the greenish schist beneath them, and much secondary calcite and chlorite, presumably derived from the secondary alteration of the schist fragments.

18. Sericitic and chloritic graywackes and graywacke-slates, from the middle horizons. Specimens 9035 (slide 2919), from 190 N., 1130 W.; 9038 (slide 2771), from 210 N., 1080 W.; 9040 (slide 2772), from 210 N., 1020 W.; 9043 (slide 2773), from 270 N., 1000 W.; 9044 (slide 2774), from 320 N., 1010 W., Sec. 27, T. 46 N., R. 2 E., Wisconsin.

The rocks are fine grained, compact, of a uniform texture and subconchoidal fracture when broken across the lamination; are often readily cleavable parallel to the lamination, into large thin plates, the cleavage surfaces showing the sheen of mica. The colors vary through shades of green, pink, gray, and purple.

The slides differ somewhat widely in the quantity of fragmental material which is recognizable as such. The finer interstitial material, varying from a quite subordinate quantity to a predominating amount, is composed of flakes of sericite and chlorite, along with some minutely crystalline quartz and also kaolin and brown iron oxide. The quartz and feldspar fragments occur as in thin sections of similar rock previously described. The feldspar particles, while fresh in the inner portions, are commonly altered upon the exterior to chlorite and kaolin, which minerals, along with the sericite and minutely crystalline quartz, are taken to be due to metasomatic changes.

19. Ferruginous and feldspathic quartzites, from the upper horizons. Specimens 9151 (slide 2802), from 310 N., 1120 W.; 9152 (slide 3104), from 310 N., 1130 W.; 9153 (slide 2803), from 310 N., 1140 W.; 9154 (slide 2804), from 350 N., 1132 W.; 9045 (slide 2885), from 395 N., 1055 W., Sec. 27, T. 46 N., R. 2 E., Wisconsin.

The specimens vary from those of a medium grain, vitreous luster, and conchoidal fracture, to those which are very fine grained and lusterless. They are stained from a light to a dark brown by hydrated iron oxide.

Rather small and well rounded fragments of quartz, now provided with interlocking enlargements, predominate in the thin sections. Fragments of orthoclase and plagioclase, commonly quite fresh, occur in some abundance. In some sections large films and areas of hydrated oxides of iron are plentiful between the fragments; in other cases (2802) chlorite flakes occur mingled with the iron oxide. (Pl. XX, Figs. 3 and 4.)

20. Quartzite, from the uppermost layers of the Quartz-slate member, being the foot wall at the Bessemer mine. Specimen 9054 (slide 2920), from 1000 N., 1838 W., Sec. 26, T. 46 N., R. 2 E., Wisconsin.

Both macroscopically and microscopically this quartzite is exactly like 14.

*From the Germania mine section.*

21. Slaty feldspathic quartzite, from a high horizon and immediately beneath 9013. Specimen 9011 (slide 2766). From 133 N., 1500 W., Sec. 24, T. 46 N., R. 2 E., Wisconsin.

The rock is composed of interstratified seams of a coarse pinkish quartzite and a fine grained green material.

Fragments of quartz and feldspar make up most of the section, the particles being quite angular. In the case of the quartz this angularity is plainly due to a secondary enlargement. Between these fragments is an interstitial material, composed in part of a minutely crystalline quartz, with limonite, kaolin, and sericite in minute flakes. The section resembles closely 2802 in 19, above described.

22. Quartzite, from the uppermost horizon, immediately in contact with the Iron-bearing member, being the foot wall of the Germania mine. Specimen 9013 (slide 2767). From 200 N., 1560 W., Sec. 24, T. 46 N., R. 2 E., Wisconsin.

Both macroscopically and microscopically this rock is like 14.

*From the Ashland mine section.*

23. Slaty and cherty quartzite, from a low horizon. Specimen 7621 (slide 2017). From 1805 N., 1910 W., Sec. 27, T. 47 N., R. 47 W., Michigan.

This rock is composed of thinly interstratified seams of a greenish or yellowish gray vitreous quartzite, and of a dark green aphanitic material.

The thin section appears to be cut wholly from one of the quartzitic seams. It shows a mixture of fragments of quartz and of a minutely crystalline cherty silica, imbedded in a cement which composes about one-third of the section, and consists of a mixture of very minutely crystalline silica, with particles of chlorite and ferrite. The quartz fragments at times show very distinct secondary enlargements. A few feldspar fragments are seen.

24. Quartzites, from a high horizon. Specimens 9005 (slide 3102), 7620 (slide 2016). From 1880 N., 1910 W., Sec. 27, T. 47 N., R. 47 W., Michigan.

These are compact, coarse grained, vitreous quartzites, of a gray color.

Quartz fragments, with the usual interlocking enlargements, and mingled with some pieces of feldspar, make up most of the sections. The enlargements of the quartz fragments are unusually wide. The outlines of the cores within these enlargements are marked in a distinct manner by films of chlorite and brown iron ore, which minerals also occur along the line of junction between the enlargements of different grains. A number of instances are noted of the enlargement of complex quartz fragments, each individual area within the fragment having received its own enlargement.

25. Sericitic ferruginous sandstone, from a high horizon. Specimens 9004 (slide 2880), 7618 (slide 2015). From 1880 N., 1910 W., Sec. 27, T. 47 N., R. 47 W., Michigan.

Specimen 7618 is massive, medium grained, dark reddish brown, and of a subvitreous luster; 9004 is nearer a slate, the quartzitic parts being interstratified with narrow green belts.

These slides are intermediate between the fragmental quartzites and the argillaceous slates of this member. The fragmental quartz particles still predominate, along with some fragmental feldspar, the quartz grains being either without enlargements or with only very narrow ones. Contained between the fragments and serving as a matrix to them is a very fine material composed of brown iron oxide, kaolin, minutely crystalline quartz, and chlorite. Numerous flakes of sericite occur also, appearing rather as if fragmental, or altered from the fragmental mica, than as if secondary to some of the other fragmental constituents of the rock (Pl. XIX, Fig. 3).

*From the Aurora mine section.*

26. Slaty and cherty quartzite, from the uppermost layers, being the foot wall of the Aurora mine. Specimen 7614 (slide 2014). From 624 N., 1000 W., Sec. 23, T. 47 N., R. 47 W., Michigan.

The thin section shows an interlamination of coarser and finer materials. The coarser bands are composed in about equal quantity of fragments of fine quartz individuals and of a chloritic chert. The finer grained bands are made up of fragments of quartz and feldspar, along with particles of probably secondary silica, chlorite, and iron oxides.

*From the section at the Mount Hope mine.*

27. Ferruginous quartzite, from the uppermost layers, being the foot-wall at the Mount Hope mine. Specimen 7611 (slide 2307). From 1140 N., 0 W., Sec. 23, T. 47 N., R. 47 W., Michigan.

The thin section is composed of large interlocking quartz areas, at the junctions of which are often films of brown iron oxide. Each quartz area is furnished with a very distinct, well rounded, fragmental core.

*From the section between the Blue Jacket and First National mines.*

28. Cherty quartzite, from a low horizon. Specimen 7602 (slide 2010). From 1900 N., 1150 W., Sec. 19, T. 47 N., R. 46 W., Michigan.

Both in the hand specimen and in the thin section this rock is like 23, which occurs at a similar horizon.

29. Ferruginous quartzite, from a middle horizon. Specimen 7603 (slide 2303). From 1980 N., 900 W., Sec. 19, T. 47 N., R. 46 W., Michigan.

The specimen and thin section are as in 27.

*From the Colby mine section.*

30. Sericitic and chloritic slate (novaculite), from a low horizon. Specimen 9523 (slide 3091). From 775 N., 770 W., Sec. 16, T. 47 N., R. 46 W., Michigan.

This rock in specimen and thin section resembles closely 9038 and 9044 in 18, from the West branch of the Montreal river. (Pl. XVIII, Fig. 4.)

31. Quartzite, from a high horizon. Specimen 7591 (slide 2006). From 1000 N., 548 W., Sec. 16, T. 47 N., R. 46 W., Michigan.

This rock in specimen and thin section is like 7620 in 24 from the Ashland mine section.

*From the Tilden mine section.*

32. Quartzite, from an upper horizon. Specimen 12524 (slide 5333). From 1228 N. to 1153 N., 1166 W., Sec. 15, T. 47 N., R. 46 W., Michigan.

The rock is a fine grained, massive, greenish gray vitreous quartzite, having a conchoidal fracture.

The thin section consists chiefly of rather small interlocking quartz areas, each with its fragmental core. A considerable quantity of fragmental feldspar is also present. Outlining the original fragments of quartz are films of chlorite and ferrite, the greenish color of the rock being produced by the former. The chlorite and ferrite particles also occur where the enlargements of the different grains meet each other.

*From the Palms mine section.*

33. Conglomerate. Specimens 12522 (slide 5388), 12893 (slide 5511). From SE. ¼ of NE. ¼, Sec. 15, T. 47 N., R. 46 W., Michigan.

A breccia composed chiefly of white, gray, black, and red chert, but containing also fragments of other minerals and of granite, and resting directly upon the granite.

The thin sections are made up mainly of rounded fragments of chert included in a matrix of the same material. This chert, in both fragments and matrix, consists of an exceedingly minutely crystalline quartz, with possibly some intermingled amorphous silica. There are also included in the matrix rounded particles of quartz and feldspar, areas of chlorite and of some carbonate, and complex fragments of granite.

*From the Black river section.*

34. Chloritic and cherty slates and quartzites, from a middle horizon. Specimens 9460 (slide 3078), from 1445 N., 1185 W.; 9461 (slide 3310), from 1460 N., 1185 W.; 9462 (slide 3079), from 1475 N., 1185 W.; 9463 (slide 3080), from 1490 N., 1185 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

These specimens represent interstratifications of slaty and quartzitic phases. The slaty phases are fine grained, in places green, in places brown, with variations from one color to the other. The quartzitic layers are gray and vitreous.

In thin sections the slaty and quartzitic phases differ from each other only in coarseness of grain and proportions of the different mineral constituents, the chief ones of which are quartz, feldspar, and chlorite, the two former being plainly in a fragmental condition. In 3079 the quartz fragments are greatly preponderant and widely enlarged. In the slaty portions, mixed with the small quartz grains, are many fragments of a minutely complex silica, which at times is in part probably even amorphous or opaline. The chlorite is particularly plentiful in the slaty phases. (Pl. XVIII, Fig. 3.)

35. Sandstones, from a high horizon. Specimens 9512 (slide 3088), 9513 (slide 3089), from 1510 N., 1950 W.; 7557*a* (slide 1986), from 1570 N., 1950 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

These are fine grained, arenaceous rocks, having strangely marked sedimentation laminæ. Some specimens are light greenish gray, others are dark brown; while in still others are found both colors arranged in the most irregular manner.

The thin sections are composed mainly of medium sized fragments of quartz and feldspar. The quartz fragments are mostly from single individuals, and have generally received secondary enlargements, but some of them are composed of finely crystalline cherty silica. The rather plentiful cementing material appears to be a mixture of minutely crystalline quartz with flakes of kaolin, chlorite, and brown iron oxide, the browner portions, as seen macroscopically, differing from those that are of paler color only in containing a larger quantity of the iron oxide.

*From the Sunday lake section.*

36. Graywacke-slates (feldspathic quartz-slate), from a middle horizon. Specimens 9442 (slide 3071), from 360 N., 1600 W.; 9443 (slide 3072), from 325 N., 1600 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

These rocks resemble closely 9038 to 9044 of 18. The sheen of hydro-mica is less marked than in those rocks.

The fragmental particles of quartz and feldspar, of which these sections are mainly composed, are more rounded and larger than in 2771 and 2774 of 18, to which in all other respects these rocks are closely similar. The enlargements of the quartz fragments are broad and well marked. In 3071 chlorite appears to be the chief interstitial material; in 3072 the chlorite is mingled with much kaolin and minutely crystalline silica. (Pl. XVIII, Figs. 1 and 2.)

37. Vitreous quartzites, from near the top of the Quartz-slate member. Specimens 9440 (slide 3069), from 450 N., 1625 W.; 9441 (slide 3070), from 400 N., 1625 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

The rock 9440 is compact, gray, and coarse grained, while 9441 is fine grained and pink. Both break with a conchoidal fracture.

The thin section 3069 furnishes a beautiful illustration of the true nature of the ordinary vitreous quartzite; the large and deeply interlocking areas of quartz which mostly compose it having each its plainly outlined fragmental core. These cores are outlined particularly by the broad films of the chlorite and limonite with which they are furnished. Slide 3070 differs from 3069 only in being much finer grained and in having mingled with the quartz a good deal of fragmental feldspar.

*From the section in the adjoining portions of Secs. 10, 15, and 14, T. 47 N., R. 45 W., Michigan.*

38. Sideritic and chloritic schists, from the bottom of the Quartz-slate member, immediately beneath the succeeding number. Specimens 12545 (slide 5337), 12546 (slide 5338). From 1975 N., 800 W., Sec. 15, T. 47 N., R. 45 W., Michigan.

The rocks are greenish gray, fine grained, and have a well developed fibrous structure. They show lamination only by somewhat difficult and irregular parallel fracture. Contained in the fine material are numerous larger grains of feldspar.

While the thin sections have a strongly crystalline appearance, they show that the rocks are unmistakably fragmental. Fragments of quartz and feldspar of medium size are contained in a fine grained matrix of a very complex character. The clastic quartz and feldspar are in part well rounded, but most of the grains are quite angular, indicating the probability that they are near their original source. Some of the quartz-grains are distinctly enlarged. Many of the feldspar fragments are much altered, the resultant products being chlorite, kaolin, sericite, and probably quartz. A few rounded complex fragments from a basic eruptive are present. The matrix of the sections is a finely complex mass of quartz, feldspar, chlorite, sericite, kaolin, and a little ferrite.

39. Quartzites, from the bottom of the Quartz-slate member, immediately beneath 40. Specimens 9444 (slide 3133), 7507 (slide 1952). From 1985 N., 750 W., Sec. 15, T. 47 N., R. 45 W., Michigan.

The specimens and thin sections resemble closely those of 24.

40. Chert-conglomerate, from near the base of the Quartz-slate member, and immediately beneath 7505 (41). Specimens 9449 (slide 3134), 7506 (slide 1951). From 1998 N., 750 W., Sec. 15, T. 47 N., R. 45 W., Michigan.

The matrix of this rock is fine grained, compact, and of a gray color. In this matrix are very numerous rounded pebbles of chert, which are sometimes several inches in diameter.

In the thin sections the matrix of this conglomerate is seen to be composed of materials of two degrees of fineness. The finer appears, as is general with the slates of this member, to be composed of minutely crystalline, and, at times, even an amorphous silica, with which are mingled some kaolin and ferrite. The coarser portion of the matrix is distinctly fragmental and is made up wholly of quartz pieces, nearly all of which show the usual secondary enlargements. The pebbles of the conglomerate are wholly of a chert identical with that characteristic of the limestone member, as previously described. They are seen to be made up of an intimate mixture of a minutely crystalline and an amorphous or opaline silica.

41. Sandstone, from a very low horizon. Specimen 7505 (slide 1948) From 0 N., 750 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

This rock in specimen and thin section resembles 35 from the Black river section.

42. Argillaceous slates or shales, from a low horizon. Specimens 7502 (slide 1944), from 2 N., 177 W.; 7503 (slide 1945), from 10 N., 177 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

Aphanitic, highly laminated slates or shales having a strong clayey odor, and colors varying from reddish brown to greenish gray.

The thin sections differ from those of 43 in that the fragmental particles of quartz and feldspar are now insignificant in quantity, the clayey matrix assuming a relatively important role.

43. Argillaceous slates or shales. Specimens 7504 (slide 1946), from 1985 N., 450 W.; 7505*a* (slide 1949), from 0 N., 750 W., Secs. 10 and 15, T. 47 N., R. 45 W., Michigan.

Compact clayey slates or shales, not always showing the lines of sedimentation; in color varying from greenish gray to reddish brown, some specimens presenting both colors.

The thin sections show small fragments of quartz and feldspar, the former the more abundant and commonly provided with secondary enlargements, imbedded in a groundmass composed of ferrite, chlorite, kaolin, and minutely crystalline silica. (Pl. XIX, Fig. 4.)

44. Sericitic graywackes, from a low horizon. Specimens 9432 (slide 3130), from 1925 N., 1915 W.; 9435 (slide 3132), from 1935 N., 1940 W.; 9436 (slide 3068), from

1935 N., 1940 W.; 7510 (slide 1966), from 1925 N., 1890 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

These are fine grained slaty rocks, of a uniform texture, and greenish to pinkish gray colors upon the cleavage surfaces. Except in 9432 the sheen of mica is seen.

The thin sections of these rocks, with the exception of 3130, which is peculiar in containing a relatively small quantity of sericite, are very close to 2771 and 2774 in 18.

45. Quartz-slate and chloritic slate. Specimens 9453 (slide 3074), 9452 (slide 3073). From 200 N., 800 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

These slates consist of alternating bands of coarse quartzitic and aphanitic greenish material.

The aphanitic portions of these rocks, as seen macroscopically, show in the thin section an intimate mixture of minute particles of quartz, feldspar, chlorite, kaolin, and biotite. The coarser seams show a groundmass of the same nature, in which are carried an abundance of rounded fragments of quartz, with which are associated numerous fragments composed of an exceedingly minutely crystalline silica, mingled with flakes of kaolin, or of a micaceous material. It seems not improbable that each of these fragments may be due to the decomposition of a single feldspar.

46. Quartzite and slate, from an upper middle horizon. Specimens 7495 (slide 1940), from 300 N., 0 W.; 7496 (slide 1941), from 140 N., 0 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

These specimens represent an interstratification of greenish gray, semivitreous, medium grained quartzite, and argillaceous slate.

The thin sections of these rocks are from the more quartzitic portions of the specimens. They closely resemble those of 37.

47. Chloritic and sericitic quartzite, from a high horizon. Specimen 9454 (slide 3075), from 370 N., 800 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

A fine grained, greenish gray, massive quartzite, with a conchoidal fracture.

The thin section shows large fragments of quartz and feldspar buried in a groundmass of minutely crystalline silica, mingled with chlorite and sericite flakes. The feldspar fragments are much altered, the resulting products being chlorite, sericite, and quartz. The manifest production of these three secondary minerals from the larger fragments of feldspar makes exceedingly probable a similar origin for the same minerals in the matrix.

48. Quartzite, from immediately beneath the Iron-bearing member at the top of the Quartz-slate member. Specimen 7513 (slide 1954), from 420 N., 873 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

A medium grained, massive, semivitreous quartzite.

The thin section of this rock closely resembles 3069 in 37.

*From the section in northern part of Sec. 14, T. 47 N., R. 45 W., Michigan.*

49. Chert-conglomerate, from the bottom of the Quartz-slate member. Specimens 9418 (slide 3059), 9419 (slides 3126, and 3127), from 1775 N., 1075 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

The matrix of this conglomerate is fine grained and of a dark green color. In the matrix are buried very plentiful rounded fragments of translucent opaline chert, which vary in size from three-fourths of an inch to two inches in diameter.

The matrix of this conglomerate is seen in the thin section to be composed of rather small fragments of quartz and feldspar, the former predominating, mingled with a considerable proportion of interstitial cherty and amorphous silica, along with some chlorite, brown iron ore, and kaolin. Large particles of mica, apparently fragmental in nature, are also seen. The pebbles are wholly composed of a chert identical with that of the limestone member below, being in part a minutely crystalline and in part an amorphous silica. The slides closely resemble 3134 and 1951 in 40. (Pl. XVII, Fig. 3.)

50. Chert-breccia or conglomerate, from the bottom of the Quartz-slate member. Specimen 9420 (slide 3060), from 1775 N., 1225 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

This rock differs from 49 in that its matrix appears to be a chloritic and ferruginous chert, while in the latter the matrix is entirely fragmental.

The pebbles and matrix in thin section differ from each other only in purity; the pebbles being composed of a semicrystalline cherty silica, while the matrix is composed of the same silica mingled with much ferrite and chlorite. A few large fragments of quartz are seen.

51. Quartzite, from near the bottom of the Quartz-slate member. Specimen 9421 (slide 3061), from 1775 N., 1200 W., Sec. 14, T. 47 N., R. 45 W., Michigan.

A dark reddish, semivitreous quartzite.

In the thin section well rounded quartz fragments with small enlargements are buried in a fine interstitial material composed of minutely crystalline and amorphous silica, kaolin, chlorite, and brown iron oxide.

*From the exposures on the Peninsular Mining Company's property.*

52. Ferruginous quartzite. Specimen 12789 (slide 5476), from 1910 N., 1040 W., Sec. 13, T. 47 N., R. 45 W., Michigan.

A medium grained, vitreous quartzite, stained a dark brown color by iron oxide.

About one-half of the thin section is composed of widely enlarged fragments of quartz; the main part of the remainder of the section consists of minutely crystalline silica, mingled with chlorite and ferrite particles, with a few fragments of orthoclase, microcline, and plagioclase.

*From the exposures in Sec. 17, T. 47 N., R. 44 W., Michigan.*

53. Feldspathic quartzites and quartz-slates, from near the bottom of the Quartz-slate member. Specimens 9410 (slides 3125 and 3271), 9411 (slide 3052), from 525 N., 1925 W.; 9389 (slide 3043), from 350 N., 1550 W.; 9390 (slide 3044), from 350 N., 1550 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

Some of these specimens are slaty, while others are more quartzitic and vitreous. The color varies from gray to black, being in places mottled with red spots.

The thin sections are made up of fragments of quartz, feldspar, chert, and jasper. The quartz fragments are usually widely enlarged; the cherty and jaspery pieces seem in the main to represent the chert of the limestone belt immediately below. There are, however, a good many fragments which appear to be intimate mixtures of chlorite, minutely crystalline quartz, ferrite, and a koalin-like mineral. These may possibly be altered feldspars. The sparse matrix is very heavily stained with brown iron oxide.

54. Chloritic slate, from near the base of the Quartz-slate member. Specimen 9409 (slide 3051), from 525 N., 1925 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

An aphanitic light green slate or shale, cleavable into thin plates parallel to the lamination.

The thin section shows an intimate mixture of an exceedingly minutely crystalline quartz, with flakes of pale green chlorite.

55. Clay-shales or clay-slates, from near the base of the Quartz-slate member. Specimens 9391 (slide 3045), from 350 N., 1550 W.; 9412 (slide 3053), from 525 N., 1925 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

These are fine grained and finely laminated slates or shales; 9412 is gray, and 9391 reddish purple. The latter shows plentiful flakes of sericite.

The thin sections of these rocks are closely like those of 42.

56. Graywackes and chloritic slates, from a low horizon. Specimens 12667 (slide 5391), 12668 (slide 5392), from 15 N., 65 W.; 12669 (slide 5393), from 78 N., 42 W.; 12670 (slide 5394), from 100 N., 105 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

These specimens range from slaty to more massive kinds, varying in color through dark green, reddish, dark brown, gray, and greenish shades. All are aphanitic.

The thin sections show that they are of the typical slate of the Quartz-slate member, being composed of fragments of quartz and feldspar, buried in the usual argillaceous matrix, in which chlorite, kaolin, sericite, and a minutely crystalline quartz are recognizable.

57. Feldspathic quartzite or graywacke, from a middle horizon. Specimen 9394 (slide 3122). From 470 N., 975 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

A coarse grained, greenish gray, vitreous quartzite.

The thin section of this rock is closely similar to 2016 in 24.

58. Chloritic slate, from a high horizon. Specimen 12682 (slide 5404). From 477 N., 790 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

An olive green rock of nearly aphanitic texture and slaty structure.

The thin section shows a predominating fine grained background composed of flakes of chlorite, sericite, and kaolin, with some minutely crystalline quartz, through which are scattered rather plentifully small fragments of quartz and feldspar. The section is cut across the lamination of the slate, and shows flakes of chlorite, sericite, etc., arranged with their longer axes in a common direction.

59. Quartzites, from a high horizon. Specimens 12680 (slide 5402), 12681 (slide 5403). From 477 N., 795 to 825 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

These specimens, taken from the same pit, differ in character; 12680 is a massive, medium grained, ordinary quartzite; 12681, a massive, strongly magnetitic quartzite.

The thin section 5402 is that of a typical quartzite, whose induration and vitreous appearance are due to the wide enlargement of each grain. Broad films of chlorite and ferrite separate cores and enlargements and occur again along the contacts of the enlargements themselves. There are some irregular areas composed of hematite, magnetite, and a minutely crystalline quartz. The quartz areas are all arranged with their longer axes in a common direction parallel to the structure, which perhaps indicates subjection to pressure. The thin section 5403 differs from 5402 in that the fragmental quartz grains compose only about half of the mass of the rock, there being a very plentiful interstitial material consisting mainly of magnetite and containing also a considerable quantity of hematite, chlorite, and minutely crystalline quartz. The magnetite in this matrix is for the most part in very regular outlined crystals. These crystals occur also within the enlargements of the quartz fragments, and occasionally appear to be even within the cores themselves, although this appearance may be due to the positions at which these grains are cut. They also occur somewhat plentifully along the bounding line between fragmental cores and enlargements. That portion of the magnetite which occurs within the cores themselves appears to be very distinctly more plentiful in the neighborhood of their outlines. As to this singular occurrence, see the description of 7.

*Contacts with the Cherty limestone member.*—As a rule the contact of the Quartz-slate member with the more southerly rocks is concealed. At several points, however, it may be seen, either in contact with or very close indeed to exposures of the white chert or of the limestone itself of the underlying formation, and in other places again with the granite, gneiss, or schist of the Southern Complex. The contacts with white chert are at Penokee gap, Sec. 14, T. 44 N., R. 3 W., Wisconsin; in the NW. ¼ Sec. 16, T. 44 N., R. 2 W., Wisconsin; in the northern part of Sec. 14, T. 47 N., R. 45 W., Michigan; and in the SW. ¼ Sec. 17, T. 47 N., R. 44 W., Michigan. It has already been intimated that in these places there are found in the lower layers of the quartz-slate numerous fragments of the chert which immediately underlies it, and sometimes the rock becomes a recomposed quartz rock, distinguishable from the underlying formation only by the presence of a small portion of plainly recognizable fragmental material. These peculiar occurrences are taken to indicate that between the two formations was a more or less extended erosion interval. The chert fragments in these places occur both in basal conglomerates and in thin bands interstratified with a nonconglomeratic slate. As the contact is receded from the chert fragments become very soon of smaller size, although pieces of the same chert are occasionally microscopically recognizable even in the higher horizons of the formation.

*Contacts with the Southern Complex.*—At Potato river and West branch of Montreal river the Quartz-slate member is seen in contact with greenish schists on the south. The Potato river junction is illustrated by Fig.


FIG. 5.—Map of exposures at Potato river. Scale: 1 inch=264 feet.

5, which shows the position of the various exposures. The river here has a bold bank some 75 feet in height, along the face of which the contact between the slate and the underlying schists is finely exposed. The best view of the contact is that obtained at the foot of the bank, where there is a perpendicular cliff of bare rock. The details of the junction shown on this cliff are represented in Figs. 6 and 7. The more southerly rock is a

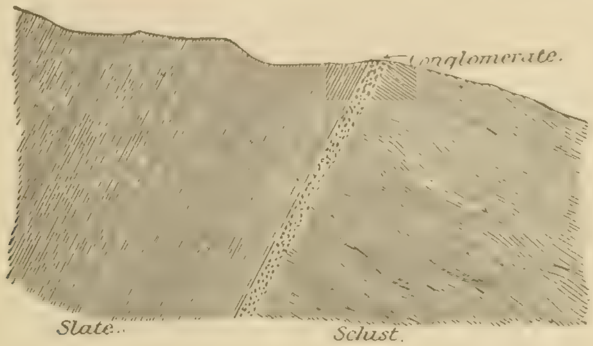



FIG. 6.—Junction of quartz-slate and green schists at Potato river.
Scale: 1 inch=20 feet.

greenish chloritic schist, with a fibrous or parallel structure in a direction almost exactly at right angles to the junction line. The thin sections show it to be probable that this rock was once some sort of a porphyritic eruptive. Whatever its original nature, however, it has certainly been most intensely altered, the minerals having been rearranged into new combinations and a parallel structure superinduced. Moreover, this alteration was all carried out previous to the deposition against it of the quartz-slate, the lowest layers of which are crowded with fragments from the schist of all sizes, from a fine detritus to blocks several feet in diameter. This exposure, then, shows one of the handsomest instances of unconformity that we have ever seen, the worn upper surface of the schist being traceable and having fitted into it a finer detrital material belonging to the overlying fragmental slate. The accompanying sketches of this contact were drawn on the ground and represent actual occurrences, the sizes of all the larger fragments of the conglomerate band being drawn in Fig. 7 to scale, while the structures of the underlying schists and overlying slates are exactly as represented. The junction at the West branch of the Montreal is in all respects similar to that on the Potato, except that the exposure of the contact is much smaller, and therefore less satisfactory. The similarity of the rocks at the two places is such as to render it extremely probable that the same contact extends for all the distance between the two streams.

Directly south of the Palms mine (Sec. 14, T. 47 N., R. 45 W., Michigan), upon a railroad spur, and about one-fourth of a mile to the west along the same track, are seen contacts of the quartz-slate and the granite. The basal conglomerate is a mere facing. The fragmental material also penetrates the granite in cracks which existed at the time of the deposition of the quartz-slate. Some of these seams of conglomerate extend from a foot to several feet into the granite. The pebbles of the conglomerate include jasper, chert, and quartz, as well as granite. The chert was probably derived from the Cherty limestone formation, while the jasper, perhaps, came from an iron-bearing formation belonging with the Cherty limestone series, but now wholly removed by erosion.

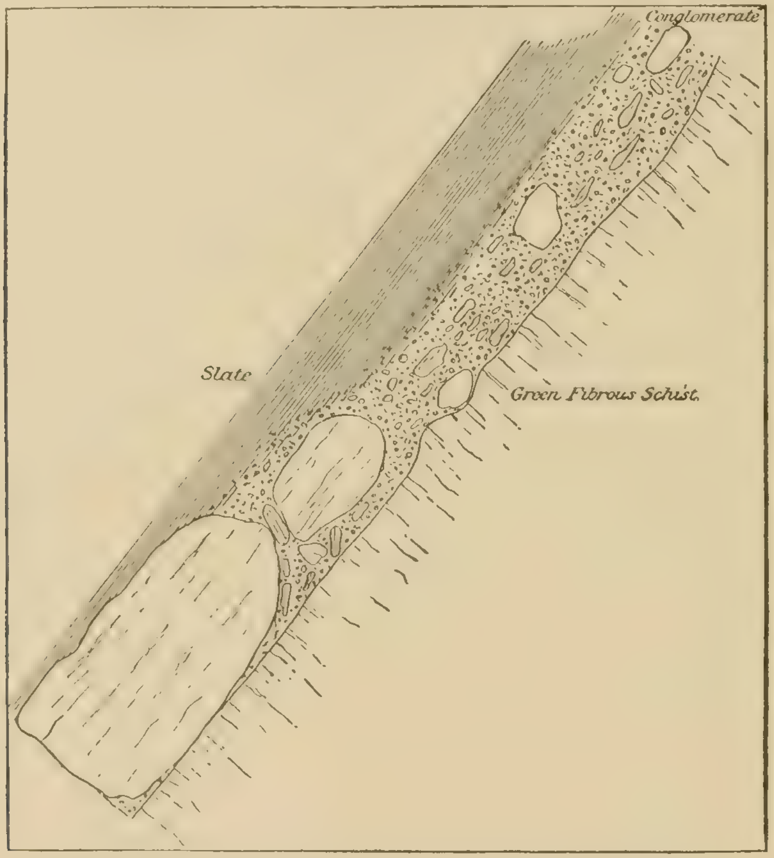



FIG. 7.—Large-scale drawing of junction of quartz-slate and green schists at Potato river.
Scale: 1 inch = 3 feet.

A contact between the Quartz-slate and the granite, very similar to that at the Palms, occurs just south of the Aurora mine.

*Change to the Iron-bearing member.*—The contact between the Quartz-slate and the Iron-bearing member which immediately overlies it is exposed in scores of places, as a result of mining operations. Nowhere where it has been seen, however, does this contact suggest anything but the most abrupt change from one formation to the other. In places the upper part of the quartzite appears to be no more than a coarse sand, and occasionally blocks of it are contained in the basement layers of the iron formation. This would seem to indicate that here and there the quartzite was somewhat broken before the beginning of the deposition of the overlying member or else by dynamic movements. Also, the upper part of the quartzite is often heavily stained with iron oxide which has been carried down along the cracks by leaching action. Nevertheless, the change from one formation to the other is astonishingly abrupt, it often being possible to locate to a fraction of an inch the plane between the two formations. Upon one side of this plane is the coarse fragmental quartzite; upon the other the nonfragmental varied rocks of the Iron-bearing member.

*Prominent exposures.*—As stated at the beginning of this chapter, the Quartz-slate is one of the best and most continuously exposed members of the entire Penokee series. This will be realized from an inspection of the detailed maps herewith (Pls. v to xiii), upon which, however, are placed only the more accurately located exposures. Further detailed work and measurements would undoubtedly enable us to locate about as many more. In the following notes we refer only to those exposures which are particularly prominent, either on account of their size or because they show some noteworthy peculiarity. Beginning at the west, the first exposures worthy of mention are the large ones running along the north side of the Marengo river in the extreme southwestern portion of Sec. 14, and northwestern portion of Sec. 23, T. 44 N., R. 5 W., Wisconsin. The river runs nearly along the strike of the slate, and also apparently along its contact with the more southern granite, which shows in bold exposures all along the south side of the river. The slate is one of the biotitic and chloritic varieties. In the extreme northeastern part of Sec. 24, T. 44 N., R. 4 W., Wisconsin, several exposures of the quartzite, which forms the uppermost horizon of the quartz-slate, are to be seen. One of these lies on the eastern line of the section at about 400 steps south of the northeast corner. Immediately to the north of this quartzite, but not directly in contact with it, are exposures of the Iron-bearing member, and immediately to the south larger ones of a biotitic and chloritic slate of the Quartz-slate. Still larger exposures of quartzite and biotitic quartz-slate are shown along the crest of the Penokee range in its course across Sec. 17, T. 44 N., R. 3 W., Wisconsin. The easternmost one of these exposures shows a contact on the north with a magnetitic schist. This contact lies 550 steps south and 400 steps west of the northeast corner of the section. Similar large exposures show in the northern part of Secs. 15 and 16, but much more striking and complete exposures are those met with in the vicinity of Penokee gap, where Bad river passes the Penokee range from south to north. The position and extent of these exposures will be best understood by an inspection of Pl. XXXVI. The most striking of them is that which forms a bold hill at the southern end of Penokee gap itself. Here the entire width of the Quartz-slate is seen, from its contact with the chert of the underlying limestone formation on the south, northward to its contact with the iron formation. The latter contact is between the usual uppermost vitreous quartzite of the Quartz-slate and an actinolite-magnetite-slate of the Iron-bearing member. Contacts are also seen at two points respectively 300 and 400 paces farther west. Except in the uppermost horizons where we have the usual vitreous and relatively massive quartzite, the greater portion of the rock here exposed is quite thinly slaty, seams of light and dark gray and light and dark greenish slate alternating rapidly with one another. On the whole these slates are more generally of the chloritic and biotitic phases above described. Proceeding farther eastward the next very noteworthy exposures are those at mount Whittlesey on the south side of the Penokee range. This bold south-facing cliff lies at the corner of Secs. 8, 9, 16, and 17, T. 44 N., R. 2 W., Wisconsin. The northward angle of inclination of the slate here varies from 56° to 65°, the edges of the inclined layers projecting on the face of the cliff in such a manner as to make an exceedingly jagged and irregular precipice. The greater part of the slate here belongs to the chloritic and biotitic quartz-slate phase. Quite a large portion of the thickness of the formation is exposed at the gorges of Carrie's creek, NE. ¼ Sec. 11, T. 44 N.,

R. 2 W., Wisconsin; and again in the NE. ¼ of the SE. ¼ Sec. 1, T. 44 N., R. 2 W., Wisconsin, where are to be noted among the more usual phases of the slate a number of layers of a pink to brick red and lead gray shale, a phase which has thus far not been noted to the west of this point, though occurring somewhat frequently farther to the east. The greater part of the thickness of the Quartz-slate formation is exposed again at the gorge of Tylers fork, SE. ¼ of the NE. ¼ Sec. 33, T. 45 N., R. 1 W., Wisconsin, the contact with the overlying iron formation being finely exposed on the west bank of the river, as indicated on the following sketch map (Fig. 8). The

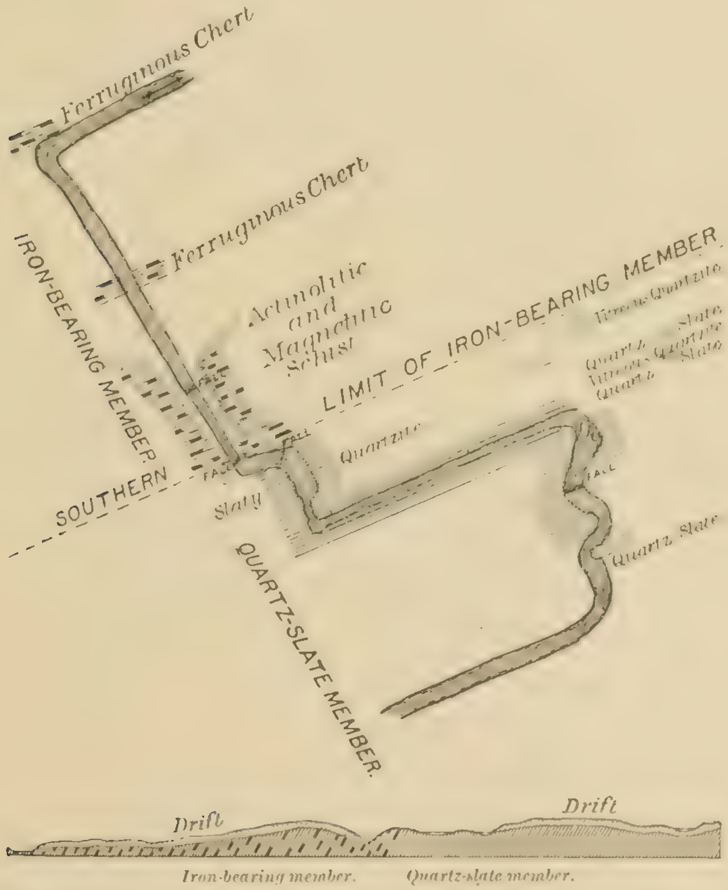



FIG. 8.—Map and section showing position of rock exposures at Tylers fork. (From Plate XIV, vol. III, Wisconsin Geological Survey.) Scale: 1 in. = 310 feet.

uppermost vitreous quartzite shows here very plainly, while the body of the formation is distinctly nearer in character to the feldspathic quartz-slate phase above described, although there are interleaved with the predominating variety some of the biotitic and chloritic slates, novaculite, and a little red clay shale. At the gorge of the Potato river, in the NE. ¼ of the SE. ¼ Sec. 19, T. 45 N., R. 1 E., Wisconsin, the exposures are again large, showing the entire width of the quartz-slate. The positions of these exposures are shown in Fig. 5. The contact on the south between this slate and the underlying greenish schist has already been described. The usual vitreous quartzite is found as the uppermost horizon and the body of the formation is made up of thinly laminated feldspathic quartz-slates. The exposures at the gorge of the West branch of the Montreal (Fig. 9) are

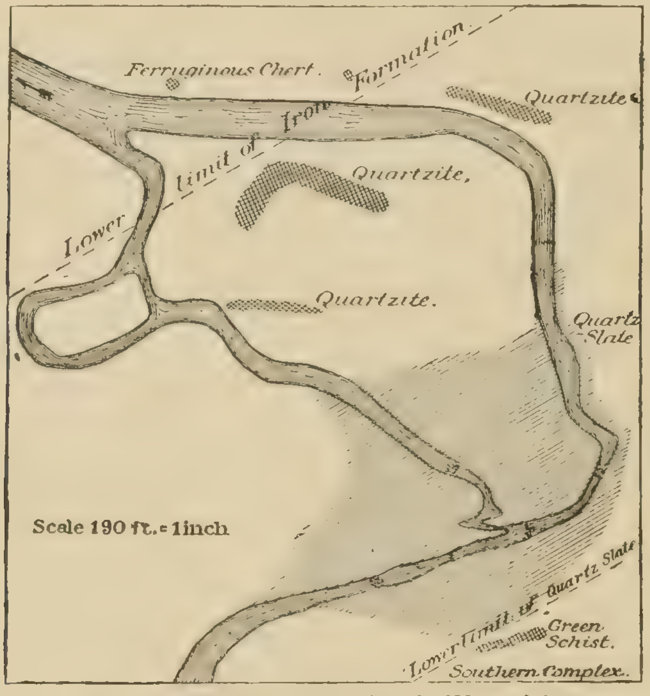



FIG. 9.—Map of exposures at West branch of Montreal river.

quite similar to those on the Potato, showing the lower junction but not the upper. From here eastward to the vicinity of Sunday lake the natural exposures of the Quartz-slate member are much rarer and smaller than those already described. However, in a very large number of places the mining or exploring operations of the district have uncovered this formation for small distances. Naturally the most commonly uncovered portion of the formation is its uppermost quartzite member, which is ordinarily the foot-wall of the mines of the Gogebic district; while the lower portions of the formation have often been exposed in test-pitting operations, so that the course and width of the belt can be quite accurately laid down. It may be noted that there are large exposures on the west side of Sec. 14, T. 47 N., R. 46 W., Michigan, where the several railroad spurs running to the Palms and Anvil mines have cut deeply into the slate. On the Black river, in the northern part of Sec. 13, T. 47 N., R. 47 W., Michigan, are natural exposures of the formation. To the east of Sunday lake, in Sec. 10, T. 47 N., R. 45 W., Michigan, where the Quartz-slate formation has an unusual thickness and its outcrop belt an unusual width, there are again very large and continuous exposures, displaying the entire thickness of the formation, which here reaches something like 800 feet. The Quartz-slate here makes up the bulk of two bold bluffs, one in the southwestern portion and the other in the southeastern portion of Sec. 10, and extending thence into Secs. 11 and 14. About all the phases that are characteristic of the Quartz-slate formation, with the exception of the chloritic and biotitic slates, are displayed in these exposures. The last exposures of this formation met with before reaching the Presque Isle river are those in the southern part of Sec. 17, T. 47 N., R. 44 W., Michigan.

*Mode of deposition and source of material.*—It has already been made evident that the various rock phases of which the Quartz-slate member is composed are of a detrital nature. Even the finest grained phases and the finer interstitial material of the coarser phases, although at times not now plainly showing their fragmental character, are taken, notwithstanding this, to be wholly of detrital origin, being composed of the same materials as the coarser phases, either in the original unaltered condition, or, as is often the case, somewhat changed by metasomatosis, the chlorite, kaolinite, micas, and finely crystalline quartz being in the main secondary derivatives from feldspathic detrital material.

The nature of the most of the detritus of which this formation is mainly composed is such as to suggest very strongly the derivation of its material from some sort of granitic or gneissic rock. The pieces of quartz, orthoclase, microcline, plagioclase (probably albite and oligoclase), and mica, are in their association and in their peculiarities just what we would expect in a granitic detritus. And more than this, they are entirely similar to the particles of these same minerals as they appear in granite and gneiss which is so largely exposed immediately to the south. One of the most noteworthy things about the formation (excepting the upper horizon) is the relatively small degree of assortment that the detrital material of which it is composed has received. The detritus, which, while quartz predominates, is still largely composed of feldspar and mica particles, can not have been carried to any great distance from its source. The quartzite, however, which forms the uppermost horizon of the formations, represents, of course, a more thoroughly assorted detritus, and it is very interesting in this connection to note the extraordinary persistency of this horizon.

At those places in which the Quartz-slate is in contact with the Cherty-limestone formation, or outcrops of it are not distant, a considerable portion of the detritus is often derived from this formation, and close to the contact the cherty detritus sometimes becomes predominant, when we have true basal conglomerates or recomposed rocks. In the higher horizons of the Quartz-slate the cherty detritus is usually sparse or absent. The presence of red jasper fragments in certain of the basal conglomerates suggests the former presence of an earlier Iron-bearing formation.

*Summary.*—The Quartz-slate member is given this name because of its slaty character, and of the fact that quartz is its prominent constituent.

In geographical extent it is the most continuous belt of the Penokee range, extending from the westernmost exposures of the series nearly to Gogebic lake.

The thickness of the greater portion of the belt varies from 300 to 400 feet, but its maximum thickness is as great as 800 feet.

Petrographically the Quartz-slate has many varieties; the most persistent of these is a vitreous quartzite, which is found at the uppermost horizon of the member.

The quartz-slates are always fragmental. Their induration is due (1) to the enlargement of quartz fragments, rarely to enlargement of the feldspars; and (2) to the alteration of the feldspars to other minerals, the most abundant of which are biotite, chlorite, and quartz.

At several places the Quartz-slate is in contact with the Cherty limestone, and here a large part of its débris is from this lower member. It is more frequently in contact with the Southern Complex. At these contacts true basal conglomerates are found. In one or two places at these contacts unconformities are nicely shown.

The change to the overlying Iron-bearing member is always abrupt, its nonfragmental rocks being found upon the vitreous quartzite.

The greater part of the material for the Quartz-slate member is derived from the underlying rocks of the Southern Complex, although locally it contains material from the Cherty limestone member.

# CHAPTER V.

BY R. D. IRVING AND C. R. VAN HISE.

## THE IRON-BEARING MEMBER.



### SECTION I. DETAILS.

*Applicability of the name.*—The name given to this member is justified by its large content of iron. Certain phases of the belt contain little or no iron, being wholly made up of silica in one form or another, but such phases have no very great extent, there being nearly always present at least a little iron oxide, while throughout the greater portion of the belt the content of metallic iron certainly exceeds 10 per cent. Very considerable thicknesses are met with in which the amount of iron reaches 20, 30, 40, and even 50 per cent. Careful measurement and sampling of the west cliff of Penokee gap at the passage of Bad river through the Penokee range showed that this cliff is made up of the following divisions—these divisions being measured at right angles to the strike, beginning with the lowest part of the cliff: 19 feet, containing 44·94 per cent of metallic iron; 7 feet 6 inches, containing 17·10 per cent; 18 feet, containing 49·4 per cent; 6 inches, nearly free from iron; 6 feet, containing 36·64 per cent; 36 feet, containing 45·87 per cent. Above and below the layers shown in this cliff are others nearly or equally rich in metallic iron, alternating with layers in which the iron is present, but in smaller quantity.

The following figures indicate the richness of various other thicknesses at Penokee gap: 7 feet, containing 43·29 per cent; 2 inches, included within the preceding measurement, 62·21 per cent; 10-inch rich seam from a different place, 57·52 per cent. The following are other figures, indicating the content of iron in considerable thicknesses at various points on the Penokee range from the Potato river westward: (1) 5 feet, containing 11·23 per cent; (2) 15 feet, containing 12·99 per cent; (3) 15 feet, containing 25·81 per cent; (4) 75 feet, containing 26·64 per cent; (5) 25 feet, containing 36·14 per cent; (6) 10 feet, containing 37 per cent; (7) 40 feet, containing 37·75 per cent; (8) 20 feet, containing 37·88 per cent; (9) 20 feet, containing 37·93 per cent; (10) 3 feet, containing 38·75 per cent; (11) 58 feet, containing 41·93 per cent; (12) 5 feet, containing 44·43 per cent; (13) 150 feet, containing 45 per cent; (14) 3 feet, containing 45·07 per cent; (15) 75 feet, containing 48·12 per cent; (16) 15 feet, containing 49·73 per cent; (17) 50 feet, containing 53·46 per cent.[1] These figures, of course,

[1] These figures are taken from tables of analyses given in the third volume of the Geology of Wisconsin, pp. 156–160. The samples were mainly selected by R. D. Irving; in a few cases by E. T. Sweet. They were all made by taking a large number of small pieces across the entire thickness indicated in each case. The places from which the samples were selected are as follows: (1) Exploring trench, NE. ¼ Sec. 15, T. 44 N., R. 3 W., Wisconsin; (2) exposure SW. ¼ Sec. 1, T. 44 N., R. 2 W., Wisconsin; (3) exposure SE. ¼ Sec. 35, T. 45 N., R. 1 W., Wisconsin; (4) exposure NW. ¼ Sec. 21, T. 44 N., R. 5 W., Wisconsin; (5) is from the west side of the passage of the Potato river through the Penokee range; (6) exposure NE. ¼ Sec. 18, T. 44 N., R. 2 W., Wisconsin; (7) exposure SW. ¼ Sec. 17, T. 44 N., R. 3 W., Wisconsin; (8) exposure SW. ¼ Sec. 1, T. 44 N., R. 2 W., Wisconsin; (9) exposure on the fourth principal meridian, Sec. 19, T. 45 N., R. 1 E., Wisconsin; (10) exposure near center of Sec. 18, T. 44 N., R. 3 W., Wisconsin; (11) trench SW. ¼ Sec. 10, T. 44 N., R. 2 W., Wisconsin; (12) exposure NE. ¼ Sec. 14, T. 44 N., R. 3 W., Wisconsin; (13) exposure NW. ¼ Sec. 23, T. 44 N., R. 5 W., Wiscon-

represent the richer portions of the belt, the layers from which they come alternating with others which run down to only a small percentage of iron.

In the more eastern portion of the belt the total amount of metallic iron may perhaps be nearly as great as at Penokee gap, but it tends to greater concentration, the result of which is the production of genuine ore bodies and of considerable thicknesses of rock, in which relatively little iron is present, though in these cases iron oxide is usually contained in bands, seams, and finely disseminated particles.

*Abruptness of transition from the underlying Quartz-slate member.*—As indicated already in Chapter II, the fundamental distinction between the Quartz-slate and Iron-bearing members lies in the fact that the former is wholly of clastic origin, being still made up mainly of fragmental material readily recognizable as such, while the latter not only contains no fragmental material whatever, but presents us with no evidence at all of ever having accumulated in a detrital condition. Upon the other hand, the slaty rocks which overlie the Iron-bearing member, though occasionally so much changed by metasomatic processes as to have lost their fragmental character, have in the main preserved it thoroughly, and are plainly of a detrital origin. The transition, then, from the Quartz-slate member to the Iron-bearing member is one from a detrital to a nondetrital formation. The contact between these two formations is to be seen at numerous points, and at all of them the change is abrupt. This conclusion has been reached, not merely by an examination in the field, but as a result of a careful study of thin sections of specimens collected on each side of the contact with the very object of obtaining light upon this point. In the more eastern portion of the district, and so far west as the vicinity of the passage of Tylers fork, in T. 45 N., R. 1 W., Wisconsin, this contact has been brought to view by mining operations at many points, the rule being, as further explained hereafter, that the principal deposits of ore lie at the base

sin; (14) trench NE. ¼ Sec. 15, T. 44 N., R. 3 W., Wisconsin; (15) exposure SW. ¼ Sec. 17, T. 44 N., R. 3 W., Wisconsin; (16) exposure NW. ¼ Sec. 16, T. 44 N., R. 3 W., Wisconsin; (17) exposure NE. ¼ Sec. 14, T. 44 N., R. 3 W., Wisconsin. The samples from which these analyses were made were all selected with reference to determining the value of these schists as iron ores, and therefore, while fairly representing the percentages of iron in the thicknesses named, were of course selected from the richer portions of the exposures.

of the Iron-bearing member and immediately upon the vitreous quartzite which forms the uppermost layer of the Quartz-slate member. In these mines the contact is between this quartzite on the one side and either the ore or a hematitic cherty material of an entirely nonfragmental character on the other. But the contact between the two formations is also visible at a number of natural exposures, as, for instance, at the passage of Tylers fork, in T. 45 N., R. 1 W., Wisconsin (Fig. 9), and the passage of Bad river at Penokee gap, in T. 44 N., R. 3 W., Wisconsin. (See Pl. XXXVI.) In these cases on one side is the magnetitic cherty and slaty rock, and on the other the vitreous quartzite; and, as usual, the two classes of materials come directly against each other without transition phases. West of Penokee gap but few contacts were seen. In a number of places, however, the exposures of the two formations were found in very close proximity to one another. (Pls. V, VI.) As already stated, the uppermost portion of the Quartz-slate is everywhere a vitreous quartzite, i. e., a sandstone in which the interstices of the quartz fragments have been filled with a secondary silica, which has in the main coordinated itself with the original fragments. However, as is usually the case in such quartzites, some of the silica has deposited in a more or less minute mosaic in the interstices. This mosaic, itself of direct chemical origin, in a few sections is not far different from the coarser grained phase of the nonfragmental silica, which forms the groundwork of most of the rock of the Iron-bearing member. But in any case the chemically deposited silica is of a secondary nature, and can not be taken as indicating a transition between the modes of deposition of the two formations.

*Geographical extent.*—Longitudinally the Iron-bearing member is coextensive in distribution with the underlying Quartz-slate; that is to say, is continuous from the western end of the Penokee range in the north half of Sec. 24, T. 44 N., R. 4 W., Wisconsin, to the NE. ¼ of Sec. 21, T. 47 N., R. 44 W., Michigan, a distance of more than 50 miles. To the west of the western end of the Penokee range, as indicated heretofore, the entire succession of the Penokee series is lost for a distance of 6 miles, in which distance exposures of the underlying granitic and gneissic rocks on the one hand and of gabbros on the other, come in close proximity to each other and make it a question whether the entire Iron-bearing series is here cut out. This statement is at variance with the maps of the Geology of Wisconsin, which indicate a continuity across R. 4 W., Wisconsin, not only of the Iron-bearing member, but of the underlying and overlying members of the Penokee series.[1] It was known at the time these maps were made that the Penokee range, with all its characteristic rock exposures, ends abruptly in the eastern part of T. 45 N., R. 4 W., Wisconsin, being succeeded to the westward by a low, marshy country, with but rare exposures, the Penokee range rocks not reappearing until in the vicinity of the bold ridge in the NE. ¼ of Sec. 24, T. 44 N., R. 5 W., Wisconsin. The late Mr. C. E. Wright, however, traced through the intervening low country a line of rather feeble magnetic attractions which he considered to establish the continuity of the Penokee range rocks beneath the drift covering. Accepting Mr. Wright's conclusion, the surface maps were drawn accordingly. As to the magnetic attractions, it is to be said that they were too feeble to base any certain conclusion upon, being perhaps explicable by the considerable quantity of magnetite occurring in the gabbro, which appears here to usurp the place of the Penokee rocks. Still, it is not impossible that this line of attractions may be due to the Penokee iron belt itself, buried here underneath a considerable drift covering. In the north half of Sec. 23, T. 44 N., R. 5 W., Wisconsin, as already stated, outcrops of the Penokee series reappear, and from here for a distance westward of 4 miles exposures of the Iron-bearing and Quartz-slate members are sufficiently frequent to indicate their continuity through this distance. The last exposure on this line is met with in the S. ½ of Sec. 20, T. 44 N., R. 5 W., Wisconsin, beyond which point no exposures have yet been found until those met with in the SE. ¼ of Sec. 26, T. 44 N., R. 6 W., Wisconsin, where the characteristic rocks of the iron belt are seen again. Still farther west Mr. Wright traced a line of feeble magnetic attractions as far as the north side of lake Numakagon. In the northern part of T. 43 N., R. 6 W., Wisconsin, beyond lake Numakagon, no further exposures of the Penokee series have been met with, while in Sec. 20, T. 43 N., R. 7 W., Wisconsin, the occurrence in close

[1] See Atlas of the Geol. of Wis., Pls. XXII and XXVII. See particularly the latter plate for the position of all exposures known at that time.

proximity of exposures of rocks characteristic of the Keweenaw series and of the granites belonging beneath the Penokee series appear to indicate the termination in that direction, for some distance at least, of the Penokee rocks. To the east of the easternmost point indicated as reached by the continuous iron belt of the Penokee range, the NE. ¼ of Sec. 21, T. 47 N., R. 44 W., Michigan, exposures of ferruginous rocks allied to those of the Iron-bearing member are met with for a distance of 6 or 7 miles, and to within 3 or 4 miles of Gogebic lake, but these occur in a peculiarly disturbed and difficult area, whose geology, whatever be the true interpretation of it, is unlike that of the Penokee belt proper. The iron-bearing rocks of this area receive special attention in Chapter VIII.

The width of the belt of country occupied by the Iron-bearing member is surprisingly uniform from the westernmost exposure as far east as the central portion of T. 47 N., R. 46 W., Michigan. Throughout this very considerable distance this width rarely falls below 800 feet and as rarely exceeds 1,000 feet; its variations being frequently explicable by changes in the dip, though apparently some part of the variation may be due to actual difference in thickness. Still, through most of this distance the thickness must be taken as more nearly constant than the width of the belt occupied. When R. 46 W., Michigan, is reached, however, a distinct widening of the belt becomes perceptible, and in the eastern part of that township this becomes so rapid that when Black river is reached it has become as much as 2,400 feet. From Black river eastward there is a still more rapid increase, the width on the east side of Secs. 7 and 18, T. 47 N., R. 45 W., Michigan, being fully 4,700 feet. A part of this great increase in width is plainly due to a very unusual flattening in the degree of northward dip, but this will not serve to explain all of the widening, a part of which may be due to an actual increase in thickness, but is owing in part at least to the presence of interbedded greenstones. Immediately east of the last named point the overlying Keweenaw rocks, whose southern boundary has been for some time rapidly approached by the northern edge of the iron-bearing belt, are reached by it. Continuing to the east, the iron belt is in part cut off by the Keweenaw series, so that at one place its surface width is not much more than 500 feet. Not far east of Sunday lake a widening comes in again. This is evidently due to a change in course of the iron belt, which now trends southward, and thus diverges from the Keweenawan beds, the divergence, however, not being so great as to allow the reappearance of the slates belonging above the Iron-bearing member as far east as the middle of T. 47 N., R. 44 W., Michigan.

*Topographical features.*—The Penokee iron range, save for several transverse cuts made through it by the northward flowing streams, is a continuous ridge from the northern half of Sec. 24, T. 44 N., R. 4 W., Wisconsin, eastward to beyond Sunday lake in Michigan. To the west of the western termination of this range, as indicated in previous chapters, are again other detached ranges, which, being made up of like strata dipping in the same northerly direction, may be looked upon as forming portions of the same general line of elevation. The same is true east of the eastern termination indicated as far as the vicinity of the Little Presque Isle river. In places the ridge rises from 100 to 300 feet above the elevated swampy area south of it, and from 100 to 600 feet above the lower area north. In its more western portions this range is wide and has a rather narrow serrated crest, while eastward from Tylers fork it becomes more and more of a gentle swell until a point west of Sunday lake is reached, where there is again a broader range. In much of this distance the ridge forms the most prominent feature of the topography of the country, being visible from the waters of lake Superior in the vicinity of the Apostle islands as a blue line against the horizon. On a preceding page the relations of the Quartz-slate member to this ridge have been indicated, and incidentally those of the Iron-bearing member also. The points of principal interest, however, may conveniently be repeated here. Along that portion of the Penokee range which is west of Bad river, and also in the detached ranges above referred to as occurring still farther west, in T. 44 N., R. 5 W., Wisconsin, the Quartz-slate member forms the foot of the bold south face of the ridge, the upper portion of the southern face, along with the crest and the upper portion of the northern slope, being all made up of the steeply inclined layers of the Iron-bearing member. The passage of Bad river through the range has been determined by the existence of a fault, which has caused a discordance in the layers of some 800 feet. Eastward from Bad river the

Quartz-slate member climbs higher and higher on the southern face of the ridge, all of which it makes up by the time mount Whittlesey is reached. Correspondingly, the Iron-bearing member creeps farther and farther down the northern slope. At Tylers fork this change has gone on so far that the crest of the ridge is now entirely within the quartz-slate, while east of that stream and all the way to the West branch of Black river the crest of the ridge is in the granitic rocks belonging to the Southern Complex. In this area the Iron-bearing member continues to creep down the northern face of the ridge until it has the greater portion of its width in the low ground to the northward. East of the West branch of Black river for a short distance the ridge again lies within the iron belt, which here contains an unusually large amount of resistant jaspery material. The changing relation thus indicated as obtaining between the positions of the ridge and that of the outcrop belt of the Iron member has been explained on a previous page as a result of a variation in the mineralogical character of the member, which, where resistant, forms the upper portions of the ridges, while in other places the rocks to the south being more resistant the course of the iron belt lies in the lower ground to the north.

*Thickness.*—It has already been said that the outcrop belt of the Iron-bearing member has a singularly constant width from 800 to 1,000 feet for all of the distance between the western extremity of the Penokee range to the middle of T. 47 N., R. 46 W., Michigan. The thickness must be yet more constant than is indicated by these figures, the variations between the limits indicated being generally explicable by a somewhat changing degree of northward inclination. Throughout this distance the actual thickness of the formation can not vary much on either side of 850 feet. How far the great increase in surface width, which has already been indicated as obtaining in the eastern portion of T. 47 N., R. 46 W., Michigan, and farther to the east, is due to an increase in actual thickness is exceedingly difficult to tell. Some of the increased width is plainly the result of an unusually low angle of northward inclination. More of it is evidently due to the intercalation of eruptive greenstone sheets; but after these two causes of widening have been considered, how much remains to be accounted for by an increased thickness of the Iron-bearing member we have no means of determining accurately. Throughout much of this area, moreover, the uppermost portion of the iron belt is missing, but how much is gone there is no means of telling. It is only possible to say in a general way that it would seem that in the eastern part of the formation its thickness may be very materially increased.

*General petrographical character.*—Three main types of rock make up the Iron-bearing member. Between these three types there are various gradation phases, while each main type presents itself in a number of forms between which there are minor differences. In certain rare instances a little detrital material has been introduced during the original deposition of these rocks, but ordinarily this is completely lacking. The three types referred to may be briefly characterized as (1) *slaty and often cherty iron carbonate*, (2) *ferruginous slates and ferruginous cherts, and* (3) *actinolitic and magnetitic slates.*

The first type is a very well marked one, and is present in very considerable thickness. It is characterized by the invariable presence of iron carbonate as a chief constituent. In some cases the iron carbonate constitutes the only important mineral in the rock, but usually it is mingled with more or less of calcium carbonate, magnesium carbonate and cherty silica, the latter ranging in character from minutely crystalline to amorphous. Other minor ingredients, one or more of which may be present, are hematite, limonite or other brown iron oxide, magnetite, carbonaceous or graphitic matter, iron pyrites, a chloritic or viriditic ingredient, an excessively fine clayey substance, and, very rarely, pieces of a fragmental quartz. In texture these rocks are commonly earthy and aphanitic, but in some cases the iron carbonate is sufficiently coarsely crystalline for the cleavage surface of the minute crystals of siderite to be perceptible to the naked eye. There is very commonly a regular and thin lamination produced by an alternation of lighter and darker gray shades of the carbonate. Frequently, however, the gray carbonate is interlaminated with seams of black graphitic matter, red jasper, red hematite, black flint, greenish black or viriditic carbonate, or with seams of carbonate in which magnetite particles are particularly abundant. While the platy or thinly stratiform habit is very characteristic of these rocks, these laminæ often become irregular, presenting the appearance of having been broken apart and recemented, in which case there is usually a considerable quantity of the cherty silica present. The observations thus far made have applied particularly to fresh surfaces. On exposed surfaces there is very apt to be a prevalent brownish or reddish iron stain from peroxidation of the iron of the carbonate. In specific gravity these rocks range generally between the two preceding types. The specific gravity of pure iron carbonate is given in the mineralogies as between 3·7 and 3·9. The rocks now considered fall below this figure because of the presence of other lighter substances, particularly the calcareous, siliceous and clayey ingredients. The following figures are the results of specific gravity determinations: 2·97, 3·04, 3·20, 3·22, 3·24, 3·29, 3·40, and 3·50.

Of the following analyses the first five represent the composition of iron carbonates from the Penokee-Gogebic district. The remainder are of similar carbonates from other districts about lake Superior, and are inserted here for the sake of comparison. No. I (specimen 9191), analyzed by Mr. R. B. Riggs, of the U. S. Geological Survey, is of a rock exposed in a test-pit in the NE. ¼ of the NE. ¼ of Sec. 6, T. 45 N., R. 2 E., Wisconsin. No. II (specimen 9472), made by Mr. W F. Hillebrand, of the U. S. Geological Survey, is of a specimen from the large precipitous exposure on the south side of the outlet of Sunday lake, NE. ¼ of Sec. 13, T. 47 N., R. 46 W., Michigan. No. III (specimen 12885), made by Mr. Thomas M. Chatard, of the U. S. Geological Survey, is of a carbonate occurring near the base of the Iron-bearing member on the Miner & Wells option, Sec. 13, T. 47 N., R. 46 W., Michigan. No. IV (specimen 12887), made by Mr. Hillebrand, is of a specimen representing a large natural exposure on the Palms property, Sec. 14, T. 47 N., R. 46 W., Michigan. No. V (specimen 12543), made by Mr. Chatard, represents a carbonate occurring at a low horizon in the member, in the NW. ¼ of Sec. 18, T. 47 N., R. 45 W., Michigan. Of the remaining analyses, No. VI (specimen 9264), by Mr. Hillebrand, represents a peculiar carbonate occurring in the SE. ¼ of Sec. 20, T. 47 N., R. 43 W., Michigan, in that confused area to the east of the Presque Isle river, which is considered in the present volume separately from the regular Penokee succession. No. VII (specimen 10575), by Mr. Chatard, is an iron carbonate from the so-called gunflint beds exposed on the eastern side of the outlet of Gunflint lake, situated on the national boundary between Minnesota and Canada. No. VIII (specimen 10598), by Mr. Chatard, is from the same beds, but from an exposure on the northern side of Gunflint lake. No. IX (specimen 10588), also by Mr. Chatard, is a ferriferous carbonate from another part of the north side of Gunflint lake. No. X (specimen 10157), by Mr. Riggs, is a black slaty and carbonaceous iron carbonate, exposed at Kakabikka falls on the Kaministiquia river, Canada. And No. XI (specimen 10160), also by Mr. Riggs, is from a less carbonaceous phase, exposed at the same place as No. X. The rocks represented by Nos. VII and XI, inclusive, of these analyses are all from the so-called Animikie series of northeastern Minnesota and the adjoining portions of Canada.

*Analyses of iron-bearing carbonates.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | XI. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Silica | 15·62 | 28·86 | 46·01 | 46·47 | 36·73 | 3·16 | 58·23 | 46·46 | 23·90 | 37·73 | 54·26 |
| Titanic oxide | ........ | 0·20 | 0·12 | 0·10 | 0·19 | ........ | trace | trace | none | ........ | ........ |
| Alumina | 4·27 | 1·29 | 0·83 | 0·70 | 0·38 | 0·08 | 0·06 | 0·24 | 0·07 | 3·41 | 2·57 |
| Iron sesquioxide | 8·14 | 1·01 | 1·35 | 0·86 | 0·98 | 0·93 | 5·01 | 0·64 | 0·44 | 6·42 | 3·62 |
| Iron protoxide | 32·85 | 37·37 | 26·00 | 28·57 | 34·74 | 15·18 | 18·41 | 26·28 | 10·65 | 22·92 | 19·63 |
| Manganous oxide | 5·06 | 0.97 | 2·09 | 0·40 | 0·52 | 1·15 | 0.25 | 0·21 | 0·28 | 0·40 | 0·19 |
| Calcium oxide | 0·81 | 0·74 | 0·63 | 0·49 | 0·48 | 26·65 | 0·38 | 1·87 | 22·25 | 1·26 | 1·07 |
| Magnesium oxide | 2·66 | 3·64 | 2·86 | 2·30 | 2·74 | 11·01 | 9·59 | 3·10 | 8·52 | 3·98 | 2·93 |
| Carbon dioxide | 30·32 | 25·21 | 17·72 | 19·24 | 22·44 | 41·10 | 5·22 | 19·96 | 32·42 | 18·01 | 14·93 |
| Phosphoric acid | ........ | trace. | 0·07 | trace. | 0·009 | 0·06 | 0·03 | 0·13 | trace. | | |
| Iron sulphide | ........ | ........ | 0·11 | ........ | 0·12 | 0·34 | 0·14 | 0·11 | 0·13 | | |
| Water at 105° | ........ | ........ | none. | ........ | 0·12 | ........ | ........ | ........ | none. | | |
| Water at 110° | ........ | ........ | ........ | ........ | ........ | ........ | 0·07 | 0·07 | ........ | ........ | ........ |
| Water at red heat | 0·68 | 0·68 | 1·71 | 0·60 | 1·40 | 0·54 | 2·01 | 1·15 | 0·99 | | 1·20 |
| Water at red heat, partly from organic matter | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 2·74 | ........ |
| Alkalies | | | (*) | | (*) | | (*) | (*) | (*) | | |
| Organic matter | | (*) | | (*) | | | | | | | |
| Carbon | | | | | | | | | | 3·54 | 0·45 |
| | 100·41 | 99·97 | 99·50 | 99·73 | 100·84 | 100·20 | 99·40 | 100·22 | 99·65 | 100·41 | 100·85 |

* Undetermined.

The rocks of the second type, which we have collected under the general designation of *ferruginous slates and ferruginous cherts*, have in common a prominent siliceous constituent, which is always of a nonfragmental nature, and ranges in crystallization from a wholly though minutely crystalline condition, through partly crystalline and chalcedonic phases to an entirely amorphous phase, the several phases being frequently associated in the same thin section. Compared with the siliceous ingredient of the rocks of the third type, between which and those now under consideration there are distinct gradation varieties, the silica of the rocks of the second type is in general very much finer in grain. Indeed, those phases in which the silica is either in so minute individuals that they can only with extreme difficulty be separated under the microscope, or in which it is mingled with more or less chalcedonic or even amorphous forms, greatly predominate. In addition to this siliceous groundmass, to all of the phases of which we apply the general term of chert, the principal ingredients of these rocks are the several iron oxides: that is, magnetite, hematite, and a brown hydrated oxide. These are generally greatly subordinate in quantity to the silica, at times sinking almost completely out of sight. In other cases they are present in considerable quantity, and frequently occur so plentifully as to furnish intermediate phases between the cherts and the iron ores of the district. The principal one of these oxides is hematite. When magnetite is present in any considerable quantity, it is generally accompanied by more or less actinolite in minute needles, and phases of gradation between the cherts and the actinolitic rocks of the third type, subsequently described, are thus produced. On the other hand, more or less iron carbonate is found in remnants in the many sections of these cherts, and by its increasing quantity leads us through phases of gradation into the rocks of the first type above described. In color these rocks vary greatly, presenting red, brown, gray, and white colors, depending upon the amount of iron oxide present. Perfectly white nonferruginous phases are occasionally met with; also light to dark gray kinds, and grayish kinds mottled irregularly with black, in which phase the iron oxide is mainly magnetite. When hematite is present in large quantity the rock may have a uniform red color. Occasionally the red iron oxide is present in just such quantity and condition as to make of the chert a genuine jasper, but such phases are not common. A rather unusual kind is quite black, apparently from the presence of carbonaceous matter.

In structure these rocks vary from the regular lamination of the first type to those that are much less regular, being either without any uniform banding, or, if the banding is present, the laminæ present the appearance of having been disrupted and the broken fragments recemented. Both the regular and irregularly laminated phases are found in large areas.

The uniformly laminated phase to which the name *ferruginous slate* is given has a uniform texture and even lamination, and varies in color from yellow to deep red, the change in color being due to different oxides of iron. This phase might be taken for a slaty iron ore, but its low specific gravity and its large content of silica, as shown by analysis, exclude it from the iron ores. The silica and iron oxide are so uniformly mingled and the silica is in such small particles that it is not macroscopically visible.

The second phase, *the ferruginous cherts*, is distinguished from the first phase by the greater concentration of the iron oxides. They occur in irregular bands and areas, interlaminated with chert layers of greater or less purity. There are all gradations in exposure, from the regularly laminated slates of the first phase through the ferruginous cherts to areas in which the iron oxide is concentrated in such large masses as to be workable deposits of iron ore. In general the texture of the chert is aphanitic; occasionally it presents a chalcedony-like appearance. In many instances there is present a more or less porous texture, minute cavities occurring throughout the specimens. Also a minute brecciation of the rock is not unfrequently perceptible to the naked eye, though this peculiar characteristic comes out more prominently in the thin section, as subsequently explained. When perceptible to the naked eye, it shows itself as an irregular mottling of dark and light gray, or of black and gray; the appearance being that of more or less angular fragments imbedded in a lighter colored matrix. The following are the results of specific gravity determinations of the ferruginous cherts: 2·65, 2·67, 2·69, 2·76, 2·90, 2·92, 2·95, 3·21, 3·25, 3·26, 3·39. Of these amounts those above three represent the more ferruginous kinds.

The rocks belonging to the third type, *the actinolitic and magnetitic slates*, are in the main very dark colored, being often black. Occasionally, however, in bands the color is lighter, in which case the light and dark colored bands present a striking striped appearance in natural exposure. The grain is usually a very fine one, being at times quite aphanitic. Occasionally each of the main individual constituents may be detected with the naked eye. More commonly, however, the use of the magnifying glass is required. These main constituents are shown by the microscope to be in most instances quartz, actinolite, hematite, and magnetite. The first of these is occasionally lacking, but such phases are unusual. The four minerals vary greatly as to relative proportion, each in turn predominating over the others, the lighter colored phases being of course the most highly quartzose ones, while the darker kinds are richer in iron oxide, which is often present in sufficient quantities to give the rock a more or less distinct metallic luster. Except in certain thin seams, however, which are at times even pure hematite and magnetite, the content is not so great but that the powder of the rock is of a light color. In the more detailed description given below it will be seen that in one unusual phase garnet is a prominent constituent, and that chlorite and biotite occur frequently as somewhat important alteration products. The lamination of these rocks is usually more or less strongly marked by variations in color, the individual laminæ more commonly running from an insignificant thickness to about one-fourth or one-half an inch, only occasionally exceeding the latter figure. Parallel to the lamination there is generally a distinct tendency to cleavage. Obliquely transverse to this bedding cleavage is a jointing which renders it exceedingly difficult to get from the ledge large sized pieces of the rock, they usually coming out in small lozenge-shaped slabs. The large amount of magnetite and hematite which nearly all phases of this rock contain render it very noticeably heavy. The following are specific gravity determinations made upon samples selected with a view to illustrating the several phases of these actinolitic rocks: 3·05, 3·37, 3·42, 3·43, 3·46, 3·50, 3·53, 3·91, 4·31, 4·54, 5·01. The last three numbers represent thin seams unusually rich in hematite and magnetite. The other numbers represent large bodies of rock, the lowest one being given by one of the most quartzose phases met with. The large amount of magnetite contained in the rocks of this kind produces extraordinary attractions upon the magnetic needle. In this connection reference should be made to the magnetic charts given in the third volume of the Geology of Wisconsin, and in the atlas accompanying that volume.[1] While the magnetic oxide of iron is the greatly

[1] Volume Pls. XXIII, XXIV, XXV, XXVI, XXVII, XXVIII, XXIX, and XXX. Atlas Pls. XXIII, XXIV, XXV, and XXVI.

predominating one in all this class of rocks, nevertheless analyses show that some of the sesquioxide is usually mingled with it, the presence of which oxide indeed is not infrequently evident to the naked eye in the more ferruginous varieties, the luster of specular iron and a reddish or purplish tint in the powder both testifying to its presence. In the less ferruginous portions of these phases the sesquioxide is less plentiful, but at times the siliceous seams present a dull reddish or jaspery appearance from the presence of hematite. In one vicinity in the eastern portion of the district a bright red jasper is thinly laminated with a typical actinolitic magnetitic slate, but this is unusual. The ordinary occurrence in the lake Superior region of the bright red phase of nonfragmental silica, commonly spoken of as jasper, is in direct association with the more brilliantly lustered, steely, specular iron ores. Such bright colored jaspers only rarely occur in immediate association with the actinolitic and magnetitic slates.[2] The following analyses of the rocks of this type are taken from the Geology of Wisconsin.[3] They are of samples selected by the senior author with direct reference to the richness of the rock in metallic iron; they therefore represent in the main the more ferruginous portions of the belt, or rather the more ferruginous portions having any considerable thickness. The original samples, having been selected for an economic purpose, were made by breaking small pieces from all across the thickness sampled. Had the analyses been made more especially

[2]The more highly siliceous phases of this class of rocks are spoken of by Irving in the Wisconsin Reports as quartzites (Geol. of Wis., 1880, vol. III, pp. 118, 119, 120, et seq.), the adjectives magnetitic, hematitic, etc., being prefixed to the word quartzite to indicate the special phases. The name quartzite was thus used in ignorance of the fundamental distinction which we now know holds between these rocks and the genuine quartzites, the latter having been shown to be always in the main composed of original fragmental material, while the siliceous constituent of the rock now especially under consideration is always of a nonfragmental nature, having been solidified in situ. The term quartzite is used, then, throughout this volume and all other later writings of the authors to designate only a genuine fragmental rock indurated by means of interstitial deposition. On Pl. XXII of the Atlas of the Geology of Wisconsin, and on page 119 of vol. III of that work, the Iron-bearing member is represented as made up of three subdivisions, a basement quartzite 50 feet thick, a series of magnetitic schists and quartzites 800 feet thick, and a garnetiferous actinolitic schist 10 feet thick. The quartz at the base of the series, although highly vitreous, we now know to be of a completely fragmental character, and to belong to the underlying Quartz-slate member rather than to the Iron-bearing member, the so-called quartzites of which prove to be wholly nonfragmental rocks.

[3] Vol. III, pp. 156-160.

for petrographic purposes, the samples would of course have been selected in a different fashion. Nevertheless, as taken, they represent quite fairly the more ferruginous portions of this phase of rocks, one (No. IV) representing a less ferruginous portion. Of these analyses, I represents a thickness of 40 feet exposed in the SW. ¼ of Sec. 17, T. 44 N., R. 3 W., Wisconsin; II, 41 inches in the NE. ¼ of Sec. 15, T. 44 N., R. 3 W., Wisconsin; III, 19 feet exposed on the west cliff at Penokee gap, NW. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin; IV, 7 feet 6 inches immediately overlying the rock represented by III; V, 10 feet from the same cliff; VI, 50 feet exposed in the NE. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin; VII, 58 feet in the SW. ¼ of Sec. 10, T. 44 N., R. 2 W., Wisconsin; VIII, 25 feet in the SW. ¼ of Sec. 1, T. 44 N., R. 2 W., Wisconsin.

*Analyses of magnetitic slates.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII |
|---|---|---|---|---|---|---|---|---|
| Iron sesquioxide | 36·414 | 49·435 | 42·897 | 15·335 | 34·770 | 67·064 | 41·241 | 40·420 |
| Iron protoxide | 15·767 | 8·460 | 19·173 | 7·851 | 15·819 | 8·332 | 16·797 | 12·331 |
| Silica | 39·532 | 33·894 | 31·838 | .......... | 42·896 | 18·472 | 36·508 | 39·171 |
| Alumina | 0·110 | 1·151 | 0·384 | .......... | none. | 0·305 | 1·025 | 1·139 |
| Calcium oxide | 1·516 | 3·156 | 1·373 | .......... | 1·330 | 2·483 | 1·383 | 1·373 |
| Magnesium oxide | 2·516 | 2·403 | 1·293 | .......... | 2·623 | 2·280 | 2·156 | 1·890 |
| Manganous oxide | 3·120 | 0·337 | 1·126 | .......... | 1·726 | 1·050 | 0·193 | 0·553 |
| Phosphoric acid | trace. | none. | none. | .......... | trace. | 0·127 | trace. | trace. |
| Sulphur | 0·421 | none. | none. | .......... | trace. | none. | 0·160 | none. |
| Water | 0·543 | 1·500 | 0·378 | .......... | 0·471 | 0·450 | 1·078 | 2·559 |
| Total | 99·939 | 100·336 | 98·462 | .......... | 99·635 | 100·613 | 100·541 | 99·436 |

It will be seen that several of these analyses show a proportion of iron sesquioxide beyond that which is required by the protoxide contents indicated to make up the mineral magnetite. In fact the excess is even slightly greater than is indicated at first sight, since a certain amount of the iron protoxide must be assigned to the amphibolic mineral which is always present. Disregarding the small correction to be made on this account and considering all of the iron protoxide indicated by the analyses as contained in magnetite, we find that the following respective proportions of magnetite and hematite are indicated for the several samples. I, 50·80 per cent and 1·37 per cent; II, 27·26 and 30·63; III, 50·56 and 11·40; IV, 23·38 per cent of magnetite and no hematite; V, 50·38 per cent of magnetite and no hematite; VI, 27 per cent of magnetite and 48·43 per cent of hematite. For VII the figures are 54·12 and 3·91; for VIII, 39·73 and 13·01; for IX, 16·27 and 28·83.

*Distribution of the three types of rock.*—In all that portion of the Iron-bearing member which lies to the west of the passage through the Penokee range of Tylers fork, in Sec. 33, T. 44 N., R. 1 W., Wisconsin, the rocks of the third type or actinolitic and magnetitic schists prevail; in fact, except that the rock of certain exposures, much more highly quartzose than usual, approaches the cherts of the second type, it may be said that these rocks are the only ones met with. At the gorge of Tylers fork, however, the actinolite has almost, though not quite, sunk out of sight, while the siliceous constituent is altogether the most prominent one. At the same time hematite and brown iron oxides begin to prevail over the magnetite.

To the east of Tylers fork the first and second types greatly predominate, though phases carrying minute quantities of actinolite continue to occur as far east as the Potato river. Nevertheless, these are very rare, and nowhere in this portion of the range has any highly actinolitic rock yet been met with. Just where these actinolitic rocks cease it is difficult to tell, but they can not continue far to the east of Tylers fork, not far from which stream the cherty and carbonated rocks of the first and second types have increased to such an extent as to occupy the whole of the iron belt, the frequent occurrence of bodies of hematite ore at the base of the member beginning at the same time with this change. For some 30 miles now to the east, or as far as near the east side of T. 47 N., R. 45 W., Michigan, the cherts and carbonates, with iron ore bodies at or near the base of the formation, continue nearly to the exclusion of the actinolitic rocks. In this distance is included with few exceptions all of the working mines of the Gogebic districts. The somewhat magnetitic and actinolitic rocks just west of Tylers fork include one mine, and the somewhat actinolitic and magnetitic rocks in T. 47 N., R. 45 W., Michigan, include several. A rude subordinate stratigraphic arrangement in the iron belt appears to hold for this distance; i. e., the purer carbonates are characteristic of the upper horizons, the ferruginous slates of the middle horizons, while the ferruginous cherts and ore bodies lie within the lower horizons. It is not meant to indicate by this statement that the transition between the cherty phases and the carbonates is a regular or sharp one, as the carbonates sink to lower horizons in some places, while the cherts rise to higher in others, but merely that exposures and the numerous test pit explorations show that there is this general arrangement. It is thought that this arrangement has a connection with the origin of the ore bodies, for which an explanation is attempted on a subsequent page. It should be said that this arrangement is much more definitely made out through T. 47 N., R. 46 and R. 47 W., Michigan, than it is farther to the west in Wisconsin, where the explorations have been fewer. So far as exposures have been found west of the state line, they indicate the continuity of this succession westward to beyond the Potato river crossing. The succession as seen in T. 47 N., R. 46 W., Michigan, may be described more fully as follows: Beginning with the uppermost portion of the belt, we find the finely laminated, little altered siderite rocks to prevail. As these are crossed to the south, more and more red hematite replaces the iron carbonate, until finally little or no unoxidized carbonate remains. Here the rock is a reddish slaty one, often preserving quite perfectly the original regular lamination, but the only constituents are more or less hydrated hematite and silica. Still farther southward the lamination becomes less and less distinct and regular; the amount of silica rapidly increases, and the rock passes into the ferruginous chert of the second type in which the iron oxide is contained in irregular blotches and noncontinuous bands. Finally, at the base of the formation the iron oxide is collected often into large bodies, which generally lie directly against the quartzite, the uppermost horizon of the Quartz-slate member.

Following the iron belt now farther eastward into T. 47 N., R. 45 W., Michigan, another change is met with—the actinolitic and magnetitic rocks of the third type coming in plentifully. At first these occur along with both the ferruginous cherts and carbonates, but as one passes farther eastward no more carbonates are met with, the actinolitic schists and ferruginous cherts only being found. The latter in turn lessen in amount, the actinolitic schists being more and more plentiful until in the exposures near the Little Presque Isle river, in T. 47 N., R. 44 W., Michigan, they are the only kinds met with. This transition from the predominance of the ferruginous cherts to that of the actinolitic type is a very gradual one, extending through a distance of 10 or 12 miles.

To one visiting the Iron-bearing member, only at two or three points distantly removed from one another, without examining the intervening portions—say, for instance, at Penokee gap and in the vicinity of the mines at Bessemer, Michigan—the difference between the rocks which compose it might be so striking as to give rise to a doubt of the actual continuity of the belt between the two places; but by one who follows it throughout its whole length no such question for a moment can be entertained. Mining developments and natural exposures make the belt practically continuous and one finds a gradual transition between the three types of rock, which take place only in the most gradual manner. Further, he finds immediately beneath the Iron-bearing member the Quartz-slate, and immediately above it the Upper slate.[1]

*Microscopical character of the cherty iron carbonates* (Pl. XXI).—This type of rock has two chief constituents, siderite and chert. In composition the siderite is an iron carbonate, bearing more or less of calcium and magnesium and not infrequently passes into a ferrodolomite. The siderite varies in its character from earthy to well crystallized. When crystallized the small individuals perfectly interlock. It is usually more or less impure, including at times green chlorite, carbonaceous matter, and occasionally numerous minute crystals of magnetite. The chert making up the other part of this type of rock is in part amorphous. It is that variety of silica or quartz which has in the polarized light a minute spotty appearance, due to exceedingly small individuals of quartz, mingled with more or less of silica which is apparently amorphous. Hornstone or flint gives in thin section the same appearance; and the chert of the iron carbonates and hornstone have a very close microscopic resemblance. That a portion of the silica is really amorphous, as indicated by the appearance of the section

[1] At the time the Wisconsin geological survey of this district was made, there had been no prospecting along the east end of the Wisconsin part of the range, and the exposures between the Potato and Montreal rivers are very sparse; yet with these few exposures, feeble magnetic attraction, and the assistance of topography, the survey was able to locate so accurately the Iron-bearing member that within it or very close to it are all the iron mines yet discovered upon the Wisconsin side of the boundary. (See Pl. XXVI, Atlas, Geology of Wisconsin.)

under the microscope, is further shown by its ready solubility in caustic alkalies. Nowhere does this chert present a concretionary or brecciated appearance.

The two constituent minerals occur sometimes in solid bands, alternating with each other, and interstratified with these are other bands composed in greater or less proportion of the chert and siderite. Sometimes the bands of siderite contain a little chert (Pl. xxi, Fig. 3), and the nearly pure bands of chert frequently contain more or less of siderite, the individuals of this mineral generally being in a regular rhombohedral form. In the unaltered rocks the chert can no more be said to be a background in which the siderite has crystallized than the reverse. Apparently, as a result of changing conditions, regular alternations of siderite and chert and various mixtures of the two have followed one after the other. Sometimes the layers of solid siderite are of considerable thickness; the same is true to a less degree of the cherty layers. These rocks appear to be in essentially their original condition. If there has been any change since they were formed, there is no evidence of it, and for our present purposes they must be regarded as original rocks. It is not impossible that they have undergone great changes, but if so we are unable to find any clew as to their nature.

From these apparently unaltered rocks of the first type there are gradations to those of the first phase of the second type. The first alteration to which these rocks are subject is an oxidation of the carbonate producing brown hydrated hematite, red hematite, or magnetite. Very frequently the decomposition of the iron carbonate has not changed the forms of the original crystals, and thus leave the various oxides as perfect pseudomorphs after the iron carbonate. (Pl. xxi, Fig. 4.) All phases of this change to each of the iron oxides is exhibited by the various sections. Frequently upon one side of the same section is unaltered iron carbonate, and upon the other side iron oxides alone, pseudomorphous after the iron carbonate. Between the two are all stages of the change. The formation of magnetite pseudomorphs after the carbonate is much less common than that of the brown hydrated hematite and the red hematite. In the siderites which were more nearly pure, this alteration, completely carried out, produces the lean ferruginous slates which are one of the characteristic rocks of the second type below described. Accompanying this oxidation of the siderite is generally a rearrangement, and apparently often an introduction of silica from extraneous sources. The silica in these altered rocks, instead of being the spotty chert, characteristic of the unaltered rock, is frequently more coarsely crystalline, and often in combination with the iron oxides has a concretionary and brecciated appearance. When this rearrangement and introduction of silica is carried to the extreme, with accompanying changes in the iron oxide, the cherty iron carbonate passes into the second phase of the second type of rocks—the ferruginous cherts.

The numerous veins and fissures which cut through the rock form a characteristic feature of the iron carbonates. These veins are of greatly varying widths, one of them frequently breaking into several smaller veins, and in some cases the sections are cut by a system of ramifying veins. They are generally composed of the same minerals which make up the section in which they are contained; that is, chert, siderite, and sometimes chlorite. Upon the whole, silica is much the more abundant filling. This silica is frequently easily separated from the remainder of the silica in the sections by being coarsely crystallized, or by having the radial fibrous arrangement of chalcedony, and in including little iron oxide. Not unfrequently, however, the veins contain a large amount of siderite. This siderite, like the silica, is usually purer and more coarsely crystallized than the original siderite.

*Microscopical character of the ferruginous slates and ferruginous cherts* (Pl. XXII).—The general macroscopic characters of this type of rock have been indicated above. It has also been said already that they are in the main composed of iron oxides and silica of a nonfragmental nature; that the rocks of this type present a gradual transition into those of the third type by an increase in the amount of actinolite and magnetite, and that similarly they present transitions into the carbonates of the first type and into the hematites of the iron-ore bodies themselves. In addition to the predominating siliceous groundmass, there is always present more or less iron oxide, which may be magnetite, hematite, or the hydrated oxide of iron, or two or all three of these together. Accessory to these two prime constituents, are detected under the microscope iron carbonate, which occurs very frequently; actinolite, which is of less frequent occurrence; carbonaceous matter, and chlorite, these two being of unusual occurrence. The predominating siliceous groundmass of these rocks varies from very minutely though completely crystalline to partly amorphous (Pl. XXII, Fig. 2), often presenting the intermediate condition characteristic of chalcedony. In some sections none of the chalcedonic or amorphous phase of silica is present, but in others all three of these phases occur together. In general there is in these rocks a much greater tendency toward the crystalline kind of silica than in those of the first type, the cherty iron carbonates; but as compared with the silica in the rocks of the third type, or actinolitic slates, there is a greater tendency toward the noncrystalline kinds. It has been shown that the actinolitic slates have their main distribution in the western portion of the iron belt, occurring again in considerable development far to the east, while in the intervening space the ferruginous cherts and carbonates have their great development. Correspondingly those phases of the ferruginous cherts, which in their content of small quantities of magnetite and actinolite present us with a gradation into the actinolitic slate type, are found particularly toward the west as one approaches the region of actinolitic slates proper, and again at the extreme east as the actinolitic rocks of that area are reached. Accompanying the presence of magnetite and actinolite in these gradation phases is usually found the most completely crystalline condition of the siliceous groundmass.

The ferruginous cherts, as indicated in the general description, present two widely different phases; the ferruginous slates in which the iron oxides and silicates are quite uniformly mingled, and rocks in which the iron oxide is concentrated to a greater or less degree in bands, rings, and shots, leaving the silica comparatively or almost wholly free from iron oxide. The rocks of the first phase are composed of intimately mingled chert and brown, somewhat hydrated hematite, red hematite, and occasionally magnetite. In the ferruginous slates there has also been a concentration of the iron oxide to a small extent in layers. At times these layers are very regular ones, between which alternate layers of chert, containing comparatively little oxide of iron. From these perfectly laminated phases, which are as regular as any of the slaty iron carbonates of the first type of rock, the specimens vary to those in which the thin section shows apparently no proper lamination, although in hand specimen there is always some evidence of stratification. In these laminated phases the chert may be a background for the iron oxide or the reverse, depending upon which is predominant.

The chert in the ferruginous slates varies from finely crystalline to the very fine spotty quartz mingled with amorphous silica, characteristic of the first type of rock. When the quartz is of the more coarsely crystalline kind the sections are often cut by veins of silica. In these cases the secondary nature of a portion of the silica at least is indicated by the fact that it does not always lie directly parallel to the lamination, but breaks across the more ferruginous bands in little veinlets, while various singular departures from the regularity of the lamination indicate the same thing. Usually the quartz shows little or no indication of a concretionary or brecciated nature. The iron oxide is generally of the brown somewhat hydrated hematite. Occasionally the hematite is bright red, when the rock becomes a jasper. These jaspery portions are not usually in any great thicknesses. Sometimes the rocks are quite regularly laminated, but often the jaspery parts are in the shape of noncontinuous fine laminæ. Less frequently the oxide of iron is in part magnetite.

The iron oxide is present in irregular areas, and frequently is in sufficient quantity to form continuous ramifying areas in which the chert is buried. In a portion of the specimens little or no iron carbonate remains, or the iron oxide, either hematite or hydroxide, may present itself as mere stains in the carbonate, replacing the carbonates in varying degrees, until finally an entire crystal or bunch of crystals of that mineral is changed to the oxides. Rhombic crystal sections, composed of oxides of iron, are to be found in nearly all of the sections. In quite a good many cases all of the iron oxide of a section, or nearly all of it, will present itself in these rhombic shapes. More often the rhombs will be perceptible only on the edges of the iron oxide areas, the middle portions of these aggregates being too compact to allow of their recognition. The carbonate itself is found in more than half of the sections examined, and in nearly all of the remainder its former presence is indicated by these rhombic crystal sections. The magnetite, when present, is commonly rhombic in outline. Such rhombic outlines may, of course, be produced by random sections of the ordinary magnetite octahedra, but the question has suggested itself as to whether it is not possible that these rhombic magnetite sections express in their shape the outlines of carbonate crystals. In some cases such magnetite crystals with similar shaped sections of carbonate and hematite are found in the same rock.

In one direction these rocks may, then, be traced into those of the first type. In the reverse direction by concentration of the iron oxides and by the development of a concretionary and brecciated character this phase passes into the second phase of the second type of rock.

In the ferruginous cherts the iron oxides are often concentrated more or less into regular bands, but besides these bands there are many oval or spherical bodies of iron oxide, so that the specimens are best described as cherts containing bands and shots of ore. These shots occur in cavities in the cherts and often they do not entirely fill them. In such cases the iron oxide is usually lined with crystals of quartz. The structure is, upon a small scale, that of a geode, the cavity of which has a layer of iron oxide, and within this quartz crystals. Even when the cavities are completely filled with iron oxide the same similarity to a geodic structure is apparent. It would seem that the cavities formed at some stage in the development of the rock (perhaps by a solution of a part of the iron carbonate at the time another part was oxidized, or else by solution of silica), were subsequently partly or completely filled with iron oxide, after which, if space remained, followed silica. (Pl. XXIII, Figs. 1 and 2.)

In this phase of rock the arrangement of the constituent particles is often closely similar to that which has been described on a preceding page as characterizing the chert of the Limestone member; that is, it often presents a more or less perfect concretionary arrangement, but in the limestones and cherts this is at times exceedingly vague. However, the concretions are so numerous as to be one of the most important characteristics of this phase of rock. (Pl. XXII, Figs. 1 and 2.) The concretionary structure affects both the iron oxide and chert, although it is most clearly made out by means of the iron oxide. In some cases the iron oxide which marks these concretionary areas is so plentiful as to render them nearly or quite opaque. From such extreme cases there is every gradation to those sections in which only an exceedingly minute amount of iron oxide remains to separate these areas from the interstitial silica, while there are not unfrequent cases in which even a minute amount of iron oxide is absent. The outlining of the areas is then perceived only in the polarized light, its silica being either nearer to or farther from the amorphous condition than that portion of the matrix immediately in contact with it.

The iron oxide which designates the concretions from the matrix presents itself in the shape of a general stain, composed of minute particles, distributed in the shape of a mere border or in concentric rings. It may be any of the three oxides—magnetite, hematite, or a brown, somewhat hydrated oxide, or a mixture of two or three of them together. In cases where the iron oxide is magnetite, as in the cherts which occur between Tylers fork and Sec. 10, T. 45 N., R. 1 E., Wisconsin, it may present itself either in the shape of an exceedingly fine dust or as sharply outlined crystals of some little size, and these crystals are not unfrequently arranged around the edges of the concretionary area, their sharp angles projecting from its outline. (Pl. XXVIII, Fig. 2.) It is not to be understood that the iron oxides are completely lacking in the interstitial material; on the contrary, they are often present either in minute stains or aggregations of particles; but the rule is that they are more plentiful in concretions than in the matrix, while in many cases the matrix appears to be almost wholly devoid of them. A concretion will often be sharply defined only along a portion of its outline, the remainder being exceedingly vague. This arises at times from lack of sufficient iron oxide stain to differentiate the concretions from the matrix, while the silica of both may be so closely of the same degree of crystallization as not to help in the definition when the section is examined with the polarized light. In some sections the outlines of the concretions are of such a nature as to suggest very strongly their having been partly dissolved away, while in many cases veinlets of purer and differently crystallized silica of the matrix enter into the mass of the concretions. (Pl. XXII, Fig. 3; Pl. XXIII, Figs. 1 and 2; Pl. XXV, Fig. 3.) These veinlets have very varying extents, and have often severed concretions into several fragments. In the concretions the iron oxide is arranged in concentric oval or spherical bands, and this is equally true whether the iron oxide is limonite, hematite, or magnetite. This iron oxide is arranged without the slightest reference to the individuals of quartz cutting through them in the most indiscriminate manner. The concretionary structure affects the silica both in concentric arrangement and coarseness of individuals. It is quite common for the individuals of quartz to be larger in the concretions than in the cherty matrix. (Pl. XXII, Figs. 1 and 2.) Rarely these concretions have nuclei from extraneous sources, as, for instance, small particles of fragmental quartz, of a comparatively large individual or a cluster of individuals of quartz, or else of iron oxide, but ordinarily they have none. Sometimes the concretions are so closely clustered that in their growth they interfere, and in such cases two or more concretions are used as a nucleus about which the bands of iron oxide arrange themselves concentrically, thus forming compound concretions. (Pl. XXVII, Fig. 3.)

A less prevalent characteristic of these rocks than the concretions consists in the extraordinary brecciated appearance which they present. (Pl. XXII, Figs. 2 and 3; Pl. XXIII, Figs. 1 and 2.) A similar appearance has already been noted as characterizing the chert of the limestone. The outlines of the fragmental areas are very commonly more or less sharply angular, while frequently convexities and projections in the outline of a detached fragmental area correspond to concavities and recessions of outline of another fragment in such a manner as to demonstrate a former continuity of the two. The concretionary areas, in which, it should be remembered, silica is still the main ingredient, occur along with the fragment-like areas, while between the two there is found such a complete series of gradations that it is impossible to resist the conclusion that in many cases both are of the same origin, only the brecciated phases have been shattered by dynamic movements.

The great variety of forms presented by the different sections fortunately relate the history of these concretionary and brecciated areas. (Pl. XXVII.) In the first place, entirely unaltered areas of iron carbonate are found associated with these concretions. . Other iron carbonate areas lying within the usual siliceous groundmass may be cut by ramifying veinlets of silica. Again, areas are seen in which curving lines of iron oxide have been developed at or near their edges. These lines may or may not complete a loop. If the outline of the original carbonate area is more or less irregular and angular, the iron oxide curve cuts off the irregularities. In other cases, again, several such complete or partial iron oxide lines, concentric with one another, have been developed. Subsequent to or alternate or simultaneous with this process silica appears within the concretion, filling the spaces between the rings of iron oxide, the iron carbonate being previously removed. At other times the space occupied by the iron carbonate is left vacant, or else only partially filled, whence arise the frequent geodic and other cavities found in this phase of rock. Finally, no iron carbonate remains, its place being taken by the concentric rings of iron oxide and the minutely crystalline to amorphous silica. Between the unaltered iron carbonate areas and the perfectly formed concretions there are at times, often in a single section, every possible gradation. If the iron oxide developed from the carbonate was very plentiful but little room was left for the entering silica, and these areas appear now nearly or quite opaque with oxide, but generally the iron oxide has been developed in the partial or complete ovals referred to, and the substitution of silica for the remaining carbonate left these lying within a siliceous background.

Quite similar has evidently been the process by which the pseudo-fragmental areas, such as shown in Pl. XXIII, Figs. 1 and 2, have been produced. In such cases the silica of the background has plainly also been rearranged, so that it resembles and merges into the silica of the concretionary areas, thus giving the vague, irregular outlines which make these forms so closely resemble fragments. More rarely the fragmental areas are tabular in form, or else show a subordinate parallel lamination which appears to be lines of original deposition. The laminæ of these areas frequently abruptly terminate at the exteriors of the apparent fragments. A number of such areas sometimes occur in a single section, now lying within the siliceous groundmass in such positions as to have the laminæ of the different areas make all sorts of angles with each other. In such cases the areas must be believed to be real fragments which have formed either in situ by an actual local brecciation of the rock caused by chemical or mechanical action, or they may be considered as having been derived from the immediately underlying layer of nonfragmental rock by a temporary mingling of fragmental and nonfragmental deposition. That the former is the true explanation of their origin we have little doubt.

It is exceedingly difficult to convey in any general description a good idea of the multitudinous phases presented by this second type of rock, but some further and more accurate conception may be obtained by an examination of the accompanying carefully described plates and study of the detailed descriptions of individual sections given below.

In connection with the second type of rock, it is necessary to allude to some peculiar phases which resemble on the one hand the brecciated rocks described above, and upon the other the true fragmental rocks of the underlying Quartz-slate member. In them there has evidently been a mingling of mechanical and chemical sedimentation. They contain simple grains of quartz which have been enlarged, the fragmental character of which can not be doubted. These same sections also contain rounded chert areas, which include sometimes little iron oxide, sometimes abundant red hematite, making them jasper, and sometimes both hematite and magnetite. Often the areas containing little or no iron oxide and those containing it abundantly are in juxtaposition. Simple fragmental grains of quartz and the chert areas are generally arranged with their longer axes in a common direction. The fragmental character of the simple quartzes, the likeness to them in form of the chert areas, and their arrangement with longer axes in a common direction, are almost conclusive proof that these parts of the rocks are genuine mechanical sediments. The fragments are cemented by a matrix, which is a ferruginous chert in every respect similar to the matrices of the ferruginous cherts of the second type of rock.

These rare occurrences of semifragmental rocks are interstratified with others which are typical forms of the Iron-bearing member. The meaning of this interlamination of the two classes of sediments will be considered later.

*Microscopical character of the actinolitic slates* (Pl. XXIII, Figs. 3 and 4; Pl. XXIV, Figs. 1 and 2; Pl. XXVIII).—As already stated, the actinolitic rocks of the third type above macroscopically described have as their four main constituents, quartz, hematite, magnetite, and actinolite. In the large exposures all of these minerals are invariably found. In hand specimens any one of them may be found, to the almost complete exclusion of the others, and also all possible combinations of any two or three of them, and of all together. The order—quartz, iron oxide, and actinolite—expresses their usual relative abundance, taking the exposures as a whole. However, in the thin section, as would of course follow from the foregoing, any one of the three may at times be the predominant constituent, while also any one or two of them may be almost or quite wanting. In order of time of crystallization, the iron oxide is always the earliest of these constituents, next the actinolite, and finally the quartz. Yet while this is true as a general statement, it is not meant to imply that the crystallization of any one constituent is finished before that of the second one begins, for they are, to a certain extent, simultaneous. The areas of iron oxide are the freest from inclusion of the other two chief constituents. The actinolite contains large quantities of iron oxide, but everywhere penetrates the quartz, a single needle of actinolite commonly cutting two or more individuals of quartz, and finally the quartz individuals include much magnetite and actinolite. However, each one of the minerals is, in certain cases, found to include both of the other two. In addition to these three main constituents, chlorite and biotite are found as extensive alteration products of the actinolite. The alteration products, chlorite and biotite, are always in minute flakes, several or many individuals of these minerals forming from a single needle or blade of actinolite. The magnetite and hematite are directly associated and probably formed at the same time. Occasionally the hematitic ingredient is manifest macroscopically by the peculiar steely luster characteristic of specular iron, or by a purplish tint to the powder of very highly ferruginous varieties; but the analyses quoted above show that this ingredient is at times contained when neither microscopic nor macroscopic characters would suggest its presence. It appears to be intimately associated with the magnetite, and occurring in aggregates of very minute metallic lustered particles, it fails frequently to give the reddish translucency ordinarily described as a characteristic of it.[1]

Of the three principal mineral constituents named, the quartz, or silica, presents itself in a general way as a very minutely crystalline groundmass or background in which the other minerals are contained. Only rarely is the crystallization of this quartz so coarse as indicated in Pl. XXVIII, Fig. 4, in which, however, the individuals are still small, being greatly magnified. On the other hand, it only rarely sinks to that excessive degree of fineness which is characteristic of the chalcedonic form of silica. Still, a few sections have been found in which it does reach this excessively fine condition, and even becomes quite amorphous; but these conditions are, as seen, far more characteristic of the cherty rocks of the type previously described. Since these two types, however, manifestly grade into one another, it is evident enough that all of the silica of the three types is of the same origin; that is to say, is all water deposited. Even where least minutely crystalline, as in some of the actinolitic slates, the individuals of quartz interlock with one another in such a fashion as to place their deposition in situ quite beyond question. Nowhere is there any indication of a fragmental origin for any of the siliceous groundmass. Cases have been noted of the occurrence of genuine fragments of quartz within the nonfragmental mass of the rocks of the first and second types, but these fragments are always sharply defined and wholly distinct in character from the prevalent nonfragmental silica.

The magnetite and hematite occur partly in the form of an excessively fine dust contained within the quartz and actinolite individuals, partly in

[1] A single individual of hematite is characterized in the thin section ordinarily by a reddish color in transmitted light, and lack of metallic luster in reflected light; but when the individuals are exceedingly small, an aggregate of hematite may readily present the metallic luster, and unless thinner than the ordinary thin section is, may at the same time appear perfectly opaque in transmitted light, in which case, if mingled with magnetite, its presence is difficult to detect with the microscope. In order to test this question a number of thin sections were made of specular hematites from various places in the lake Superior region. Some of these, after powdering, yielded nothing at all to the magnet, while others contained more or less magnetite intermingled with the hematite. In all cases, however, where the grain is sufficiently fine, it was found that the hematite presented the same metallic luster in the reflected light and opacity in transmitted light as the magnetite. Many of these thin sections, when the ore contained no magnetite whatever, presented in the transmitted light a mixture of red translucent and black opaque material, this opaque material giving the metallic luster in the reflected light.

the shape of single crystals, or groups of crystals, of moderately large size, and partly in the irregular, oval, opaque bunches of crystals above mentioned. The outlines of the single crystals are usually very sharply defined, square, hexagonal, and rhombic outlines presenting themselves constantly. On the whole the rhombic outline is the most common. In the most regularly slaty phases of the actinolitic schists the iron oxides are found to be aggregated much more plentifully in certain bands than in others, the individual laminæ of these slaty rocks presenting in turn each of the three main constituents as the predominant one. Pl. XXVIII, Fig. 4, shows the arrangement of the minerals in one of the more quartzose laminæ of such a slaty rock, while Pl. XXIII, Figs. 3 and 4, from photographs, show, with a much smaller degree of enlargement, portions of three laminæ, the central one composed mainly of quartz and actinolite, while the other two are richer in magnetite, but these last two figures represent by no means a highly magnetitic phase. The rocks of the second or ferruginous chert type have been described as presenting very commonly a most singular occurrence of the oxides of iron, the particles of these oxides being distributed upon the quartz background in rude circles or ovals, or in two or more concentric circles or ovals. In these cases the curving lines, made up of particles of one or more of the three oxides, present no relation whatever to the silica individuals, traversing a number of these individuals indifferently, and looking as though painted upon the silica background. While this occurrence is far more common among the cherty rocks of the second type, it is also met with among some of the highly actinolitic slates, in which case the actinolite is usually associated with the curving lines of iron oxide. In some cases actinolite and magnetite are associated in a bunchy fashion, as, for instance, in Pl. XXIV, Fig. 2, and are at times dissevered from one another by the intrusion of silica, this silica, however, presenting the appearance of passing about the several detached areas where these are sufficiently translucent to allow such a relation to be seen. These relations are still better shown by certain rocks from the Animikie series. (Pl. XXIX, Fig. 2.) The existence of this peculiar structure in the highly actinolitic rocks is of very considerable interest, since it furnishes one more link between them and the ferruginous cherts of the last type, one more thing to indicate that all are derived from essentially the same original material. The actinolitic ingredient of these rocks presents itself usually in bunches of minute radiating blades of a pale greenish tint. Occasionally the individual blades are large enough, as indicated previously, for them to be seen with the naked eye or with the magnifying glass, but more usually they are microscopic. Even these radiating bunches of actinolite are aggregated into certain laminæ to the approximate exclusion of the other mineral ingredients. They occur also in single blades scattered through the thin section, many minute blades being not infrequently inclosed in a single grain of quartz, while other blades or bunches of blades often traverse a number of quartz individuals.

One unusual phase of the actinolitic rocks deserves especial description. At Penokee gap, both on the west and on the east side of the fault which there occurs (see Pl. XXXVI), the uppermost layers of the Iron-bearing member are composed of a thin belt of peculiar slate, in which garnet is a prominent constituent. This slate is nearly aphanitic, of a dark color, banded vaguely with lighter streaks, and cleaves readily parallel to the lamination. Minute individuals of garnet may at times be detected with a strong magnifying glass in the lighter colored streaks, but usually they require the microscope for their detection. Under the microscope this rock is seen to be almost wholly composed of actinolite, magnetite, and garnet. The garnet is in small and very numerous individuals, presenting a pale pinkish tint. In the ordinary light many of these garnets are to be seen provided with crystal outlines, but in the polarized light this becomes less evident, because many of the garnets are penetrated by numerous needles of actinolite, which are frequently very plentiful in the outer portions of the garnet individuals. The actinolite also makes up most of the interstitial portions of the thin sections, while the magnetite, in fine particles, at times provided with sharp crystal outlines, is scattered uniformly throughout all portions of the section, being included within each of the other minerals. Numerous minute flakes of biotite occur always in such relation to the actinolite as to suggest their possible derivation from it. Chlorite occurs also in some sections quite plentifully as an alteration product of the actinolite. In some cases brown iron oxide stains the actinolite blades. A separation of the garnet (specimen 9553) by W. S. Bayley having been made, the following analysis[1] of the separated material was made by Dr. Thomas M. Chatard, of the laboratory of the U. S. Geological Survey: Silica, 39·31; alumina, 12·86; iron sesquioxide, 10·21; iron protoxide, 32·81; manganous oxide, 1·03; calcium oxide, 1·88; magnesium oxide, 1·90=100·00. Dr. Chatard observes that this analysis is close to that of an average almandite. At one time in our study of this rock it was supposed that the actinolitic ingredient might be the result of a secondary alteration of the garnet, but the abundance of the same actinolite in the underlying magnetitic and actinolitic schists with which this rock is so intimately associated, and in which the actinolite is surely not an alteration product of garnet, seemed to render such an origin improbable. A further study of the sections appears to show that the actinolite, even in the garnetiferous rock itself, is independent of the garnet, having been in part a simultaneous crystallization and in part an earlier crystallization. This conclusion is borne out by the analysis above quoted, from which it appears that the composition of this garnet is such that the actinolite could not readily have been derived from it. Immediately overlying this garnetiferous rock is found a black fragmental slate.[2] At the junction between the two the garnets are found to occur within the fragmental material, an occurrence which suggests the possibility that this fragmental material furnished some of the ingredients which subsequently made up the garnet.

[1] With regard to this analysis Dr. Chatard says that the amount of material furnished was only 1.2 grams, and that owing to the loss of a portion there remained but 0.54 gram for the determination of the absolute amount of iron protoxide. This remnant being too small for the determination, the iron protoxide was calculated from the excess over 100 in the summation of the entire analysis after estimating all the iron as the sesquioxide. Dr. Chatard also says that this method of calculation "gives a result close to the average analysis of almandite garnet, which the mineral undoubtedly is."

[2] For an early description of this garnetiferous slate, which, though not frequently met with in the Penokee region, is closely allied to certain garnetiferous actinolitic schists occurring more widely in the Marquette region of Michigan, see Geol. of Wis., vol. III, pp. 123, 124; see also for rude colored drawings of the thin sections of the same rocks, Figs. 1 and 2 of Pl. XVa of the same volume.

In the detailed description of the actinolitic and magnetitic schists below, the iron oxide is spoken of as if wholly magnetite, unless the hematite can be microscopically discriminated. However, as shown by the analyses, page 197, the magnetite is always accompanied by hematite. The actinolite is so named because it has the microscopical properties of that mineral. No separations of it have been attempted, but the universal presence of considerable quantities of magnesium and calcium in these rocks, as shown by the analyses referred to, renders it probable that the mineral is actinolite rather than grünerite; since no other silicate is common and the only remaining important minerals are quartz and iron oxide.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.

*From the exposures in the SE. ¼ of Sec. 26, T. 44 N., R. 6 W., Wisconsin.*

1. Magnetitic actinolite-schist. Specimens 202 Wr.,[1] 203 Wr., from 350 N., 650 W., Sec. 26, T. 44 N., R. 6 W., Wisconsin.

A dark colored slaty rock, in which bands about one-fourth of an inch wide are mainly composed respectively of magnetite and actinolite, the latter arranged in quite large, dark green radiating blades. In some cases the magnetitic bands are wider, however, and show the minute actinolites mingled with the magnetite.

The thin sections are both cut from the more actinolitic seams. In both sections the actinolite is in very large and interlocking blades, which are often altered to chlorite and have in places given rise to a secondary biotite. Included within the actinolite blades are numerous small particles of magnetite, often with crystal outlines.

2. Magnetitic actinolite-schist. Specimen 9698 (slide 3171); from 480 N., 520 W., Sec. 26, T. 44 N., R. 6 W., Wisconsin.

A dark gray, nearly aphanitic rock, with faint lamination lines, and narrow seams parallel to the lamination, which are quite rich in magnetite. The magnifying glass reveals the presence in the body of the rock of numerous minute actinolite blades, mingled with quartz particles and some magnetite. Sp. gr., 3·50.

In thin section interlaced blades and needles of actinolite compose the larger part of the rock. This actinolite is partly altered to chlorite and includes numerous small particles of magnetite.

[1]The numbers of specimens and slides are usually those of the collection of the lake Superior division. Specimens with Wr. after the numbers are from the collection of the late Mr. Charles E. Wright. Specimens with Wis. after the numbers are from the collection of the Wisconsin Geological Survey. Locations are given from the southeast corner of the sections, in steps of 2,000 per mile.

3. Magnetitic actinolite-schist. Specimen 9696 (slide 3170); from 620 N., 380 W., Sec. 26, T. 44 N., R. 6 W., Wisconsin.

This rock is closely similar to 2.

The thin section shows a background of minutely crystalline quartz. Traversing this background are numerous blades of actinolite, which are often arranged in rosette form. The individual blades of actinolite each frequently traverse several quartz individuals, but there are also seen included within single quartz grains a number of minute actinolite needles. Magnetite occurs in minute particles within the actinolite. But little biotite and chlorite, secondary to the actinolite, are present.

*From the Atkins lake iron range.*

4. Actinolitic and magnetitic quartz-schist, from a lower horizon than 5. Specimen 9680 (slide 3167); from 625 N., 685 W., Sec. 20, T. 44 N., R. 5 W., Wisconsin.

This rock is very closely like 2, differing only in being still finer in grain and more quartzose.

The thin section shows a background of intricately interlocking completely crystalline quartz, within which are included numerous concretionary areas composed of magnetite, actinolite, and quartz, the former at times being predominant. Within these areas the magnetite and actinolite particles show a tendency to an arrangement in curving concentric lines which traverse the quartz individuals indifferently. The minerals between the concretions are not different from those that compose them, only the quartz is greatly predominant and more coarsely crystallized. Many of the larger mostly interstitial grains of quartz run over into adjacent concretions just as though they were not there, then including the bands of actinolite and magnetite. The concretions have strongly the appearance of being painted on a quartzose background. No section could present better evidence that the quartz was the last mineral to crystallize than does that of this rock. (Pl. XXIV, Fig. 2.)

5. Magnetitic actinolite-schist, from a higher horizon than 4. Specimen 9684 (slide 3168); from 1340 N., 330 W., Sec. 20, T. 44 N., R. 5 W., Wisconsin.

The rock resembles 2, except in being darker in color, richer in magnetite, and finer in grain. Sp. gr., 3·43.

The thin section is like that of 2.

6. Magnetitic and actinolitic quartz-schist, from a higher horizon than 5. Specimen 9692 (slide 3169); from 400 N., 1000 W., Sec. 16, T. 44 N., R. 5 W., Wisconsin.

A very compact rock, composed of vaguely defined lighter and darker colored bands, the latter so rich in magnetite as to give a metallic luster. The lighter colored ones are seen with the magnifying glass to contain more quartz. Sp. gr., 3·46.

The groundmass is composed of finely crystalline quartz. Magnetite particles are scattered generally through the groundmass, but are also often grouped in irregular outlined clusters. Actinolite, with its alteration product, chlorite, occurs as in 2.

*From the Marengo river iron range, Sec. 23, T. 44 N., R. 5 W., Wisconsin.*

7. Magnetitic actinolitic schist. Specimen 186 Wr.; from 1900 N., 1325 W., Sec. 23, T. 44 N., R. 5 W., Wisconsin.

An aphanitic, dark gray, slaty rock, so excessively fine grained that the magnifying glass detects none of its constituents.

The thin section is mainly made up of interlaced, often radiating, blades of actinolite, within which are included numerous crystals and particles of magnetite. The particles of the latter mineral are also at times aggregated into bunches of some size.

8. Magnetitic actinolite-schist. Specimen 180 Wr.; from 500 N., 500 W., Sec. 23 T. 44 N., R. 5 W., Wisconsin.

A dark gray, nearly aphanitic rock, showing on the weathered portions very thin and regular lamination. The magnifying glass can barely detect the magnetite particles and minute needles of actinolite.

The thin section is similar to that of 7, save that the actinolite is in larger blades and that the rock contains a larger proportion of magnetite.

*From the exposures in Sec. 24, T. 44 N., R. 4 W., Wisconsin.*

9. Actinolitic and magnetitic quartz-schist, from a low horizon. Specimen 9649 (slide 3159); from 1637 N., 0 W., Sec. 24, T. 44 N., R. 4 W., Wisconsin.

This rock closely resembles 2 and 4, being composed of dark colored, strongly magnetitic bands and light colored, quartzose, ones.

The thin section of this rock is similar to that of 4.

*From the exposures in Sec. 9, T. 44 N., R. 3 W., Wisconsin.*

10. Actinolitic and magnetitic quartz-schists, from a middle horizon. Specimens 9641 (slide 3151), from 0 N., 400 W., and 9642 (slide 3152), from 0 N., 500–600 W., Sec. 9, T. 44 N., R. 3 W., Wisconsin.

These rocks, again, are closely like 2 and 4, having the same interlamination of lighter and darker materials. The darker colored bands are very rich in magnetite, quite aphanitic, and have a conchoidal fracture. Sp. gr. of magnetite seam in 9642, 4·54.

The thin sections show a groundmass of minutely crystalline quartz, the individuals for the most part interlocking with one another more or less deeply, though some of the more minute ones are provided with crystal outlines. This groundmass in slide 3152 composes two-thirds of the rock; in 3151 less than half. Magnetite is scattered through the groundmass in numerous minute grains and crystals, which are included within the quartz individuals. These are so abundant in 3152 as to make up a half of the whole section. Actinolite occurs in a few blades which are heavily stained with iron oxide and traverse the groundmass in such a manner that each blade cuts a number of quartz individuals.

*From the Penokee gap section.*

11. Magnetitic actinolitic quartz-schists, from middle horizons. Specimens 9556 (slide 3142), from 1900 N., 1500 W.; 9557 (slide 3096), from 1850 N., 1500 W.; 9558 (slide 3191), from 1800 N., 1500 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

These specimens represent the composition of the west cliff at Penokee gap. This cliff is made up of alternating bands of lighter and darker colors, individual bands varying very greatly in width and in the amount of distinctness of definition. The darker bands, often in themselves thinly laminated, are very rich in magnetite, at times so much so as to present a distinct metallic luster. The lighter colored portions are highly quartzose and carry relatively little magnetite. The bands which are richest in magnetite are usually found running from a fraction of an inch to several inches in thickness, but thicknesses of a number of feet are met with in which there is as much as 40 per cent of metallic iron. The darker colored, very highly magnetitic phases are quite aphanitic, but the lighter colored portions, though still very fine grained, show distinctly under the magnifying glass a mixture of minute actinolitic blades and quartz. Sp. gr. of 9556, 3·37; of 9557, 4·31; of 9558, 3·91.

The thin sections are composed of magnetite, actinolite, and quartz, named in order of time of crystallization. The only difference between the thin sections lies in the varying coarseness of grain and the varying proportions of the three constituents, each one of which is in turn the preponderating ingredient, and again insignificant in quantity. The quartz forms a groundmass of closely fitted or interlocked grains, the smaller ones of which are often provided with crystal outlines. Nowhere do these grains show any traces of fragmental cores, the whole appearance forbidding any thought of a detrital origin for any portion of the section. The actinolite is in colorless to pale green, feebly dichroic needles and blades, at times arranged in radiating aggregations which vary very greatly in size. Numbers of the more minute needles occur often within single quartz grains, while the larger needles and blades extend through a number of quartz individuals. The arrangement of the actinolite has plainly been without any reference whatever to the quartz, which appears therefore to be of subsequent origin. The magnetite occurs in minute dust-like particles within both quartz and actinolite, and also in quite large aggregations of irregular outline. At times these aggregates of magnetite include particles of actinolite and quartz, but such cases seem rather to be explicable on the idea that the actinolite and quartz have entered into cavities within the magnetite aggregations subsequent to their solidification. No evidence is found that these two minerals ever are included within or traverse single individuals of magnetite. (Pl. XXIV, Fig. 1.)

12. Magnetitic and actinolitic quartz-schists, from near the summit of the Iron member. Specimens 9555 (slide 3190), from 0 N., 1625 W., Sec. 11; and 9567 (slide 3195), from 1675 N., 1100 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

These specimens are from very near the summit of the Iron-bearing horizon, having been taken immediately beneath the very thin and peculiar garnetiferous rock which lies at the top of this member. They are thinly laminated in light and dark gray shades, aphanitic, and very closely resemble the rocks last described. Sp. gr. of 9555, 3·05.

The thin sections of these specimens present appearances like those of 11. (Pl. XXIII, Figs. 3, 4; Pl. XXVIII, Fig. 4.)

13. Magnetitic and garnetiferous actinolite-schists, from the summit of the Iron member on the west side of Penokee gap. Specimens 9553 (slide 3188), from 0 N., 1800 W.; 1404, Wis. (slide 241), from 0 N., 1900 W.; 1444, Wis. (slide 263), from 0 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

These are dark colored aphanitic rocks, banded vaguely with lighter streaks, having a pronounced conchoidal cross fracture, but cleaving readily parallel to the lamination. In some places, with a strong magnifying glass minute individuals of garnet may be detected. These appear most abundant in the light colored streaks. Sp. gr. of 9553, 3·42.

The thin sections are almost wholly composed of magnetite, actinolite, and garnet. The garnet is in rather small and very numerous individuals, which present a pale pinkish tint in the thin sections. In the ordinary light many of them are seen to be provided with crystal outlines; in the polarized light this becomes less evident, because many of the garnets are penetrated by numerous needles of actinolite, which are frequently more plentiful in the outer portions of the garnet. The actinolite makes up most of the interstitial portions of the sections, but also penetrates and is included within the garnet individuals. It was at first supposed that this actinolite is an alteration product of the garnet, but the fact of the abundance of the actinolite in the immediately underlying magnetitic and actinolitic schists with which this garnetiferous rock is so intimately associated, and in which the actinolite is surely not an alteration product of garnet, seeming to render such an origin improbable, this view was abandoned. A further study of the section seems to show that the bulk of the actinolite is rather independent of the garnet, having been in part of a simultaneous crystallization with it and in part of a previous crystallization. The magnetite, in fine particles, at times crystal outlined, is scattered uniformly through all portions of the section, being included within all of the other minerals. Biotite occurs in numerous minute flakes, which appear in all cases to be secondary to the actinolite individuals.

14. Altered garnetiferous actinolite-schists, from the summit of the Iron member on the west side of Penokee gap. Specimens 1501, Wis. (slide 276), from 1670 N., 1100 W.; 1502 Wis. (slide 277), from 1670 N., 1100 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

Macroscopically these rocks resemble 13.

This resemblance holds in the thin sections, save that the garnet is less abundant and that the actinolite has been much more largely altered. The alteration products are biotite and chlorite, but more or less brown iron oxide accompanies the biotite.

*From the Penokee range, Sec. 9, T. 44 N., R. 2 W., Wisconsin.*

15. Magnetitic and actinolitic quartz-schist, from a low horizon. Specimen 2064 Wis. (slide 300), from 0 N., 1000 W., Sec. 9, T. 44 N., R. 2 W., Wisconsin.

The thin section of this rock does not differ in any essential respect from those of the Penokee gap actinolitic schists, 11 and 12. The actinolite is arranged in the usual radiating bundles and is more or less stained with brown and red iron oxides. The quartz, as usual in these rocks, is very minutely crystalline, and wholly without any appearance of a fragmental origin.

*From the gorge of Tylers fork, Wisconsin.*

16. Ferruginous quartz schists, from a low horizon. Specimens 9620 (slide 3147), from 1170 N., 160 W.; 9624 (slide 3149), from 1235 N., 193 W., Sec. 33, T. 45 N., R. 1 W., Wisconsin.

The exposures of the Iron-bearing member at the gorge of Tylers fork present rocks having a general resemblance to those of the Penokee gap section, including darker colored, more magnetitic, and lighter colored more quartzose phases; but one is impressed at once with the relatively small proportion of magnetite contained in the Tylers fork section where the light colored, more quartzose kinds very greatly predominate, and where the thin banding which characterizes the Penokee section is only developed in one or two places. Specimens 9620 and 9624 are mainly made up of the lighter colored phase, which, it should be said, is still lighter colored than any of the Penokee gap rocks. No actinolite is perceptible with the magnifying glass, while the appearance of the quartz is quite peculiar, suggesting some sort of a concretionary arrangement. The lean ferruginous seams are exceedingly irregular in thickness and in course, branching and running in all sorts of irregular fashions instead of lying parallel to the general bedding of the rock. Sp. gr. of the quartzose portion of 9620, 2·93; of magnetitic banding seams, 5·01.

The thin sections are composed of quartz, actinolite, and magnetite, and so far are analogous to the actinolitic and magnetitic schists of Penokee gap above described, but there are some important differences. In the first place, the actinolite in the Tylers fork rocks is very much less plentiful, and as a rule is in much more minute blades. A much more pronounced difference, however, consists in the striking tendency toward a concretionary development that these Tylers fork rocks show. This is brought out particularly in the arrangement of the individuals of the greatly predominating quartz of the groundmass and comes out with special prominence in the polarized light, when there is seen a tendency of the coarser individuals of the quartz to arrange themselves in the centers of areas whose outer portions are made up of more minute particles. The magnetite, however, also shows some slight tendency to a concretionary arrangement, while the minute actinolite blades are aggregated into little clusters, which appear in the main to lie in the spaces between the concretionary areas or in the outer portions of these areas. The magnetite occurs in bunches of crystals, and in curvilinear aggregations, and also in single individuals scattered indiscriminately, though sparsely, throughout the section. Another noticeable difference between these rocks and those from Penokee gap consists in their lack of the highly developed lamination which the latter rocks show, both in the thin section and in the hand specimen. There is no trace of evidence that the quartz of these rocks is in any measure of a fragmental nature. In fact, its concretionary arrangement and the interlocking of the different individuals puts such an origin entirely out of the question. In slide 3147 stains of brown iron oxide occur here and there, usually mingled with the clusters of the minute actinolite blades. In the section of this specimen there is seen also a single rhombic crystal section, which, on examination with a high power, proves to be made up chiefly of a number of actinolite blades, which on the border of the crystal are deeply stained by brown iron oxide. The shape of this piece suggests the probability that it was originally a single individual of iron carbonate. (Pl. XXVIII, Fig. 1.)

17. Ferruginous quartz-schist, from a low horizon. Specimens 9617 (slide 3100), 9623 from 1175 N., 120 W., 9618 (slide 3148), from 1245 N., 185 W., Sec. 33, T. 45 N., R. 1 W., Wisconsin.

These specimens resemble those of 16 in all respects, except that numerous spots of reddish jasper are seen upon them. These stand out in a prominent fashion and in such a way as to suggest a fragmental origin for them. In the same ledge, however, are large bands of the same jasper (9618), directly interlaminated with the other materials; Specimen 9617 shows the peculiar concretionary, or partly fragmental, character described under 16. Sp. gr., of 9617, 2·76; of 9618, 2·92.

The thin sections show that these rocks differ from 16 in containing no actinolite; but a more interesting difference lies in the very much more striking development which they show of a concretionary structure. This appearance shows not merely in the quartz background itself, as seen in the polarized light, but in the arrangement of the particles of iron oxides, which include both hematite and magnetite, and in smaller quantity the brown oxide. In some cases the magnetite and hematite are aggregated into opaque, round or oval areas, the edges of which show the projecting corners of numerous individual crystals of magnetite; but there are more plentiful areas in which these oxides are seen to be disposed in concentric bands, made up of more or less separated particles of the oxides, and having between them the ordinary quartz background of the rock. When these areas are examined in the polarized light they are found to lie in the quartz background in such a fashion as to suggest their having been painted upon it, a single band of the iron oxide traversing multitudes of quartz individuals, to whose arrangement it bears little or no relation. As usual, the quartz in these rocks is plainly the last separated ingredient, and it seems that its concretionary form had something to do with the concentric arrangement of the iron oxide also. From what follows later, it is probable that the bands of iron oxide are the remains of iron carbonate areas which have altered to iron oxide in part, but have partly been replaced by silica, these processes producing the concretions. Besides these concretionary areas, there are other areas whose outlines in the polarized light suggest their being fragments. These are mainly made up of silica like that of the groundmass, except that in some cases they are possibly finer grained and have the iron oxide particles scattered through them irregularly. This is particularly noticeable in slide 3148, which appears with a low power, as if it might have been a fragmental rock whose fragments had all been silicified, the same silica filling the spaces between the fragments. In this section also some of the apparent fragments are jaspery—that is to say, a mixture of red iron oxide and quartz—and appear therefore quite different from the rest of the rock. Of particular interest is the occurrence in this slide of quite an amount of iron carbonate. This substance, which is usually more or less stained with brown iron oxide, but is very plainly recognizable as a carbonate, appears both in single individuals scattered through the groundmass and in clusters of individuals. These clusters often lie in groups, between which are areas of the groundmass, in such a fashion as to render it evident that they were once connected with one another and have since been separated by the insertion of the quartz. In a few cases some of the apparent fragments above alluded to are mainly made up of this brown stained carbonate, little veins and streaks of the quartzose groundmass entering into them or even entirely traversing them. This occurrence of the carbonate is of great interest, because it seems to indicate that all of the apparently fragmental and concretionary areas which are now made up of quartz and iron oxide were originally composed of this substance. Whether the fragmental appearance which these rocks have is due to a real fragmental character, or is caused by the same processes which have formed the rounded and oval concretions (i. e., is of a secondary nature), will be discussed later.

18. Ferruginous quartz-schist, from a middle horizon. Specimen 9625 (slide 3150); from 1285 N., 230 W., Sec. 33, T. 45 N., R. 1 W., Wisconsin.

A nearly black aphanitic flinty rock in which the only ingredient recognizable with the magnifier is hematite in minute metallic lustered scales. Sp. gr., 2·90.

The thin section of this rock, examined with a low power and in the ordinary light, presents a much more striking irregular appearance than those immediately above described (except slide 3148), being made up of round or oval areas, which differ from the whiter quite sparse matrix in being dotted over with a fine black dust. These areas are usually outlined by a border of magnetite crystals, but otherwise there is none of the concretionary appearance about them that characterizes the apparent fragments of 17. Examined with a higher power in the polarized light, some of these areas are found to be made up mainly of quartz, which for the most part is quite like that of the interspaces, though the latter is occasionally coarser than is seen within the apparent fragments. The black particles alluded to appear to be wholly iron oxide and in the main magnetite, which mineral, however, occurs also in quite large sized crystals, arranged in bands, as already stated, bordering the apparent fragments, but also sometimes scattered through them, and again in clusters within the interstitial quartz. (Pl. XXVIII, Fig 2.)

*From the Penokee range in Sec. 24, T. 45 N., R. 1 W., Wisconsin.*

19. Magnetitic quartz-schist. Specimen 9081 (slide 4206); from 140 N., 0 W., Sec. 24, T. 45 N., R. 1 W., Wisconsin.

The rock is a very highly magnetitic, fine grained, dark gray schist, in which the magnifier reveals only quartz and magnetite, certain irregular bands being much more highly magnetitic than the rest of the rock.

The thin section of this rock is very closely like those of the Tylers fork rocks, particularly 17, presenting the singular concretionary and apparent fragmental appearance. In the case of the present rock there is more of the red and brown oxides of iron than of the magnetite. In many places the iron carbonate is found in the concretions. Here at times the iron carbonate extends beyond the outlines of the concretions and apparent fragmental areas in such a manner as to make it probable that the iron carbonate was the original material, and that the minerals contained in it—iron oxide, actinolite, and quartz, making up concretionary and apparently fragmental areas—have formed from in part and replaced in part the original iron carbonate. In places the rhombic shapes of the brown and red iron oxides make it evident that these are the direct results of oxidation of siderite individuals. (Pl. XXIII, Figs. 1 and 2.)

*From the Potato river section.*

20. Magnetitic quartz-schist. Specimen 9104 (slide 4214); from 1050 N., 250 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

A fine grained, nearly white, cherty rock, dotted with magnetite particles, and irregularly banded with thin seams of the same mineral. Sp. gr., 3·21.

The thin section of this rock resembles those of the actinolitic and magnetitic quartz-schists of Penokee gap (11 and 12), particularly those in which there is the minimum of parallelism in arrangement of the several ingredients. The arrangement of the quartz individuals and the bunchiness of the magnetite and actinolite suggest a vague concretionary arrangement. The actinolite is scattered about through the quartz groundmass, but occurs very plentifully also among the magnetite aggregations. As compared with the last rocks described, and others like it, this rock lacks the distinct separation into a relatively pure quartzose matrix and dark colored areas in which the iron oxides are particularly abundant, and which are outlined so distinctly as to suggest their having been fragments. However, after having seen the sections in which this arrangement is very pronounced, one realizes that even in a case like the present one there is a faint indication of the same structure. More or less of the iron oxide occurs in the hematitic and hydrated forms.

21. Magnetitic quartz-schist. Specimen 9183 (slide 4213); from 1050 N., 270 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

The rock is a fine grained, dark gray magnetitic schist, closely resembling 19. Sp. gr., 3·39.

The thin section resembles the last described as to its constituents, but differs from it in having the concretionary and pseudo-fragmental structure more largely developed. Since the two come from the same rockmass, it is evident that the faint indication of this peculiar structure seen in slide 4214 (20) points to a similar origin for the two rocks. Quite a little quantity of carbonate remains in some of the apparent fragments. Minute actinolite blades occur here, as in other similar sections, aggregated in minute needles about the clusters of magnetite.

*From the Penokee range in Sec. 16, T. 45 N., R. 1 E., Wisconsin.*

22. Ferruginous quartz-schist. Specimen 12831 (slide 5495); from 513 N., 1647 W., Sec. 16, T. 45 N., R. 1 E., Wisconsin.

The rock is fine grained, dark gray schist, banded with seams of black iron oxide.

The thin section of this rock resembles those of the several peculiar concretionary or pseudo-fragmental rocks above described, particularly 20. As seen in the ordinary light, it shows a colorless background, which is thickly studded with distinctly outlined areas that differ from the background merely in containing numerous minute dark colored particles. Some of these areas, however, are surrounded by a rim of the several iron oxides and occasionally these iron oxides, particularly the red and brown oxides, cover the whole of one of these areas. In the polarized light the spotted areas lose much of their definiteness and are seen to be mainly made up, like the matrix, of a very minutely crystalline cherty quartz. Some of the areas are quite angular in outline, but most of them are more or less rounded, while at times a number of the areas are so related to one another as to seem to have been once continuous, having been severed by insertion of the matrix material along irregular rifts. Here and there these areas are seen to have not merely a single ring of iron oxide, but to have also one within and concentric to the outer one.

*From the Penokee range in Sec. 10, T. 45 N., R. 1 E., Wisconsin.*

23. Ferruginous and actinolitic chert, or quartz and chert. Specimen 9185 (slide 4211); from 0 N., 1200 W., Sec. 10, T. 45 N., R. 1 E., Wisconsin.

The rock is a fine grained chert-schist, much stained with brown iron oxide. On close examination it is seen to be minutely porous. The fresh fracture is studded with little clusters of bright lustered magnetite, of which mineral the weight shows that there is a considerable portion present. Sp. gr., 3·26.

The section is a rather confused one, on account of the large amount of brown iron oxide, but careful examination shows that it consists of a number of more or less thoroughly detached areas, between which is a background of minutely crystalline silica. The areas referred to are of an angular to roundish outline, and in them the oxides of iron, including the brown oxide and magnetite, are mainly aggregated. When the iron oxide is least thick they show sheaf-like aggregations of actinolite blades in a background of minutely crystalline silica. Actinolite needles also occur in the groundmass.

*From the Penokee range in Sec. 12, T. 45 N., R. 1 E., Wisconsin.*

24. Ferruginous chert-schist. Specimen 9189 (slide 2930); from 1920 N., 1825 W., Sec. 12, T. 45 N., R. 1 E., Wisconsin.

A very fine grained chert, analogous to 9185, deeply stained with brown and red iron oxides, which minerals occur also in little bands of some thickness.

The thin section is made from some of the less ferruginous portions. It presents essentially the same appearance as that of 26, below described. The silica individuals are, however, more generally of somewhat larger size than in the latter section, although still quite small, and the concretionary structure is not so strongly developed. Neither is there so much iron oxide present. The concretionary areas and apparent fragments seen in 26 are less evident in the present case because they have less iron remaining in them, but many are readily seen in ordinary light, minute films of iron oxide still outlining them, while their interiors are commonly composed of a somewhat more minutely divided silica than that of the matrix.

25. Hematite iron ore in thin seams directly interstratified with 24. Specimen 9187 (slide 3105); from 1950 N., 1825 W., Sec. 12, T. 45 N., R. 1 E., Wisconsin.

The rock is a dark purplish red slaty hematite iron ore.

The thin section of this rock differs from that of 24 only in that it is mainly composed of a nearly opaque mass of particles of the red and brown oxides of iron. Small areas of minutely crystalline silica are seen, and a single vein of quartz of later origin than the iron oxide traverses the section. The quartz of this vein is in quite large individuals compared with those of the groundmass proper.

*From the Penokee range in Sec. 6, T. 45 N., R. 2 E., Wisconsin.*

26. Ferruginous chert-schist, from the base of the Iron-bearing member. Specimen 9190 (slide 2931); from 1825 N., 325 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

The rock is a brown stained porous chert.

The greater part of the section is made up of a concentrically arranged silica, quite analogous in its appearance to the concretionary cherts already described as belonging to the Limestone member of the Penokee series. This silica is in the main divided off into minute interlocking quartz individuals, which vary somewhat in degree of minuteness, the finest material at times passing over into chalcedony. Here and there through the section are seen what appear in the ordinary light to be areas of some different material from the rest of the section. These are stained a light brown color, and have smooth, curved outlines, concentric with which there is at times near the edges of them a curvilinear arrangement of the particles composing the iron oxide stain. In the polarized light these areas are seen to be made up of a minutely divided silica analogous to that forming the bulk of the rock, but usually defined from that portion of the matrix with which it is directly in contact by being much finer grained. Some of the areas, however, lack definiteness of outline, and appear as if invaded and dissolved away by the surrounding matrix. In one or two cases remnants of iron carbonates were detected within them. Scattered through the chert matrix in irregularly outlined aggregates and curving lines is a brown iron oxide in which may be seen at times remnants of iron carbonate. The cavities seen macroscopically in the specimen appear in the thin section as holes with ragged outlines, which are brought into particular prominence by a coating of iron oxide.

27. Flint or chert, from near the base of the Iron-bearing member. Specimen 9144 (slide 2799); from 1150 N., 1625 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

The rock is an aphanitic, white, chalcedony-like flint or chert, translucent on the edges, and possessed of a conchoidal fracture. Irregular bands of a nearly black color also occur. Sp. gr. of white portion, 2·67; of black bands, 2·69.

The thin section is composed almost wholly of a colorless silica, which for the most part polarizes only as an aggregate and very feebly. High powers, however, bring out distinctly minute polarizing particles, which are mingled with much material which seems to be quite amorphous. Portions of the section show, running through this silica, cloudy bands and streaks arranged in general parallelism to one another; a number of these streaks appearing as if once continuous bands which have been separated by the intrusion of silica. These bands owe their cloudiness, in part at least, to the presence of a minutely divided brown iron oxide. In the main, however, their substance seems now to be made up of silica more thoroughly amorphous than is that of the bulk of the rock. In some of these streaks are apparent remnants of a carbonate, in aggregates of minute individuals. This section is of particular interest as bearing upon the question as to whether such an excessively fine grained silica as that seen here is of the same origin with the more completely crystalline material more generally characteristic of the various ferruginous schists. The appearance of this section would seem to make it very probable that some of the fine grained silica is of a secondary origin and not in the nature of an original deposition.

28. Magnetitic siderite, from a lower middle horizon. Specimen 9191 (slide 2996); from 1850 N., 325 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

A dark gray, aphanitic, very heavy rock, possessed of a very thin lamination, the laminæ being alternately light gray and dark gray. Some of the darker colored laminæ contain enough magnetite to make them attractable by the magnet, but the high specific gravity is plainly not wholly due to the presence of this magnetite in the darker colored bands. Sp. gr., 3·50. Composition: Silica, 15·62; alumina, 4·27; ferric oxide, 8·14; ferrous oxide, 32·85; manganous oxide, 5·06; calcium oxide, 0·81; magnesium oxide, 2·66; carbon dioxide, 30·32; water, 0·68=100·41.

The thin section is from the predominating grayish part of the rock—none of the black magnetitic bands being represented in it—which seems to be composed almost entirely of a gray felted mass of siderite individuals. These are known to be siderite from analysis. Mingled with this siderite is a small proportion of an exceedingly minutely crystalline and even amorphous silica, and probably clay; and scattered sparsely through it are minute crystals and irregularly outlined particles of magnetite. Both in the hand specimen and in the thin section the rock presents every appearance of being in an unaltered original condition. (Pl. XXI, Fig. 3.)

*From the section on the West Branch of the Montreal river.*

29. Ferruginous chert or flint, from a low horizon. Specimen 9048 (slide 2886); from 400 N., 1165 W., Sec. 27, T. 46 N., R. 2 E., Wisconsin.

The rock is a compact chert or flint of a dark brown color, mottled irregularly with white spots. Sp. gr. 2·65.

The thin section is made up mainly of a silica, which ranges from very minutely crystalline through a chalcedonic phase to an entirely amorphous material. Staining this background of silica, in irregular patches and particularly in strongly marked concretionary areas, is a pale brown hydrated oxide. The concretionary areas are most striking, being composed of concentric bands of the iron oxide, which lie in appearance as mere stains in the siliceous background. These concretionary areas are closely similar to those described above as characterizing the thin sections of 4, 17, 21, 22, 24, 26, with this difference, however, that instead of a black magnetite or a nearly opaque hematite, the iron oxide concerned is now a pale brown hydrated kind. Whatever may be the origin of these peculiar concretionary areas, it is certainly the same in this case as in the case of the other rocks referred to. The siliceous background of this rock, as examined in the polarized light, does not appear to have been much affected by concretionary action, except that here and there the larger individuals are bunched in irregular oval areas. Two or three slender veins of quartz traverse the section. In these the individuals of quartz are larger than in the general background of silica. Here and there the nuclei of the concretionary areas referred to are seen to be composed of a number of unusually large sized quartz individuals (Pl. XXII, Figs. 1 and 2.)

30. Ferruginous chert, from a low horizon. Specimen 9047 (slide 2775); from 405 N., 1095 W., Sec. 27, T. 46 N., R. 2 E., Wisconsin.

The rock is a brown chert similar to 29, but having a darker color and containing some spots which are bright red and jaspery.

The thin section is composed of a finely divided but still wholly crystalline silica, the larger sized individuals being much more plentiful than in 29. Irregularly blotching this background are areas of nearly opaque hematite, which are without any perfect concretionary arrangement, which arrangement is also only faintly indicated in a portion of the siliceous background itself.

*From the Germania mine.*

31. Ferruginous chert or flint, from a very low horizon. Specimen 9015 (slide 3103); from 200 N., 1575 W., Sec. 24, T. 46 N., R. 2 E., Wisconsin.

A dark brownish gray, aphanitic, cherty rock, carrying irregular seams of hematite.

This section shows an almost pure chert, quite closely resembling that which forms the background of 29. A few concretionary areas only faintly marked with iron oxide are seen.

*From the Montreal river section.*

32. Ferruginous chert or flint, at the base of the Iron-bearing member, Ashland mine. Specimen 7619 (slide 2308); from 1965 N., 1925 W., Sec. 27, T. 47 N., R. 47 W., Michigan.

The thin section is made up almost wholly of silica in an exceedingly finely divided and even amorphous state, at times showing faintly the radial chalcedonic arrangement. Brownish and reddish iron oxides occur here and there in irregular patches and spots. They also appear in very distinctly outlined rhombic sections, which suggest a derivation from the oxidation of an iron carbonate; a suggestion which is borne out by the presence in some of the rhombic sections of areas of unaltered carbonate.

33. Black banded flint and siderite, from a high horizon. Specimens 9007 (slide 2916), 9009 (slide 2765); from 160 N., 100 W., Sec. 21, T. 47 N., R. 47 W., Michigan.

A fresh fracture of these rocks shows an interbanding of dark gray and black layers ranging from about one-eighth to one-half inch in width. The black bands are composed of an aphanitic flint; the dark gray bands, while containing more or less of this flint, appear to be made up of a crystalline aggregation of some carbonate, the crystallization being coarse enough for the naked eye to detect the cleavages of the individual crystals. Sp. gr. of 9009, 3·24.

In thin sections the *black bands* of the rock represented by these specimens prove to be made up mainly of an amorphous and an exceedingly finely crystalline silica. In this siliceous background are included numerous minute black particles, to which evidently the black color of the bands is due. These particles, when examined with a high power, are found to be exceedingly irregular in shape, though often they are aggregated into thin belts, which are so plentiful as to give a strongly laminated appearance to these portions of the sections. They appear to be quite without crystal outlines, and from the macroscopic appearance of the rock and its close resemblance to others in which carbonaceous matter has been detected on analysis it is supposed that these particles are of that nature also. Very possibly they may be mingled with more or less of pyrite and iron oxides. A few pieces of what appears to be a fragmental quartz are met with in those portions of these sections which represent the black bands, and also a few irregular areas of iron carbonate which are analogous in structure and alterations to those spoken of under 32. The *gray bands* seen microscopically have a background or groundmass similar to the material which composes the bulk of the black bands. But in this case there are contained in this groundmass, so plentifully as to constitute the larger portion of these parts of the sections, irregular areas of the iron carbonate in various stages of alteration and others less plentiful of a greenish chlorite. These greenish areas have often an oval form. The viridite or chlorite which makes them up is arranged in fan-like aggregations. The areas of iron carbonate vary greatly in size, the smaller ones being almost perfect single rhombohedra; while the larger ones, although aggregates of a number of individuals, show around their borders the projecting edges of rhombohedra. Much of this iron carbonate has altered more or less thoroughly to iron oxides, including both the brown oxide and hematite. In many cases where the alteration has been complete the secondary iron oxides are plainly perfectly pseudomorphous after the siderite, i. e., they preserve still the rhombic outlines of the siderite crystals. More usually, however, the alteration has been only partial, and in such cases the secondary oxides are either in irregular bunches or (and this is very much more commonly the case) are arranged in very irregular concentric spherical rings, of which there are generally several in one area, though in other cases a single ring is seen or a single ring with the beginnings of one or more others. These rings of iron oxide, which are so plainly the result of a secondary oxidation of the carbonate, occur quite without any reference to the individuals of the latter mineral; that is to say, a single ring or a set of rings traverses an area made up of a number of carbonate individuals. In some of the most completely altered areas of carbonate there is contained more or less of the finely divided silica of the matrix, and in such cases we appear to have an intermediate phase between the unaltered carbonate and those cases above described as characterizing other sections where simple rings of iron oxide are within a siliceous background. In other words, the iron carbonate remaining after formation of rings of oxide has been more or less removed and silica deposited in its place. As has been noted above, these concentric areas of iron oxide and iron oxide and silica are found in every stage of formation until the iron carbonate disappears. (Pl. XXVII, Fig. 4.)

34. Ferruginous and sideritic chert, from a high horizon, interstratified with 33. Specimen 7622 (slide 2072); from 160 N., 100 W., Sec. 21, T. 47 N., R. 47 W., Michigan.

The rock is from another layer of the ledge from which 33 comes. It has a most striking and peculiar character, being grayish, mottled with black, and suggests even to the naked eye a fragmental texture, blackish angular fragments being imbedded in a grayish cherty mass.

In thin section, a minutely crystalline to amorphous silica forms a groundmass which occupies a relatively small portion of the whole area. Contained in this groundmass are small crystals and aggregates of crystals of siderite, oval or spherical concretions of mingled flinty silica and iron oxides, particles of a blackish, probably carbonaceous, material, with or without accompanying siderite, and also irregularly outlined and even sharply angular areas or fragments composed of a mixture of flinty silica, iron oxide, and carbonaceous material with or without siderite. The iron carbonate, except that it is more often fresh, appears as in 33. Where altered, its alterations are the same as in those sections, the peculiar beautiful concretionary forms there described occurring here also and are evidently of the same origin. The more irregular outlines, and especially the angular fragment-like areas that appear in this groundmass, are entirely similar in composition and structure to the material which has been described as composing the blacker bands in 33. These are at times plainly fragments, as may be seen from their angular outlines, sharp definition from the matrix of the rock and from the fact that the lamination lines abruptly terminate at the extremities of the areas. The lines of lamination in these fragments, when they are perceptible, are never parallel for any two fragments.

It seems evident that the history of the rock exposed where Nos. 9007, 9008, 9009 and 7622 were obtained has been about as follows: It was first a stratiform carbonate of iron, including apparently more or less carbonaceous matter, as such stratiform carbonates so generally do, and perhaps more or less of silica. By a process of subsequent silicification, accompanied by oxidation, the structures now apparent were produced. At times the substitution of the silica and the solution and oxidation of the carbonate went on so as not seriously to break up the continuity of the original layers; but in other cases the rock had become shattered and the silica entered into the minute cracks and interstices of the rock, and this shattering was often produced after a certain amount of alteration had been effected, inasmuch as the fragments themselves have evidently been in part altered before being torn apart. The process continuing, these disrupted pieces, so far as they were still pretty pure carbonate, had developed in them by oxidation the concretionary structure, and finally were often replaced more or less completely by siliceous material. Into many of the fragmental areas ramifying veinlets of the siliceous groundmass extend, so that the various appearances presented by the section seem all explicable by a continuing process of solution, oxidation, and silicification, accompanied by a certain amount of dynamic movement.

While the above process explains a part of the fragmental character of the rock, it seems probable that it has been to some extent actually shattered by erosion. The layers here contain some fragmental quartz; they are at a high horizon, which represents probably the beginning of the change from nonclastic to clastic sedimentation. The nonclastic sediments immediately after deposition were perhaps broken to a greater or less extent, forming detritus, which was mingled with the same kind of sediments which continued to form at favorable times. (Pl. XXII, Figs. 3 and 4; Pl. XXVII, Figs. 2 and 3.)

*From the section on the Mount Hope property.*

35. Hematitic flint, from a middle horizon. Specimen 7610 (slide 2306); from 1150 N., 0 W., Sec. 23, T. 47 N., R. 47 W., Michigan.

The thin section shows seams composed entirely of a very minutely crystalline to quite amorphous silica, interbanded with others in which the red and brown iron oxides are mingled with more or less of the silica. There is no brecciation apparent in the section. Here and there are minute patches of iron carbonate from whose oxidation it may be supposed the iron oxides came.

*From the section on the Puritan property.*

36. Ferruginous cherts or flints, from lower and middle upper horizons. Specimens 7604 (slide 2304); from 70 N., 1000 W.; 7605 (slides 2011, 2069); from 150 N., 1050 W.; 7606 (slide 2305); from 276 N., 1175 W. All from Sec. 18, T. 47 N., R. 46 W., Michigan.

The rocks are grayish to whitish cherts, banded by reddish seams.

The sections of these rocks are made up of minutely crystalline chalcedonic and amorphous silica, mingled with bands and irregular patches of brown and red iron oxides. Occasional remnants of iron carbonate may be detected, and at times the background presents vaguely the concretionary appearance described in foregoing sections.

37. Hematitic flint or chert, from a low horizon. Specimen 7601 (slide 2302); from 275 N., 0 W., Sec. 18, T. 47 N., R. 46 W., Michigan.

The prevailing siliceous groundmass is in large proportion of exceedingly finely crystalline spotty quartz mingled with amorphous material. In irregular areas and bands in this groundmass are opaque aggregations of red iron oxide. They are in part plainly derived directly from an iron carbonate, since the rhombic portions of the crystalline sections are plainly visible, particularly around the borders of the opaque aggregations. There is also abundantly in the groundmass vaguely outlined areas representing probably the silicified areas of the carbonate. These are analogous to those occurring in above described sections, but are of rather small size.

38. Hematitic flint or chert, from a low horizon. Specimen 7600 (slide 2009); from 300 N., 1500 W., Sec. 17, T. 47 N., R. 46 W., Michigan.

In thin section the chert background is completely though minutely crystalline. It otherwise closely resembles the last section described. The hematite aggregates, however, show somewhat larger remnants of unaltered iron carbonate.

39. Hematitic flint or chert, from a middle horizon. Specimen 7596 (slide 2301); from 453 N., 1300 W., Sec. 17, T. 47 N., R. 46 W., Michigan.

This section differs from the two last described only in the very much larger proportion of iron oxide contained and that the silica is intermediate in crystallization between the silica of them. The iron oxides appear in the same sort of aggregates in which are often to be seen the rhombic crystal outlines of the original carbonate. The texture of the chert in this case also is somewhat open, numerous cavities being contained by the section.

*From the Colby mine section.*

40. Siliceous iron carbonate, from a high horizon. Specimen 12508 (slide 5522); from 1125 N., 175 W., Sec. 16, T. 47 N., R. 46 W., Michigan.

A very fine grained rock, with an irregular division into light and dark gray laminæ. Scattered along these laminæ are minute shining facets of a carbonate, which show however, more plentifully in much larger individuals irregularly blotched all over the specimen without any reference to the arrangement of the bands. The appearance of this carbonate alone is sufficient to identify it as siderite, an identification which is confirmed by the deep brown weathering that the specimen shows.

This section differs from many of those previously described in the very large amount of fresh iron carbonate which it contains. This mineral occurs not only in single individuals, but in compact aggregations of individuals, which sometimes occupy quite extensive areas in the section. Irregularly interwoven with the carbonate areas are areas of silica which are largely amorphous. In this siliceous background are seen, however, in places the peculiar concretionary areas described as characterizing some of the above sections. These areas very plainly originate from a change of the carbonate aggregates. Dotted through the section are particles of quartz of varying size. These are partly in the background and partly within the masses of carbonate, the larger ones often appearing as if of fragmental origin. (Pl. XXVII, Fig. 1.)

*From the section on the Tilden mine property*

41. Hematitic flint or chert, from a middle horizon. Specimen 7571 (slide 1993); from 1500 N., 1215 W., Sec. 15, T. 47 N., R. 46 W., Michigan.

The thin section is a chert containing much finely divided hematite.

42. Hematitic flint or chert, from a middle horizon. Specimen 7565 (slide 2064); from 1450 N., 1185 W., Sec. 15, T. 47 N., R. 46 W., Michigan.

The section is a hematitic flint analogous to that of 41. The hematite in the larger part of the section is, however, more uniformly contained and in more minute particles. It is arranged so as to show faint but perfect concretions. In parts of the section are concentrated large areas of hematite.

*From the section on the Palms property*

43. Cherty and altered iron carbonate, from a middle horizon. Specimen 7573 (slide 1996); from 1600 N., 1955 W., Sec. 14, T. 47 N., R. 46 W., Michigan.

About half the area of the thin section is a light gray and the other half a reddish brown. The light colored portion is composed of uniformly mingled minutely crystalline quartz and gray siderite. The siderite occurs within the siliceous groundmass both in detached individuals and in complex areas, the single individuals showing usually very distinctly the rhombic outlines. The brown portion of the slide is like the other portion so far as the siliceous groundmass is concerned, but here the brown and red oxides of iron take the place of the siderite of the lighter colored part of the slide. Since these iron oxides show often the same rhombic outlines as seen in the siderite; since they occupy precisely the same relation to the chert; since there is a gradation and not a sharp definition between the two portions of the section; and, finally, since the single individuals of siderite may be seen partly changed to iron oxide, it is evident that the latter mineral is a secondary product of the former.

*From the section on Black river.*

44. Jasper and ferruginous chert, from very near the base of the Iron-bearing member. Specimens 9508 (slide 2983), from 1665 N., 1915 W.; 9509 (slide 3137), from 1600 N., 1900 W.; 9510 (slide 3087), from 1580 N., 1900 W. All in Sec. 13, T. 47 N., R. 46 W., Michigan.

Specimen 9508 is a bright red jasper, banded with very thin seams of brilliantly metallic lustered hematite. Specimen 9509 is a dark brownish gray chert. Specimen 9510 is similar to 9508 but is mottled with irregular blotches of red iron oxide.

The thin section 2983 consists of finely crystalline, mingled with some amorphous silica, in which are included very numerous minute particles of bright red hematite, which are aggregated more thickly along certain bands. Many of the hematite particles have rhombic crystal outlines, and appear therefore to have originated from the oxidation of iron carbonate.

In slides 3137 and 3087 the quartz is more coarsely crystalline, and the iron oxide is mainly the brown hydrated variety. The iron oxides in them are arranged in concretionary and brecciated forms, and the silica is affected, although less plainly, by the same arrangement. Some of the larger concretions are complex, one of them perhaps including several smaller concretions. The areas in 3137 are very irregular, and suggest a mechanical brecciation or a brecciation caused by the processes of alteration.

45. Ferruginous chert, from a low horizon. Specimens 7554 (slide 2298), 7555 (slide 1983); both from 1680 N., 1900 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

Slide 2298 is an exceedingly finely and regularly laminated ferruginous chert, quite analogous in general character to the black bands of 33; while 1983 is a brecciated chert closely analogous to 34, which in turn is directly interstratified with 33. In other words, we have here a representation of the phenomena presented by the exposure on the Montreal river, from which 33 and 34 came, except that here all of the iron carbonate has been removed.

46. Siliceous siderite, from a lower middle horizon. Specimen 9504 (slide 3186), from 1725 N., 1900 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

A very fine grained, dark gray, evenly and finely laminated earthy rock. Sp. gr., 2·07.

The thin section shows an intimate mixture of minutely crystalline, with perhaps some amorphous silica, with minute grayish rhombohedra of siderite only slightly altered here and there by oxidation. These rhombohedra are generally single, but are at times aggregated closely into bunches.

47. Ferruginous chert or jasper, from an upper middle horizon. Specimen 9500 (slide 3182), from 1840 N., 1975 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

The rock is an aphanitic chert or jasper, the colors varying in irregular blotches through dark gray to bright red.

The thin section is a brecciated concretionary chert like others above described; rounded areas of a finely crystalline and amorphous silica, mingled with more or less brown and red iron oxides, being embedded in a silica which is usually more coarsely crystalline. Occasionally, instead of the rounded areas, there are long tabular pieces showing the lamination of the original chert. In both kinds of areas there are numerous places where the rhombohedral outlines of the original carbonate reproduced in the iron oxide may be seen. Besides this are to be seen within the chert fragments rhombic areas, often of large size, composed of silica similar to the rest, but outlined distinctly by brown iron oxide. These again are taken to be substitutions for original carbonate crystals.

48. Ferruginous chert, from an upper middle horizon. Specimens 9501 (slide 3183), 9502 (slide 3184); both from 1840 N., 1975 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

The rocks are dark red cherts or jaspers, which for the most part lack, however, the aphanitic flinty appearance of true jasper. They are banded quite regularly with lighter colored seams.

The thin section 3183 shows a background of exceedingly finely crystalline, mingled probably with amorphous silica, through which are scattered a few small apparently fragmental particles of the same material and numerous minute stains of brown hydrated iron oxide which occasionally present rhombic outlines. The thin section 3184 differs from 3183 simply in containing much larger and even predominating quantities of iron oxide, much of which is hematite. Rhombic outlines to the particles of iron oxide are frequently to be seen. The iron oxide is aggregated especially into certain bands, so as to give the section a laminated appearance.

49. A ferruginous chert, from an upper middle horizon. Specimen 9503 (slide 3185), from 1775 N., 1925 W., Sec. 13, T. 47 N., R. 46 W., Michigan.

A light gray, evenly laminated earthy rock, banded with seams of dark red hematite.

The thin section is a ferruginous chert very closely resembling 3183 in 48.

50. Iron carbonate or siderite rock, from an upper horizon. Specimens 9481 (slide 3177), 9482 (slide 3178), 9483 (slide 3348). All from 250 N., 1000 W., Sec. 12, T. 47 N., R. 46 W., Michigan.

An aphanitic, dark gray, earthy looking, stratiform rock, banded in some portions with nearly black bands, which are at times broken and the detached portions imbedded in a lighter colored material. Sp. gr., from 3·22 to 3·40.

The thin sections are composed mainly of a felted mass of iron carbonate, which in some of the darker bands is mingled with a dark colored material in fine particles, presumably of a carbonaceous nature. Certain bands, as seen in section 3177, contain a finely divided silica which has a distorted lamination, the carbonate being separated into more or less detached areas. At the same time these bands show large sized patches of a greenish chlorite. The carbonate is also altered to a considerable extent to iron oxide, the latter being largely arranged in rings. This is another good illustration of the formation of concretions.

51. Ferruginous chert, from an upper horizon. Specimen 9485 (slide 3179); 295 N., 980 W., Sec. 12, T. 47 N., R. 46 W., Michigan.

A very dark colored, nearly black aphanitic rock, banded irregularly with ill defined dark red seams.

The thin section is evidently from one of the dark reddish brown seams. It presents a confused admixture of chlorite, brown iron oxide, and magnetite, the latter mineral being in distinctly outlined crystals, all in a minutely crystalline and amorphous siliceous background. Many of the brown particles also present rhombic outlines, and are taken to have arisen from an oxidation of the carbonate. Siderite is not, however, recognizable in the section, but may be present plentifully in the dark colored earthy looking bands mentioned above.

52. Black chert, from the summit of the Iron-bearing member. Specimen 7534 (slide 1968), from 500 N., 1075 W., 7535 (slide 1969), from 535 N., 1050 W., Sec. 12, T. 47 N., R. 46 W., Michigan.

The thin sections are concretionary, brecciated, and ferruginous cherts, analogous to a number above described. Slide 1968 shows a predominating groundmass of exceedingly finely crystalline and amorphous silica, in which are strewn small particles of quartz which are certainly fragmental. The fragmental grains of quartz stand out in the background in a wonderfully distinct way. They vary from well rounded to angular; some of them are distinctly enlarged. This section illustrates well the great difference in appearance between fragmental quartz and the nonfragmental quartz of the iron formation. Here, as in previously described rocks, as an upper horizon, is a mingling of chemical and mechanical sedimentation; the beginning of the transition to the upper fragmental member of the series. There are also present magnetite, hematite, and iron carbonate, all of which are arranged in a semiconcretionary fashion, and in such a way as to suggest the derivation of the whole from an original carbonate. Slide 1969 differs from 1968 only in containing large areas of what seems to be a secondary calcite.

*From the section on the Miner & Wells property.*

53. Cherty iron carbonate, from near the base of the Iron-bearing member. Specimens 12885 (slide 5507), 12886 (slide 5508); Sec. 13, T. 47 N., R. 46 W., Michigan.

An aphanitic rock, showing a very thin and for the most part regular lamination, though in certain layers these laminæ are somewhat bent. The laminæ range in thickness from that of a sheet of paper to as much as a quarter or half an inch. They range in color from black through various shades of brownish gray and greenish gray to a very light gray. All save the black bands show a very earthy, compact look, and the whole appears at first sight as that of some banded or earthy limestone; but the high specific gravity of the rock proves at once the presence of much iron. The surfaces of some of the black laminæ glisten brightly as though containing a carbonaceous or graphitic material. Composition of 12885: silica, 46·01; titanic oxide, 0·12; alumina, 0·83; iron sesquioxide, 1·35; iron protoxide, 26·00; manganous oxide, 2·09; calcium oxide, 0·63; magnesium oxide, 2·86; carbon dioxide, 17·72; phosphoric acid, 0·07; iron sulphide, 0·11; water at red heat, 1·71 = 99·50.

In the thin sections the light colored bands are seen to consist of an almost solid aggregate of minute rhombohedra of iron carbonate, whose outlines are particularly well observed on the borders of the bands where separated slightly from the rest of the mass by the silica, which, while constituting the main constituent of the darker colored bands, penetrates the siderite in irregular tongues and seams. This silica is exceedingly finely crystalline and perhaps in part amorphous. Mingled with it in the darker colored bands are films of chlorite, detached rhombohedra of iron carbonate, and dark colored seams lying parallel to the general lamination of the rock, but noncontinuous. These consist mainly of chlorite, but may probably also include some carbonaceous material. Similar films appear also in the light colored bands. The section is cut by small veins running in various directions, which are filled as often with siderite as quartz, and sometimes a single vein contains both minerals; also occasionally chlorite is contained.

54. Cherty iron carbonates, from middle horizons. Specimens 9472 (slide 3135), 9473 (slide 3081), 9474 (slide 3082); 9475 (slide 3083), 9476 (slide 3084), 9477 (slide 3085); all from 1400 N., 180 W.; 9479 (slide 3175), 9480 (slide 3176); both from 1325 N., 180 W.; also 7548 (slide 2061), 7549 (slide 2062); from 1450 to 1500 N., 150 W. All in Sec. 13, T. 47 N., R. 46 W., Michigan.

These specimens represent a large precipitous exposure of a ferruginous slaty rock in the bed and on the south side of the outlet of Sunday lake. In the main the exposures show a dark colored platy look with an earthy fracture and the general appearance of an earthy carbonate. Interbedded with these earthy portions, which are themselves finely laminated, are nearly black flinty seams. These again show a fine banding of lighter and darker shades. In certain portions there are very often black seams, which upon their surfaces show a graphitic luster. The exposure is in general heavily stained with red and brown iron oxides, the fresh fractures showing these oxides often arranged along certain of the laminæ, which they have at times entirely replaced, but in other cases along irregular cracks. Some of these streaks of iron oxides reach as much as a foot in width, in which case they form a moderately rich hematite iron ore with a porous texture and slight metallic luster. Some more minute cracks have been filled with brilliantly lustered specular iron. The sp. gr. of the more compact and less siliceous portions varies from 3 to 3·50. The chemical composition of 9472, which is little altered and includes a number of minute silicified bands, is: silica, 28·86; titanic oxide, 0·20; alumina, 1·29; iron sesquioxide, 1·01; iron protoxide, 37·37; manganous oxide, 0·97; calcium oxide, 0·74; magnesium oxide, 3·64; water, 0·68; carbon dioxide, 25·21; phosphoric acid, trace; organic matter, undetermined = 99·97.

The thin sections from these specimens show a rock closely resembling that of 43. The sections differ from one another only in relative proportions of minerals contained, and in that some of them coatain a little chlorite. The relation of the silica, iron carbonate, and of the blackish supposedly carbonaceous seams are all as in 43. Some of the sections include portions of the hematite seams, in which case one side of each section shows the unaltered carbonate rhombohedra, the middle of the section showing these rhombohedra partly changed to hematite, while on the other side of the slide they are completely replaced by the hematite. (Pl. XXI, Fig. 4.)

*From the exposures in Secs. 7 and 18, T. 47 N., R. 45 W., Michigan.*

55. Cherty iron carbonate, from a low horizon. Specimen 12513 (slide 5336); from 1600 N., 1075 W., Sec. 18, T. 47 N., R. 45 W., Michigan.

A rock closely similar to 12886 in 53. Sp. gr., 3·29. Composition: silica, 36·73; titanic oxide, 0·19; alumina, 0·38; iron sesquioxide, 0·98; iron protoxide, 34·74; manganous oxide, 0·52; calcium oxide, 0·48; magnesium oxide, 2·74; carbon dioxide, 22·44; phosphoric acid, 0·009; iron sulphide, 0·12; water at 105°, 0·12; water above 1·05°, 1·40 = 100·84.

The thin section shows bands of an almost compact siderite with very slight admixture of silica, which very gradually grade into and alternate with others composed mainly of a very minutely crystalline and amorphous silica. In the latter are included numerous rhombohedra of iron carbonate. The differences noted between this rock and 53 lie in the somewhat larger size of the siderite rhombohedra, the presence of only a small proportion of chlorite, and in exhibiting the transition between siderite and iron oxide. The section is cut by veins, which are filled with quartz, siderite, and actinolite. The quartz and siderite are in larger individuals here than in the remainder of the section.

56. Cherty iron carbonates, from middle horizons. Specimens 7526 (slide 1962), from 0 N., 1730 W.; 7527 (slide 2297), from 0 N., 1000 W.; 7528 (slide 2059), from 0 N., 735 W., Sec. 7, T. 47 N., R. 45 W., Michigan.

The thin sections all contain a considerable quantity of iron carbonate. In slide 2059 it is the chief constituent, in 1962 it about equals in quantity the flinty background, while in 2297 it is subordinate in quantity. Slide 1962 is essentially like 53. The alteration of the iron carbonate in 2059 has resulted in the formation of abundant hematite and numerous small crystals of magnetite. In 2297 the alteration of the carbonate and the introduction of silica has resulted in forming numerous beautiful concretions, most of which contain several concentric belts of iron oxide. In quite a large number of these concretions iron carbonate varies in quantity from little to a chief constituent.

57. Ferruginous chert and jasper, from a middle horizon. Specimen 12665 (slide 5389), from 200 N., 1475 W., Sec. 7, T. 47 N., R. 45 W., Michigan.

A fine grained, dark purplish rock carrying vaguely outlined bright red spots which have the appearance of jasper.

The thin section is one of the brecciated mixtures of chert and silica, differing from a number above described only in having the iron oxide mainly bright red hematite instead of magnetite or the brown oxide. A greenish chloritic material is present in a number of the concretionary areas. The silica ranges from very finely crystalline to amorphous. Remnants of iron carbonate are apparent in some of the concretionary areas. The very large proportion of iron peroxide present in this section disguises its structure somewhat, but enough is perceptible to make it evident that we have here to do with a phase of one of the brecciated rocks.

58. Magnetic cherty iron carbonates, from high horizons. Specimens 7530 (slide 1964), from 840 N., 500 W.; 7524 (slide 2296), from 700 N., 100 W., Sec. 7, T. 47 N., R. 45 W., Michigan.

The unaltered portions of the thin sections are made up mainly of grayish aggregates of siderite individuals mingled with more or less amorphous or minutely crystalline silica, and some darkening material in certain bands which is perhaps in the nature of carbonaceous matter. Numerous minute black crystals of magnetite are scattered through the siderite. From these less altered forms there are grades of transition to an opaque mass of red iron oxide, which is aggregated particularly along certain seams. In slide 2296 there is mingled with the other ingredients a considerable proportion of greenish chlorite and a few small particles of fragmental quartz.

*From the exposures in Secs. 10 and 11, T. 47 N., R. 45 W., Michigan.*

59. Actinolitic and magnetitic quartz-schist, from a low horizon. Specimen 7512 (slide 2294), from 570 N., 873 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

The thin section of this rock shows magnetite and hematite predominating, and for the most part aggregated into opaque masses. Within the masses, however, are irregular areas and streaks of lighter colored materials which are in part minutely divided crystalline quartz, and in part a greenish material which includes both actinolite and chlorite, the latter apparently derived from the actinolite. Quite often the small detached particles of the iron oxide are seen to have a rhombic outline. In the section are a number of small rounded grains of fragmental quartz. These quartz grains are often enlarged, and are all readily distinguishable from the nonfragmental finely crystalline interlocking quartzose background.

60. Cherty iron carbonate, from a middle horizon and just beneath a greenstone of the Keweenaw series. Specimen 7516 (slide 2295), from 815 N., 1470 W., Sec. 10, T. 47 N., R. 45 W., Michigan.

The thin section is composed mainly of a compact grayish mass of siderite, slightly stained along certain lines with iron oxide and containing here and there particles of magnetite. On one side of the section is a band of very minutely crystalline to amorphous silica containing numerous particles of iron carbonate, which are separated from the main mass by the silica.

61. Ferruginous chert and jasper, from a middle horizon, and only a short distance beneath a greenstone of the Keweenaw series. Specimens 12791 (slide 5477), 12794 (slide 5478), 12794*a* (slide 5479). All from the SW. ¼ of the SE. ¼, Sec. 11, T. 47 N., R. 45 W., Michigan.

These specimens represent the several laminations seen in the crosscut at the bottom of a test pit. Specimen 12791 shows a thin lamination of bright red jasper with black seams. Specimen 12794 shows nearly the same, except that the jaspery portions take on a more cherty appearance and whitish color, and the dark colored bands now and then present the metallic luster of magnetite. Specimen 12794*a* is mainly composed of a thinly laminated dark red hematite, being rich enough in iron to constitute an iron ore.

In thin sections the black seams above mentioned appear to owe their dark color mainly to the presence of magnetite, which is in sharply outlined crystals, the outlines being nearly always rhombic. In some cases the magnetite appears to constitute the main ingredient of the dark colored bands, while in others it is mingled with more or less hematite and actinolite. The red bands are an admixture of finely divided bright red hematite and very minutely crystalline to amorphous silica. These two minerals are arranged in such a fashion as to produce a general laminated appearance, the hematite being aggregated in thin belts. There are portions of these jasper bands which show relatively little hematite, being made up mostly of silica. The belts of silica follow the lamination in a general way, now and then breaking across it, while a single seam of the silica often branches. In some of the black bands a considerable quantity of actinolite arranged in aggregates of dark green blades is visible. The red iron ore seams above referred to are small portions richer than usual in the sesquioxide of iron. (Pl. XXVIII, Fig. 3.)

*From the test-pit near the center of Sec. 18, T. 47 N., R. 44 W., Michigan.*

62. Hematitic siderite, from a low horizon. Specimen 12788 (slide 5638); from near the center of Sec. 18, T. 47 N., R. 44 W., Michigan.

An aphanitic, earthy, light reddish rock. Sp. gr. 2.86.

Iron carbonate, in part well crystallized, makes up the larger part of the thin section. It is as usual mingled with some minutely crystalline to amorphous quartz and particles of red and brown iron oxides.

*From the test-pit in Sec. 17, T. 47 N., R. 44 W., Michigan.*

63. Cherty siderite, from a low horizon. Specimens 12783 (slide 5471), 12784 (slide 5472); from 550 N., 1100 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

The rocks are composed of alternate bands of an aphanitic, earthy looking, dark gray material and of reddish cherty and jaspery looking material, in which are perceptible numerous pieces of a translucent quartz, red jasper, and black flint. Sp. gr. of gray bands, 3.20; of cherty bands, 2.34.

In thin sections the dark colored bands are composed of a mixture of grayish siderite and finely crystalline, with perhaps amorphous, silica. Irregular dark colored streaks traverse these bands in a direction parallel to the lamination of the rock. These streaks are made up of minute dark colored particles, which are taken to be mainly the oxides of iron, but may be partly of carbonaceous material. Crystals of magnetite are seen scattered here and there, and the relations of the silica and carbonate are such as have been repeatedly described above. In the cherty belts a very finely crystalline quartzose background, including little oxide, with perhaps some amorphous silica, contains many well rounded large simple grains of fragmental quartz which have undergone a second growth, and very many more rounded areas of ferruginous chert. The chert areas comprise those with little iron oxide, with abundant red hematite making them jasper, with magnetite, and finally with hematite and magnetite. Often the areas which contain little or no iron oxide and those containing the largest amounts are in juxtaposition. The simple grains of fragmental quartz and the chert areas alike are generally arranged with their longer axes in a common direction. The unmistakable fragmental character of the simple quartz, the essential likeness to them of the chert areas in outlines, and their arrangement with longer axes in a common direction, are conclusive proofs that they are all mechanical sediments—not fragments caused by a later intrusion of silica, or to concretionary action in connection with such introduction of silica. In fact, these areas show an entire absence of any concretionary structure, except beyond their outer borders. Here such a structure is at times seen, but the same thing is true of the enlarged fragmental quartzes, and is in all cases plainly in the cementing silica. In this rock is therefore a sharp alternation of clastic and nonclastic sedimentation, the interlaminated belts being at times not more than an inch broad.

64. Sideritic cherts, from low horizons. Specimens 9396 (slide 4222), from 600 N., 1085 W.; 9397 (slide 4219), from 615 N., 1085 W. Sec. 17, T. 47 N., R. 44 W. Michigan.

A thinly laminated rock, in which fine grained, dark gray bands alternate with red jaspery and cherty ones. Sp. gr. of the grayish bands, 3.04.

In the thin sections, narrow bands are composed of a nearly pure aggregate of iron carbonate, but these grade off into other portions which are mainly composed of minutely divided silica, which contains a good deal of hematite and magnetite. In slide 4222 these reddish bands are in the main of the peculiar type described in 63, although containing less fragmental quartz in simple grains. In 4219 a fragmental character is less plain.

65. Ferruginous chert or flint, from a lower middle horizon. Specimens 12686 (slide 5408), 12687 (slide 5409); from 850 N., 1650 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

The rocks are aphanitic, dark reddish brown cherts, in which are seen aggregated in certain portions numerous grains of limpid quartz. Sp. gr. of the more highly hematitic portions, 3.62.

The thin sections are in all essential respects like the fragmental parts of 63. The amount of simple fragmental quartz in slide 5409 is less than that in 5408 and in 63. The iron oxide in the fragments and matrix is mostly hematite, although magnetite is present. The grains of simple quartz have been well rounded, and are often widely enlarged. They quite often contain within their cores crystals of hematite and magnetite. In this respect they are closely like the ferruginous quartzite 12680, described page 171. In fact, the chief difference between the two rocks is that in 12680 the fragmental material is more abundant.

66. Jaspery and cherty siderite, from an upper middle horizon. Specimens 12683 (slide 5405), 12684 (slide 5406), 12685 (slide 5407). All from 1260 N., 1350 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

This is a laminated rock, composed of an aphanitic to dark gray earthy looking material, which is minutely banded in itself with lighter and darker shades, and alternates with bands of very bright red jasper, which range from the thickness of a sheet of paper to an inch in width. Sp. gr. of 12685, 2.97.

The jaspery bands in thin section 5405 are seen to be mainly composed of a uniform intermixture of minutely crystalline quartz and bright red hematite, with which are mingled some magnetite particles. Occasionally the hematite shows rhombic outlines, but these are not generally perceptible, perhaps because of the close aggregation of the particles. The dark colored seams prove in the thin section to be in part a mixture of crystals of magnetite and minutely crystalline quartz. Such bands as this are found to be directly interlaminated with the bright red jasper. In other cases the darker colored bands owe their dark color to a mixture of minute particles, which are in part probably of a carbonaceous nature. Such bands as this are found interlaminated more directly with those portions in which carbonate of iron is abundant (5407). The lighter colored portions of 5407 are in part a mixture of iron carbonate, brown and red iron oxides, magnetite particles, actinolite needles, and minutely crystalline silica, the latter mineral being the least plentiful. Still other bands are made up mainly of a silica which ranges from very minutely crystalline to nearly or quite amorphous. In this flint or chert are found remains of bands of iron carbonate, single rhombohedra of the same, and scattering crystals of magnetite.

67. Actinolitic magnetite-slate, from a high horizon. Specimens 12703 (slide 5420), from 1180 N., 655 W.; 12704 (slide 5421); from 1200 N., 655 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

A very heavy aphanitic slaty rock, made up of minute alternating laminæ of dark gray and black shades. Portions of the specimens show a distinct metallic luster, particularly on the black laminæ, and quite large pieces are lifted by the magnet. Interlaminated with this material are bands of a much lighter color.

In thin section, the lighter colored bands (5420), last referred to, are seen to have a minutely crystalline siliceous groundmass, in which are included numerous minute actinolite needles and particles of iron oxide, including the magnetic oxide. The actinolite is on the whole quite as plentiful as the silica, and in portions of the section is aggregated into felted masses. The earthy black portions of the rock present a section which differs from that just described mainly in the relatively great abundance of iron oxides, particularly magnetite; this last mineral being more especially aggregated into irregular laminæ. Actinolite is very abundant, constituting in considerable portions of the section an iron-stained felted mass of minute needles.

68. Magnetitic actinolite-schist, from a very high horizon immediately beneath the Keweenawan greenstone. Specimen 10402 (slide 5321); from 1540 N., 1600 W., Sec. 17, T. 47 N., R. 44 W., Michigan.

A felted mass of actinolite needles composes the background of the section. This mass is commonly stained red and brown by iron oxides, and contains besides, opaque aggregations of magnetite crystals which make up as much as half the section.

*From the exposures and test-pits in Secs. 15, 16 and 21, T. 47 N., R. 44 W., Michigan.*

69. Actinolitic magnetite-schist, from a low horizon. Specimens 12786 (slide 5474), 12787 (slide 5475); from 1625 N., 650 W., Sec. 21, T. 47 N., R. 44 W., Michigan.

An aphanitic, laminated, very dark gray rock, analogous to those described under 68. Sp. gr. of 12787, 3.53.

The thin sections are typical actinolitic magnetite schists, such as have been described already as occurring at Penokee gap, etc. The groundmass is a finely crystalline quartz, throughout which are contained minute blades of actinolite. The magnetite occurs as usual in bunchy aggregations of sharply outlined crystals, and also in single crystals scattered throughout the groundmass. In slide 5475 there is a general tendency towards a concretionary arrangement, which in portions of the section is very strongly developed; and after having seen the various concretionary developments of the foregoing rocks one has no hesitation in saying that these are of the same origin with all the rest.

70. Actinolitic magnetite-schist, from a low horizon. Specimen 12781 (slide 5470); from 70 N., 1790 W., Sec. 15, T. 47 N., R. 44 W., Michigan.

A very heavy, slaty, dark gray rock, analogous to that last described, except that certain vaguely defined bands have a pale reddish or jaspery appearance. The content of magnetite is evidently great, as large sized pieces are easily lifted by the magnet.

The section is again one of the typical actinolitic magnetite-schists. The background, as usual, is a minutely crystalline quartz. In this are contained fan-like aggregates of unusually large actinolite blades, and crystals of magnetite, partly aggregated in certain bands, in which are contained a large proportion of red and brown iron oxides.

71. Ferruginous cherts, from a middle horizon. Specimens 12671 (slide 5395), 12672 (slide 5396), 12675 (slide 5398); all from 450 N., 675 to 729 W., Sec. 16, T. 47 N., R. 44 W., Michigan.

The rocks are brown and red stained, highly ferruginous cherty schists, made up of alternating laminæ of black, red, and brown colors.

The thin sections are composed essentially of a minutely crystalline to amorphous silica with the red and brown and magnetic oxides of iron. These oxides are aggregated more especially into certain laminæ, other laminæ being almost pure chert. On the edges of the iron oxide laminæ the individual particles of hematite and brown oxide are seen very frequently to have sharp rhombic outlines. The magnetite is quite subordinate in quantity to the other oxides, being, however, more plentiful in some bands than in others. It occurs in sharply outlined crystals. The hematite particles that occur in these bands, which are mainly made up of flinty silica, are often arranged in a radiate manner.

72. Ferruginous chert-schists, from a high horizon. Specimens 12691 (slide 5412), 12692 (slide 5413), 12693 (slide 5414); all from 1380 N., 1960 W., Sec. 15, T. 47 N., R. 44 W., Michigan.

These specimens represent alternating laminæ of gray and red stained chert and hematite iron ore. The iron oxide seams show a more distinct subordinate lamination than is perceptible in the cherty portions. Sp. gr. of irony layers (12693), 3.25.

The cherty layers in the thin section are seen to be made up almost entirely of a minutely crystalline to nearly amorphous silica. There is also throughout this silica a general tendency to a concretionary structure, which is brought out by a vague concentric arrangement of the more or less completely crystalline particles. The whole appearance of this chert is very strikingly like the cherts which have been above described and figured as characteristic of the limestone member of the Penokee series. In these cherts occur irregular bunches of hematite and brown iron oxide, the particles of which often show most distinctly rhombic outlines of the carbonate crystals, from whose alterations they are taken to have originated. Some of these rhombic crystals are of unusually large size; and in one or two places appear to still retain portions of the original carbonate. The more highly ferruginous laminæ differ from the cherty phases mainly in the large proportion of the oxides of iron, which now preponderate greatly over the siliceous matrix. The particles of iron oxide are here arranged in regular lines, which, without much doubt, mark the original lamination of the rock. The rhombic outlines to the hematite particles are frequent, and some of the silica shows the radiating structure characteristic of chalcedony.

73. Actinolitic ferruginous schist, from a high horizon and immediately in contact with overlying Keweenawan greenstone. Specimens 9381 (slide 3269), 9382 (slide 3039). From 670 N., 1020 W., Sec. 16, T. 47 N., R. 44 W., Michigan.

The specimens present an alternation of brown cherty, red jaspery, dark green and black aphanitic laminæ, the whole rock having a distinct slaty or parallel structure. Sp. gr. of the black laminæ (9382), 3.90.

The thin sections of these rocks are particularly interesting and instructive, in that they generally show in a single section all of the characteristic minerals of this class of rocks; i. e., brown and red oxides of iron, magnetite, actinolite, and cherty or flinty silica. These different minerals occur more or less intermingled, but the varying appearance of the laminæ as seen macroscopically is due to the preponderance of different minerals in the different bands. The black bands are particularly rich in magnetite. The red and brown laminæ are nearly opaque aggregations of particles of hematite and hydro-sesquioxide. The greenish bands are particularly rich in actinolite. The siliceous groundmass is relatively not abundant, but runs throughout the section. The banding of this rock is taken to be dependent upon an original sedimentary lamination, but the way in which the bands are seen now to be swollen, minutely contorted, or abruptly broken off is a strong indication of the secondary origin of a portion of the minerals which are now present. Besides following the original lamination, the various groupings of the minerals have often traversed this lamination. One traversing seam of actinolite and silica is particularly noteworthy. This is a structure which can hardly be described, but is of importance in its bearing upon the origin of these singular ferruginous rocks.

## SECTION II.—ORIGIN OF THE ROCKS OF THE IRON-BEARING MEMBER.[1]

Knowing the exact facts as to the nature and method of occurrence of the iron-bearing rocks, we are now prepared to present some consistent account of their origin. In the detailed tabulations and in the general account of their macroscopic and microscopic characters, it has been necessary to anticipate, to some extent the origin of certain phases. To the degree that their genesis has thus been anticipated it is not in the nature of theory, but fact, because the stages of their development to this extent have actually been observed. Before attempting to give a history of the rocks, it will perhaps be well to recapitulate the more important of the observed facts.

(1) The Iron-bearing member throughout most of its area gives absolutely no evidence of a fragmental character. This characteristic is one of the greatest importance. The quartz rocks of the iron-bearing belt have been confused with the underlying quartzites. By most observers they have been taken to be fragmental, and have been supposed to have reached their present condition by one of the various mysterious processes of metamorphism. It has, however, been seen that the fragmental character of the underlying quartzites and the overlying slates is manifest when their thin sections are examined with a microscope. Now, this Iron-bearing member lies between these two fragmental belts, and yet nowhere in its typical rocks is

[1]Section I was nearly completed when Prof. Irving's sudden death occurred. From the beginning of this section the junior author is alone responsible for the form, although much of the substance of Sections II and III is Prof. Irving's work.

there any indication of a fragmental character. Occasionally, it is true, in narrow transition bands between the iron-bearing and the fragmental belts, there is mingled with the nonfragmental material a small quantity of fragmental quartz and feldspar. Also at the eastern extremity of the district clastic and nonclastic sedimentation have alternated to some extent. However, this very appearance of fragmental material but more strongly emphasizes the fact of the nonfragmental character of the belt as a whole, by bringing into the same thin sections clastic and nonclastic material. The clastic particles are recognized at a glance as entirely different from the mass of the finely crystalline or partly amorphous completely interlocking material which composes the rocks of the Iron-bearing member. (Pl. xxxv, Fig. 1.)

(2) The rocks of the Iron-bearing member are laminated. Through large parts of its area the lamination is as perfect and minute as is possible in any sedimentary stratified rock. These regularly laminated portions are found at all horizons, and nowhere is a fair degree of regularity of stratification absent. The most perfectly laminated parts of the belt are of the first type of rock—the cherty iron carbonates. As the lamination becomes less regular, rocks of the second and third types—the ferruginous cherts and the actinolitic slates—appear.

(3) There have been observed at many places actual stratigraphical transitions of the regularly bedded carbonates into the remaining rocks of the belt. This gradation sometimes occurs in passing from east to west, as, for instance, the cherty carbonates and the ferruginous cherts grade into the actinolitic slates, or the gradation may be a transverse one; that is, the cherty iron carbonates at a higher horizon grade into the ferruginous cherts at lower horizons. This stratigraphical gradation of the three types of rock into each other is alone sufficient to make very probable for all of them a common origin. The gradation is repeated in thin sections, nearly all stages of the various transitions being clearly worked out.

*The original rock.*—The foregoing facts all point unmistakably in the same direction; that is, to the conclusion that these rocks at one time were cherty iron carbonates. There may be differences of opinion as to whether at some earlier stage they did not have another form; there may be differences of opinion as to the manner in which, from the cherty carbonates, some of the multitudinous phases of rock now found have been formed; but the conclusion can not be escaped that these rocks, which still make up so large a proportion of the belt, were the original rocks of the member. It is extremely improbable that, in a narrow belt of regularly stratified rocks about 800 feet thick, interstratified with other belts of sedimentary rocks, there should be deposited in patches here and there, large and small, at nearly all horizons, cherty iron carbonate, and a short distance east or west ferruginous cherts and actinolitic slates.

The question arises whether the cherty iron carbonates, the least altered rocks now observable, have been derived from an earlier and different rock. They are apparently unaltered, and that they were originally deposited in the condition now found is probable enough from analogies presented by later geological times. The cherty ironstones from the Carboniferous, which occur so plentifully in our own country in Ohio and Pennsylvania and so extensively in other countries, are like these thinly bedded carbonates, except that they are generally more argillaceous. Certain Ohio ores are so remarkably like some of the iron carbonates of the Penokee-Gogebic series that they can hardly be distinguished in hand specimen or thin section from one another. This essential likeness is shown by Pl. XXVII, Figs. 1 and 2, and Pl. XXIX, Fig. 4. The last is an Ohio cherty carbonate; the first two are Penokee carbonates. The only difference between the two is the unimportant one as to the nature of the inclusions. The clayey character of the Carboniferous carbonates is no more than an accident, and to a certain extent is also characteristic of the older carbonates of the Northwest. It simply means that the nonfragmental sedimentation was accompanied by mechanical sedimentation to a greater extent in the Carboniferous than in the Iron-bearing series of the Northwest.

In Mississippi, in the Claiborne formation of the Tertiary,[1] there are extensive beds of cherty iron carbonate, which, according to analyses published, are almost identical in composition with the cherty iron carbonates of the Penokee series. A third analogy presented by the formations of more

[1] A New Discovery of Carbonate Iron Ore at Enterprise, Mississippi, by Alfred F. Brainerd. Trans. Am. Inst. Min. Eng., vol. XVI, 1888, pp. 146–149.

recent times is in the cherty limestones, which are so widely found at all horizons. It may be a question as to these limestones whether the chert was originally in nodules and layers or was scattered through the limestone as disseminated particles of silica, but from later investigations it appears certain that in some cases the chert was originally deposited in the position in which it is now found. There is in these limestones a close association between the cherts and calcium and magnesium carbonates. In the cherty iron carbonates of the Penokee-Gogebic series calcium and magnesium are present as in the limestones, and we need only to replace a portion of these elements by iron to have rocks which are the exact analogue of the cherty limestones of later times. As has been seen also, such cherty limestones occur in deposits of considerable thickness at the base of the Penokee-Gogebic series itself. From analogy it is then extremely probable that the chert and iron carbonates were simultaneously deposited, although it may be a possibility (as has been maintained with reference to some of the cherty carbonates of later time) that the chert entered very early in the history of the rock as a pseudomorph, replacing carbonates.

At any rate, it is certain that a large portion of the silica now present in these rocks was there very early in their history. In other districts in the lake Superior country, notably at Gunflint lake, in the Animikie series, a similar cherty carbonate is found in extensive beds. That the chert was here present at a very early day can not be doubted. The cherty bands, where there is no folding, are evenly interlaminated with the carbonates, but in folded areas the brittle cherts have been fractured in every direction, so that the rock, instead of being a regularly laminated one, is a breccia, which contains angular fragments of chert of greatly varying sizes. Such a brecciated rock frequently runs into the regularly laminated kinds in the space of a few inches. It is then certain that the chert of these beds was present before the folding of the rocks. Further, there is no evidence that most of this chert was not deposited simultaneously or alternately with the iron carbonate. The relations of a portion of the chert and the iron carbonate are, however, such as to show that either the chert has entered by subsequent solution, or that the silica originally deposited with the carbonate was subsequently, to a greater or less extent, rearranged. This is indicated by the facts that the silica is quite completely crystallized, and that the silica belts, instead of being laminated with the carbonate, at times break across them in the most irregular manner. This fissuring must have been subsequent to the deposition of the carbonate, and may imply the entrance of silica from an extraneous source, but also may mean no more than that silica originally present has been taken into solution and recrystallized. In either case there is no proof that the greater part of the silica was not an original deposition.

It is assumed that such a cherty carbonate is water-deposited, as a direct eruptive origin has never been maintained for a rock of this character. Such an origin has, however, been asserted for some of the ferruginous cherts and jaspers which in other parts of the lake Superior country are found associated with the carbonates.[1]

Taking it for granted, then, that this cherty carbonate is a water-deposited sediment, the questions arise, in what manner the iron carbonate and silica were originally dissolved and how they were precipitated. We may, without varying too far from the law of uniformity, believe that in very ancient times the atmosphere was more highly charged with carbon dioxide than at present. We may also believe that the rocks composing the crust of the earth were then at a somewhat higher temperature. An increase in heat of but a few degrees would be a powerful assistance in the process of solution of the iron, and this would be especially true if the atmosphere at this time was still richly charged with carbon dioxide. The atmospheric waters would absorb this acid and carry it into the rocks which bordered the ancient sea, would decompose them, and take in solution ferrous carbonate. Such waters escaping into the shallow ocean at hand would bear the material for these irony deposits. While it is believed that these conditions may possibly have been present, their assumption is not necessary to account for the solution of the iron; for it is well known that thick beds of iron ore have formed in recent times by virtue of the solubility of iron as a carbonate under ordinary conditions. It is also not impossible that its solu-

[1] Notes on the Geology of the Iron and Copper Districts of lake Superior, by M. E. Wadsworth. Bull. Mus. Comp. Zool. Harvard Coll., whole series, vol. VII, Geological series, vol. 1, No. 1. 1880, pp. 62–68.

tion was greatly assisted by means of terrestrial life. That there was marine life at this time, as will be seen, we have strong evidence. Of terrestrial life we have no such proof, but it is highly probable that life existed on the land, and if so, the organic acids would be of assistance in decomposing the rocks and taking iron carbonates into solution. The iron is a carbonate rather than a hydroxide, for the same reasons that the bedded carbonates of Carboniferous times are so. It is usually taken for granted that in the Carboniferous deposits the presence of a large amount of organic matter explains the presence of the iron as a carbonate. Whether the iron was originally precipitated as a carbonate, or was decomposed and precipitated as a hydrated sesquioxide, just as limonite now forms from iron carbonate in places where bog ore is depositing, is uncertain. If the latter is taken to be the case (and it is perhaps the more probable supposition), it is necessary to believe that the organic matter with which the limonite was associated later reduced the latter to the protoxide, and by its decomposition furnished the carbon dioxide to unite with this protoxide and thus reproduce iron carbonate. Analyses of the carbonates of the Penokee series show conclusively that there still remains in these rocks quite a large percentage of organic matter. Also in the thinly bedded argillaceous slates above them the percentages of hydrocarbons are at times quite large. Some of the black slaty carbonates and black slates of the other iron-bearing series in the Northwest remarkably resemble the black carbonaceous slates of the Carboniferous. That carbon in the form of graphite could be produced in other ways than by life may be conceded; but it will hardly be urged that the finely disseminated carbon and hydrocarbons in these slates is other than of organic origin.

Text-books commonly explain chert contained in limestones as of organic origin More recently it has been maintained by a number of writers that this chert is a chemical sediment, which has entered the carbonates as a pseudomorph shortly after its deposition. The evidence that any of the chert is not of organic origin is of a negative character; but, as has been said, it is not at all impossible that the crust of the earth had a higher temperature at the time of the formation of these rocks than at present. If so, we need not necessarily go to life to account for this silica. What a powerful assistance an increase of temperature is in the solution of silica is shown by the geyserite deposits so well described by Hague.[1] While it may thus be possible that a part of the silica is a direct chemical precipitate, it is certain that life is sufficient alone to collect from sea waters silica in solution and form extensive deposits. So far as we know, this was first shown of the Trimmingham chalks, the chert of which seems without question to be the remains of life.[2] Later it has been shown by Dr. G. J. Hinde that extensive deposits of chert in Ireland, England, Wales and Spitzbergen are largely, and possibly wholly, accumulations of sponge spicules. The deposits of Ireland are described,[3] as follows:

> They consist of nodular masses of irregular form, inclosed in beds of hard, bluish limestones, and following the planes of bedding much in the same way as the flints in the Upper Chalk; but, unlike the flints, these nodular masses are not sharply delimited from the limestones in which they are interbedded, but there is a gradual passage from the chert to the limestone.
>
> More frequently, however, the chert exists in definite beds from 1 to 5 inches (.025–.12m.) in thickness, which intervene at irregular intervals between beds of limestone. These beds sometimes occur also as well marked layers in the central portions of beds of limestone. Both the nodular aggregations and the horizontally bedded chert usually occur in the same series of rocks. The particular mode of deposition probably depends on the extent to which the sponge remains (of which it will be shown the chert consists) are present in the respective areas.

It will be seen that this description conforms in a remarkable manner to the occurrence of chert and carbonate in the Penokee series. At Spitzbergen, Axels island, Yorkshire, and North Wales there are alternations of chert and limestone, the pure cherty layers of which are here, however, often quite a number of feet in thickness. The most remarkable occurrence is that of Spitzbergen and Axels island. The beds of cherty material

[1] Geological History of the Yellowstone National Park, by Arnold Hague. Trans. Am. Inst. Min. Eng., vol. XVI, 1888, pp. 783–803.

[2] On the Flint Nodules of the Trimmingham Chalks, by Prof. W. J. Sollas. Annals Nat. Hist. 1880, pp. 384–395, 437–461.

[3] On the Organic Origin of the Chert in the Carboniferous Limestone Series of Ireland, and its similarity to that in the corresponding strata in North Wales and Yorkshire, by George Jennings Hinde. Geol. Mag., London, New Series (Decade III), vol. IV, pp. 435–446. On the Chert and Siliceous Schists of the Permo-Carboniferous Strata of Spitzbergen, and on the characters of the sponges therefrom, which have been described by Dr. E. von Dunikowski. Dr. Hinde. Ibid., vol. V, pp. 241, 251.

here aggregate 870 feet in thickness. That the cherty layers of Wales and England are almost wholly, if not wholly, of organic origin seems to be conclusively shown. Also, it is certain that a part of the chert of Ireland, Spitzbergen, and Axels island is of organic origin. Dr. Hinde concludes that—

> It is true that the number of specimens of chert available for examination are very few, and they might be regarded as insufficient of themselves to warrant the conclusion that this great thickness of rock, which at one locality on Axels island reaches 870 feet, is due to the accumulation of the skeletal debris of siliceous sponges; but taking into consideration the fact that beds of similar cherty rock, which in Yorkshire have an estimated thickness of 90 feet and in North Wales of 350 feet, can be proved to be due to sponge remains, there is nothing extravagant in the supposition that this much greater thickness of rock has had a similar origin.

These cherts in Great Britain are Carboniferous; those of Spitzbergen and Axels island are Permian. It is of interest to note that these are the terranes in which the most extensive beds of iron carbonate in Paleozoic time are found. Further, the sponge remains pass into a "pure translucent chert." If, as Dr. Hinde maintains, all this silica is derived from sponge spicules, it must now in some cases be extensively rearranged; for a large part of the chert appears from the descriptions at the present time to be cherty or chalcedonic silica in forms independent of organic remains. In the Penokee cherts no evidence of organic origin for any of them has been found. This fact does not seem, however, to be any proof that the chert was not originally deposited in the form of sponge spicules; for if the silica in deposits so late as the Cretaceous has been so extensively rearranged as has the chert in the Trimmingham chalks, it would be strange if similar deposits, so far back in geological time as the Penokee series, had not lost the evidence of organic origin.

Our conclusion is, then, that we have no satisfactory proof as to whether the chert of the Penokee series is an original chemical sediment or the remains of life, but the latter is considered more probable. The quantity of chert which is contained, supposing the whole Iron-bearing belt to be as rich in silica as are the upper horizons, could not have been beyond 300 or 400 feet. It appears clear that original formations of chert have occurred which have more than twice this thickness, so there is no improbability in the statement made, that this material was deposited simultaneously with the iron carbonate with which it is so closely associated.

*The ferruginous slates.*—The microscopical description of the first phase of the second type of rock, the ferruginous slates (pp. 203-205) has so fully indicated its origin that but little more need be said here than to bring together the actual facts of observation. Into the genesis of this phase of rock little or no theory enters, as all of the stages of its growth have been seen. The only conclusion which goes beyond the observed facts is the comparatively safe one as to the nature of those exposures which cannot be directly traced into the cherty carbonates. The more important of the facts which bear upon their origin are as follows: The stratification of these slates is precisely like that of the original carbonates; the mineral composition of the two rocks is the same, except that iron oxide in the ferruginous slates takes the place of siderite; the change from siderite to the various iron oxides of the slate has been repeatedly noted in all its phases in thin section and is everywhere found in the slides when in the field the change from the cherty carbonate to the ferruginous slate could be traced. The background of the slates is at times more coarsely crystalline than in the cherty carbonates; also, the rocks are cut by veinlets of silica to a greater extent. These differences imply a partial rearrangement of the silica which they originally contained, and also perhaps the introduction of a small additional amount of silica. The quantity contained is not materially greater than in the unaltered cherty carbonates, and it seems a sufficient explanation of its variation in character to suppose that it is mostly due to a rearrangement; that is, the silica has been taken into solution to some extent and subsequently crystallized (other silica perhaps at the same time being added), thus becoming more perfectly quartzose and forming the veins which cut across the laminæ of the rocks. The only chemical change implied in the above transformation of the cherty carbonates into the ferruginous slates is the decomposition of the iron carbonate and the peroxidation of the iron which it contained. In the transition forms which occur between these slates and the ferruginous cherts there have been doubtless other chemical changes, but they can best be considered in connection with the origin of this rock.

*The ferruginous cherts.*—In explaining the genesis of the second phase of the second type of rocks it is necessary to account for its concretionary and brecciated character; for the production of brown hydrated hematite, red hematite, and magnetite; for the concentration of the iron oxide in shots and bands; for the large quantity of silica which it contains; for the somewhat coarsely crystalline character of the chert as compared with that of the original carbonates; and for the presence of numerous ramifying veins of finely crystalline quartz.

In the microscopical description of this phase of rock (pp. 205-209) the concretionary and brecciated character has already been accounted for. These peculiar areas have been actually observed in all stages of their formation, so that their history is not theory, but definitely observed fact, and will not be repeated here. The oxides of iron have been produced from the iron carbonate just as are the oxides of the first phase of rock, the only difference being that here occasionally magnetite is formed. This mineral, however, is readily accounted for by the decomposition of iron carbonate under conditions not favorable to complete oxidation. It is not to be supposed that these rocks were highly heated, but it may be remarked that a low degree of heat is sufficient to change iron carbonate into magnetic oxide of iron with the liberation of carbon monoxide and dioxide. It is not believed that any carbon monoxide has been liberated, for the oxygen needed to change the protoxide of iron into the proto-sesquioxide was doubtless supplied by oxygen in percolating water. The manner of concentration of the iron oxides in bands and shots will be fully discussed in considering the origin of the iron ores, but it is here necessary to mention the causes which have produced such concentration. Percolating waters bearing oxygen in solution have decomposed a part of the iron carbonate, the carbon dioxide passing into the water and oxygen passing from the water into the rock, thus simultaneously forming sesquioxide of iron and solutions capable of taking up other iron carbonate. Such iron-bearing waters would after a time reach some crack or channel in the rock. This opening in many cases would serve as a passage for other waters more directly from the surface bearing oxygen in solution, and as a result of this mingling the iron in solution would be precipitated, and thus concentrations of the iron oxide in bands and shots would occur. This explanation is not a wholly suppositious one, but accords with the facts of observation as seen in numerous exposures, one of which, the cliff bordering the outlet of Sunday lake, in Sec. 13, T. 47 N., R. 46 W., Michigan, is fully described (section IV) in connection with the origin of the ores.

The concentration of silica in these cherts is partly explained by the abstraction of iron carbonate taken into solution. This chert is rarely pure, and frequently contains a large amount of iron oxide; and this is what would be expected from the character of the processes above indicated, yet the silica is much more abundant in the ferruginous cherts than in the unaltered carbonates. It is to be remembered that most of these cherts are at low horizons, and it is probable that they have to a considerable extent been silicified. The proof of this silicification lies both in the abundance of the silica itself and in the manner of its occurrence. The greater part of it is relatively perfectly crystalline as compared with the chert of the carbonates. The cavities which the rock frequently contain are lined with quartz crystals. Numerous veins of quartz cut through the rock in every direction. The concretions, as explained (pp. 205-209), are areas which were originally carbonate of iron, but are now largely composed of silica. Many of them have been severed by veinlets of silica. All these facts imply an extensive rearrangement of the silica originally present and the introduction of additional silica. In a subsequent consideration of the origin of the ore deposits it will be seen that it is probable that the silica necessary for this silicification was derived from original cherty carbonates which have been swept away by erosion. If this is the case, a portion of the silica within the ferruginous cherts must have been carried some distance. The ferruginous cherts are cut, as shown by mining operations, by numerous dikes, which are much decomposed and are certainly more basic than they were originally. This alteration of the dikes may also have furnished a portion of the silica for the silicification of these ferruginous cherts. The nature of the solutions which dissolve silica in rocks and deposit it in other places is becoming better known, and that it is largely carried is certain.[1] The quantity of silica required to fill the interspaces of

[1] For foreign localities, see Roth's Allgemeine und Chemische Geologie, vol. I, 1879. For United States localities, see Bulletins of the U. S. Geological Survey, No. 32, List and Analyses of the

a thick bed of loose sandstone must be enormous; yet it is absolutely certain that such cementation has occurred again and again. Silica in silicates, in the amorphous forms, and even in a quartzose condition, is soluble in alkalies, although with great difficulty in the latter case. Professor Sollas, in a paper already alluded to,[2] has drawn a sharp distinction between organic and mineral silica, the first being easily soluble, while the latter is relatively insoluble. Probably most of the silica, even in the cherty carbonates, would fall in his class of mineral silica; but a part of it is amorphous, and a portion of it certainly is quite readily soluble, as shown by actual laboratory tests with caustic alkalies. In accounting for this increase in the quantity of silica, we have explained its relatively coarsely crystalline character and the presence of the veinlets; for in the silicification of the rock, as explained, these are the phenomena which we would expect to find.

The genesis, then, of these ferruginous cherts has been something as follows: The rock originally occupying the place now taken by them was a cherty iron carbonate. Percolating solutions have decomposed a part of the siderite and at the same time have taken up another part. This iron carbonate has been in other places peroxidized and precipitated in bands and shots. Silica, at the same time or subsequently, has been taken into solution to a greater or less extent, and in other places, under different conditions, has deen deposited as chert. Incoming solutions have brought with them a further amount of silica, which has filled the spaces left by the removal of the carbonate. It is probable that the peroxidation and removal of iron carbonate and the deposition of silica have to some extent been simultaneous; but it seems to be the case that they have in general been in part successive—that is, the first process began before the second and was

Mineral Springs of the United States, Albert C. Peale; No. 47, Analyses of Waters of the Yellowstone National Park, with an Account of the Methods of Analysis employed, Frank Austin Gooch and James Edward Whitfield; No. 8, On secondary Enlargement of Mineral Fragments in certain Rocks, R. D. Irving and C. R. Van Hise. The Pre-Cambrian Rocks of the Black hills, C. R. Van Hise; Bull. Geol. Soc. of America, vol. 1, pp. 220-221. Bulletin No. 47 gives over forty water analyses, in all of which silica is found. In many it constitutes 25 or more per cent of the total soluble material, while in one case it runs as high as 50 per cent.

[2] Prof. W. J. Sollas: On the Flint Nodules of the Trimmingham Chalks; Annals Nat. Hist. 1880, pp. 384-395; 437-461.

completed before the latter ended. The arrangement of the iron oxide and quartz in rough layers in the rock and in concentric belts in the cavities go to show this. The cavities generally have as an exterior casing an iron oxide. This was formed at the stage in which the iron carbonate was partly decomposed and partly removed. Later, the solutions passing through the rocks began to carry silica, and finally the silicification was the chief reaction; as a result of which, the layers of quartz crystals formed within the cavities and in veins in the cracks, oftentimes entirely filling them. In producing the many peculiar phases and mixtures of chert and iron oxides the conditions must have varied in different places. With the stages of growth of one particular form, the concretions, we are familiar. In them the series of operation seems to have been exactly as described above.

*The actinolitic slates.*—The field relations of the actinolitic slates are such as to show that they, like the ferruginous cherts, are almost certainly derived from iron carbonates. There is not here the intimate association between these two types of rock that there is between the cherty carbonates and the ferruginous cherts. The latter are for many miles directly overlain by the carbonates. Within their mass they contain large exposures of this rock, so that between the two, both in exposure and in thin section, we have transitions showing all the intermediate phases. The ferruginous cherts and iron carbonates which occupy the central portion of the iron formation grade into the actinolitic slates to the east and west. This transition is slow, occupying in each case several miles of distance; but above the actinolitic slates no carbonate is found; also within the belt itself there are no bodies of this material; so that the only proof of the derivation of this rock from the cherts and carbonates lies in the facts that the two classes of rock occupy the same horizon, and in the passage from one to the other there are transition phases.

The actinolitic slates are not so different from the ferruginous cherts in their essential characteristics as might at first be thought. In mineral constitution the two types of rock are the same, except that in the actinolitic slates the additional mineral actinolite is present and magnetite more plentiful. In the peculiar arrangement of the iron oxide and silica the ferruginous cherts and actinolite slates are often identical, the regular laminæ of iron ore and silica, the concretions, and the breaking of these concretions and laminæ by veinlets, all occurring in both classes of rocks (Pl. xxiii, Figs. 3 and 4; Pl. xxiv, Figs. 1 and 2). Also the two types of rock are alike, in that they both contain at times residual iron carbonate. It is true that the amount of siderite is not so great in the actinolitic slates as in the ferruginous cherts. A further likeness between the two rocks lies in the occasional pseudomorphous aggregates of actinolite and magnetite after iron carbonate, as exhibited by Pl. xxviii, Fig. 1. The only essential difference, then, between the two classes of rocks is the introduction of actinolite; the subordinate differences are the more completely crystalline character of the quartz and the abundance of magnetite. To account for the actinolite is comparatively easy. We have only to suppose that the silica-bearing waters at the time of the rearrangement and silicification of these rocks united with a portion of the protoxides of calcium, magnesium, and iron, thus producing actinolite. As has been seen by the description, page 210, the order of crystallization of the minerals in these slates is magnetite, actinolite, and quartz. The condition which explains the large amount of magnetite also explains the production of the actinolite. In the ferruginous cherts it has been seen that the oxidation of the carbonate was mainly prior to the rearrangement and introduction of silica; so in the actinolitic slates, the first step in the process of alteration from the cherty carbonates was the production of magnetite by the decomposition of siderite. That this resultant oxide is largely magnetite is proof of an insufficient amount of oxidizing agent. When the rearrangement and subsequent introduction of silica occurred a portion of it simply united with the protoxide bases present and thus formed actinolite. An abundance of protoxide of iron was here perhaps as carbonate, and certainly in the magnetite. In this connection the relations of the actinolite and magnetite are of great significance. The actinolite frequently surrounds the magnetite areas, less often penetrates them, and is usually, although not always, associated with them. In the final stage in the process of the formation of this rock the most of the silica separated as quartz, but apparently actinolite continued to form to the very last, as it is almost everywhere included within the quartz. To explain the differences between these rocks and the ferruginous cherts we need, then, only to suppose one different condition—the absence of a sufficient amount of oxygen at the time of their alteration to change all of the iron to the peroxide. As has been suggested before, it is possible that those parts of the iron formation in which the actinolitic slates occur were more highly heated than the other parts. The more coarsely crystalline character of the silica so prevalent in them may also be explained by this supposed increase in temperature; for, as has been shown by laboratory experiments, a temperature considerably above the normal is favorable to the production of coarsely crystalline quartz.[1] This supposed increase of temperature is rendered plausible by the frequent if not universal association of large quantities of basic eruptives with the iron formation at the places where the actinolitic rocks occur. Also these cutting or interlaminated eruptives may have excluded to some extent surface water and thus caused the supply of oxygen to be deficient.

The details by which the particular phases of the actinolitic slates have been produced cannot be satisfactorily given, for in so few of them is there any remaining iron carbonate. However, taken in connection with their position and intermediate links, there can be little question of their derivation from a cherty iron carbonate. If there is any doubt upon this point it is set at rest by considering the occurrences in the Animikie series in northeastern Minnesota. That these two iron-bearing series are stratigraphically equivalent can hardly be doubted. It has been seen that in the Animikie series all the transition phases between cherty iron carbonates and the most crystalline actinolitic slates are as perfectly illustrated as are the intermediate phases between the cherty iron carbonates and the ferruginous cherts in the Penokee series.

The origin of these actinolitic slates is analogous to that of the tremolitic limestones, so widely present in the iron-bearing series of the Northwest and in later geologic times. Tremolite is calcium-magnesium-silicate; actinolite is calcium-magnesium-iron-silicate. The tremolitic limestones are, aside from the tremolite, mostly composed of calcium-magnesium-carbonate. The original material from which the actinolitic slates were

[1] Roscoe and Schorlemmer, Treatise on Chemistry, vol. I, p. 569.

derived is a siliceous iron carbonate bearing calcium and magnesium. In this case the silica had but to unite with these bases to produce the actinolite; like solutions in the limestones had only to unite with the bases there present to produce tremolite.

### SECTION III.—THE ANIMIKIE IRON-BEARING SERIES.

Before leaving this part of the subject it is necessary to make some allusion to like formations in other parts of the lake Superior country. The Animikie and Vermilion lake series of northeastern Minnesota and Ontario, the Marquette and Felch mountain series of Michigan, and the Menominee series of Michigan and Wisconsin, all contain large developments of rocks which in their characters are almost exact reproductions of the iron-formation rocks in the Penokee series. In each of the districts mentioned all the types and most of the varieties described in the latter series are quite widely found. Cherty iron carbonate is not extensively known in some of them, but in one is more largely developed than in the Penokee series itself, while in the most folded and altered series mentioned this rock typically occurs, as is shown by Pl. XXIV, Figs. 3 and 4. A general condensed account of the iron formations and ore bodies of these various districts, including the Iron-bearing rocks of the Penokee series, has been published by us.[1] While a continued study has made some modifications of detail necessary, the main conclusion of the papers has been rendered more certain; i. e., that the many phases of peculiar rocks associated with the iron ores in these various districts have been derived mainly from a clayey or cherty iron carbonate. In the first paper referred to an exception was taken in the case of some of the coarser grained actinolitic slates which are foundin the Marquette country, "as to whose relations to the other ferruginous materials we feel now unwilling to speak." Later investigations make it not improbable that some of these rocks have been derived from eruptives; but the origin of this class of rocks has not yet

[1] R. D. Irving: Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region; Am. Jour. Sci., 3d series, vol. XXXII, 1886, pp. 255–272 C. R. Van Hise: The Iron Ores of the Marquette District of Michigan; Am. Jour. Sci., 3d series, vol. XLIII, 1892, pp. 116–132. C. R. Van Hise: The Iron Ores of the Lake Superior Region; Trans. Wisconsin Acad. of Sci., Arts, and Letters, vol. VIII, 1892, pp. 219–228.

been certainly determined. Nothing will be here added to what was said as to the character of the ferruginous rocks of the Marquette, Menominee, and Vermilion lake districts, except to state that not infrequently mingled with the nonmechanical detritus are considerable quantities of mechanical material. While much additional work has been done upon them, it has not gone far enough to warrant a detailed account. However, the Animikie series, in its iron formation and its simple unfolded condition, is so remarkably like the Iron-bearing member of the Penokee series, that additional material has been obtained and a careful study made of it in order to compare its character and origin with those of the latter series.

The following general description of that part the Animikie series which contains in its best development the iron formation is by the senior author.[1]

The Animikie rocks are exposed in four distinct areas, one of which is separated from the others by an overlap of the great gabbro which forms the base of the Keweenaw series. The others are separated from one another, so far as known, by drift covering only. The first of these areas is that which, with its principal development in Canada, along the shores of Thunder bay, crosses into the United States in northeastern Minnesota, the national boundary line being within this formation from the outlet of Gunflint lake eastward to the eastern extremity of Pigeon point. Around Thunder bay the rocks of this series, which are chiefly black slates, graywackes, argillaceous quartzite, interstratified diabase, and gabbro layers, which are many in number and individually often have a considerable thickness, are exposed on a large scale. Immense dikes of gabbro and diabase also penetrate these layers, the gabbro dikes, which are at times several hundred feet in thickness, being noticeably much closer in character to the great gabbro at the base of the Keweenaw series than to those gabbros which are interleaved with the Animikie slates.

In the vicinity of Thunder bay the Animikie rocks are often nearly horizontal, but show a general tendency toward a southeastward inclination. As the formation crosses into United States territory it shows more marked inclinations, which average probably about ten degrees, though at times less than this, and sometimes reach as much as twenty degrees. The national boundary line is situated within this formation from the mouth of Pigeon river to Gunflint lake; but on the north side of the latter lake, and again to the north of the next lake to the east, called North lake, the unconformable abutment of the Animikie series against an older formation of granite and schists is very handsomely shown. The actual contact of the two formations is

[1] R. D. Irving: On the Classification of the Early Cambrian and Pre-Cambrian Formations; 7th Annual Report U. S. Geol. Survey, 1888, pp. 420–422.

not seen, but the exposures approach to within a few feet of each other, and the relative attitudes of the two formations are such as to leave no question whatever with regard to the unconformity. Not only is this shown by the vertical position of the schists as contrasted with the flat inclinations of the slaty series, but also by the way in which the latter beds, to the north of the two lakes mentioned, fit into the sinuosities of outline of the older formations. The entire contrast as to lithological characters between the two sets of rocks furnishes further proof. . . . So far as it is developed along the national boundary line the lowest layers of the Animikie series in sight are those on Gunflint lake [see Pl. XXXVII, this Monograph]. The highest layers are those in the vicinity of Grand Portage bay, the whole succession between these points being some thousands of feet in thickness. The iron-bearing horizon at the base of this succession is lithologically identical with that of the Penokee series of northern Wisconsin and Michigan, while the black slates, graywackes, etc., which succeed the iron-bearing horizon, are in turn the counterparts of those which form the middle and upper portions of the Penokee series. The interstratified gabbros of the Animikie are wanting, however, or are relatively rare in the Penokee region.

The iron formation of the above described area of the Animikie series contains all the phases found in the Penokee district, with the exception that no extensive ore deposits have yet been developed. There is, further, a much more intimate association of the less altered and most crystalline forms than in the Penokee series. The relations of the original cherty carbonate with the various phases of the actinolitic slates are as intimate as are the relations of the unaltered rocks with the ferruginous cherts in the Penokee series.

*The cherty iron carbonates* (Pl. XXV).—The cherty iron carbonates are found extensively exposed in various localities. They are known as far east as lake Superior, on the ridge which is just back of port Arthur. They are also largely found on the Kaministiquia river, but the best known and most characteristic exposures are at and northeast of Gunflint lake, T. 65 N., R. 2 and 3 W., Minnesota. At times these rocks are very nearly pure carbonate, and contain from 35 per cent to 45 per cent of metallic iron (for analyses see p. 192). These beds of comparatively pure carbonate are, however, not usually of any considerable thickness. They alternate with layers which contain a large percentage of calcium and magnesium carbonates and with belts of chert of greater or less purity. Sometimes the transition from the thick bands of carbonate to those of chert is abrupt;

at other times the carbonate layers contain thin seams of chert finely interlaminated with them. Not unfrequently the chert is in nodular forms, or a layer of chert which has been continuous for some distance has a somewhat abrupt oval termination (Pl. xxv, Fig. 4). The carbonate areas may contain here and there minute particles of cherty material, just as the cherty areas contain rhombohedra of siderite. In fact, there is every possible gradation between bands of almost pure carbonate and others of almost pure chert. Upon the weathered surface these rocks show in a marked degree the peculiar weathering exhibited by cherty limestones. Because of the resistant character of the chert the carbonates are more rapidly dissolved, and thus leave the siliceous bands in ridges protruding from the face of the rock, varying in width from those not more than a hair's breadth to those several inches across.

That this material is of the same origin as the rock which has been regarded as an original one in the Penokee series is manifest. The rocks of the two districts are so remarkably alike, that if the specimens from them were mingled many of them could not be separated by their difference of appearance. Upon the whole some phases approach more nearly to certain of the Ohio carbonates and those near old Livingston manor house, Hudson river, New York, than do most of the Penokee carbonates. That the silica now present in these rocks was there at a very early date is shown by the remarkable brecciation which they exhibit where folded. In general the series is quite uniformly flat-lying or gently tilted, but the exposures upon the north side of the main body of Gunflint lake exhibit in places somewhat sharp bowing. The layers, where cherty, have not yielded to this bowing uniformly, but have been shattered like a rigid, brittle, inelastic body, and thus conform themselves by a succession of fractures to the general bowing taken by the strata. As a result of this peculiar feature the chert and carbonate are in places as finely and uniformly laminated as when found in any sedimentary formations (Pl xxv, Fig. 3). From this regularity they suddenly change to rough breccias along zones of fracture. These breccias alone might be taken to be a water-deposited fragmental rock, but, as examined in exposure, their positions at the places of abrupt variation in the bedding of the rock prove that they have resulted from the folding. The contained fragments are exceedingly angular, as would be expected, and give no indication of having undergone any considerable change since the folding, except that their interspaces are cemented with chert and iron carbonate which must subsequently have infiltrated.

When these rocks are examined in thin section the relations of the chert and carbonate are seen to be exactly like those in the Penokee series. As a general rule there is a regularity of interlamination of the two, but quite frequently also the cherty layers break across the belts of carbonate in such a manner as to imply an introduction of silica subsequent to the carbonate layers. This introduction may show merely a rearrangement of the silica which was originally deposited in the rocks, as explained with reference to the Penokee series, but it may imply an actual introduction of silica from an extraneous source, that is, a secondary silicification. The siderite is often well crystallized in perfect rhombohedra or oval forms (Pl. xxv, Figs. 1 and 2). These rhombohedra often average larger than in the corresponding rocks of the Penokee district, but, as in them, they are occasionally argillaceous. The chert also varies greatly in the coarseness of its grains, running from almost completely amorphous to almost completely crystallized. The wholly amorphous condition is, however, unusual.

*The ferruginous slates.*—The ferruginous slates are always found associated with the unaltered cherty carbonate. They are not known to be so extensively developed as in the Penokee region. In microscopical character they differ from them only in that magnetite is relatively more abundant. Their derivation from the iron carbonates is seen in all its phases. A description of these stages of gradation would be but a repetition of what has been said as to similar rocks in the Penokee series and so will not here be given.

*The ferruginous cherts.*—(Pls. xxvi, xxvii and xxviii, Fig. 2.)—The ferruginous cherts are abundant. They comprise all the phases described in the Penokee series, and exhibit as finely their origin and also the character of the brecciation which sometimes accompanies these concretionary forms. The chief difference exhibited by the ferruginous cherts of the Animikie from the Penokee district is relatively greater abundance of magnetite. To describe the ordinary concretionary and brecciated forms would be a repetition of what has already been given as applying to rocks in the Penokee series, so that here all that will be said is in reference to the manner of occurrence of the magnetite. It has been noted that magnetite is occasionally pseudomorphous after siderite in the Penokee series. This is often the case in the Animikie series. The formation of magnetite from iron carbonate, as exhibited in many sections in all its phases, is finely illustrated in Pl. xxv, Fig. 2, which shows on one side of the figure oval and rhombohedral areas of nearly pure siderite and in the middle of the section similar areas which have completely altered to magnetite. In the intermediate parts of the figure all the transition phases can be made out. In this section the magnetite has taken its forms from the siderite but it is more often the case that its crystal forms are independent of the original areas of carbonate. In sections in which there is a good deal of both siderite and magnetite, the magnetite is ordinarily found scattered through the section, disconnected with, adjacent to, or included in the exterior parts or even quite to the centers of the siderite areas. The relations are such as to show that the magnetite is in the process of formation from the siderite, but the crystals of the oxide included in it generally have their own octahedral form, and their outlines consequently bear no relation to those of the carbonate from which they are derived (Pl. xxix, Fig 3). Magnetite and hematite in these sections are most closely associated. Generally areas are made up of an intimate mingling of the two. In very thin sections, in transmitted light, the blood red hematite can be seen as spots here and there through the magnetite areas (Pl. xxix, Fig. 1); or, if the hematite predominates, the reverse is the case. In some cases, however, the relation between these two minerals is somewhat peculiar. The magnetite is found as cores in the hematite areas. In this case it is either possible that magnetite was originally formed from the iron carbonate and that it has subsequently peroxidized upon its exterior and thus formed hematite; or that at first the conditions were favorable for the production of magnetite and subsequently changed so as to produce hematite.

*The actinolitic slates.*—(Pl. xxv, Figs. 3 and 4; Pl. xxix, Figs. 2 and 3.)—The most important addition to our knowledge of the origin of iron-formation rocks given by the Animikie series is from the actinolitic slates. It has been seen that in the Penokee series the transition phases were somewhat sparingly present. This is not the case in the Animikie. The many phases of unaltered carbonate, ferruginous slate, and ferruginous chert contain actinolite and magnetite. Different sections exhibit these two minerals in quantity from minor to chief constituents. There are kinds which are mainly composed of actinolite and siderite, others which are mainly composed of actinolite and iron oxide including magnetite, and still others which are composed of actinolite, iron oxides, and chert; the latter including the most concretionary and brecciated forms.

The evidence that the actinolite slates have been formed from cherty iron carbonates is like that which proves the ferruginous cherts and the ferruginous slates to be of this origin.

It has already been shown that the magnetite is largely a secondary product of siderite, being very frequently pseudomorphous after it. Also, when not thus pseudomorphous, its relations are often such to the siderite as to show that it is secondary to it. The relations of magnetite and the other oxides of iron in the concretions have already been given. The growth of these concretions has been traced out step by step precisely as in the Penokee series; so that there is no doubt that the magnetite in them is secondary to the siderite. The proportion of this mineral derived from siderite is so great that it is exceedingly probable that it is of secondary origin even in those cases in which this can not be demonstrated.

The secondary character of the actinolite can not always be clearly shown; but the cases in which its origin can be made out are so numerous, that the conclusion is reached that all of it is of the same nature. That the silica in the actinolite slates has been extensively rearranged and more coarsely crystallized, with the probable addition of silica to that which the original rock contained, can not be doubted. The way in which the silica cuts the other minerals is nicely illustrated by Pl. xxix, Figs. 1 and 2. The actinolite constantly cuts the quartz. The association of the actinolite with the magnetite and siderite, that is, with minerals which contain protoxide of iron, is characteristic. The actinolite began to form at the time of the entrance and rearrangement of the silica, the magnetite and siderite furnishing the necessary bases and the silica furnishing the acid for its formation. The reactionary nature of this actinolite is well illustrated by Pl. xxv, Fig. 4, where the actinolite constitutes an almost solid band between a cherty nodule composed mostly of silica and the finely laminated slate which largely contains siderite and magnetite. Also actinolite and magnetite occur together in well formed concretions. Frequently in the concretions a ring of magnetite is inclosed upon both sides by a border of actinolite. Again, in other places, when a magnetite ring is not quite complete, the actinolite border which follows the magnetite throughout the part of the concretion where it is present completes the ring.

It has been suggested of the actinolitic slates in the Penokee series that the conditions which explain the presence of the magnetite also explain the appearance of the actinolite. Yet it is not always true that actinolite is accompanied by magnetite; magnetite may also appear without the presence of actinolite. In some few of the sections actinolite and a calcium-magnesium-bearing siderite are the only important constituents, silica, however, always being present; and the rock then becomes an actinolitic carbonate. It is here to be noted that this rock is an exact analogue of the tremolitic limestones; silica in the case of the limestones has united with the bases present to form tremolite; in a similar way the actinolite has formed in the ferriferous carbonate by the union of silica with the bases.

*General.*—It need hardly be said that the rocks of this formation are mainly nonfragmental. It is, however, the case that fragmental material is more widely mingled with the iron formation of the Animikie than of the Penokee series. A good many thin sections contain a considerable amount of fragmental quartz, which instantly exhibits itself in its true character, showing its rounded outlines and frequent enlargements. This occurrence then furnishes another illustration of the ease of separating a fragmental from a nonfragmental quartz when the rock has not been subjected to dynamic action and of the fundamental difference of their natures.

The relations and order of crystallization of the minerals contained in the actinolitic slates and ferruginous cherts are then precisely the same as in the Penokee series. A cherty ferriferous carbonate was the original rock. From this the iron oxides have been in the main the first to form. Before their formation was complete, when actinolite is present, it has begun to develop, and is included in the oxides, and particularly in the magnetite. Its growth is most pronounced at the beginning of the rearrangement and introduction of silica, as would be expected from its requiring this material to produce it. The average amount of silica is much greater than in the original cherty carbonates, and it is also more largely in the form of quartz. The final stage in the development of these rocks has been, then, a rearrangement of silica already present and an addition of silica to a greater or less degree at the time when most of the quartz formed. Cherty carbonate located elsewhere may have been the source whence the most of this silica was derived, as will be more apparent after the origin of the ores in the Penokee series is considered. Interbedded with the Animikie rocks are also heavy beds of diabase and gabbro, alteration of which may also have furnished silica for the silicification. The likeness of the Animikie and Penokee iron formations is further exhibited in a striking manner by the fact that, in the most typical exposures, the Animikie series upon Gunflint lake, in upper horizons, are almost pure cherty carbonate; in intermediate horizons, ferruginous cherts and carbonates; and in the lower horizons, actinolite slates, jaspers, and ferruginous and concretionary cherts, which, however, often contain siderite.

## SECTION IV.—THE IRON ORES.[1]

*Position of the ores in the Iron-bearing member.*—The iron ores are all located, as far as known at present, in that part of the iron-bearing formation between Sec. 33, T. 45 N., R. 1 W., Wisconsin, and the east line of T. 47 N., R. 45 W., Michigan, a distance of about 30 miles. The greater

[1] A brief account of the contents of section IV was published in advance in the Am. Jour. Sci., 3d series, vol. XXXVII, pp. 32–48, by the junior author. Dr. Irving had not considered this part of the subject.

This section indicates the development of the mines at the time it was written. A recent visit to the Penokee range enables me to say that later developments accord with the conclusions herein contained, but the mining of the years since this section was written has wholly changed the maps of the mines.

number of the larger deposits are found in the central half of this area. Also, most of the known deposits lie at the base, or very near the base of the Iron-bearing member; that is, they rest upon or close to the coarse grained fragmental quartzite, which constitutes the uppermost horizon of the Quartz-slate. The number of shipping mines is about twenty, and in them all the deposits lie upon this fragmental quartzite except the following, which are given in order from west to east: (1) The Tyler's fork mine, in the E. ½ of Sec. 33, T. 45 N., R. 1 W., Wisconsin. (2) The Iron Belt mine, NE. ¼ Sec. 11, T. 45 N, R. 1 E., Wisconsin. (3) The Montreal mine, a short distance east of the west quarter post of Sec. 33, T. 46 N., R. 2 E., Wisconsin. This mine has shipped quite a large quantity of ore from a deposit which was at first an open pit and which has not been carried to the fragmental quartzite. This deposit at the present time is not the more important one upon the property, the main ore body resting upon the fragmental quartzite. (4) The Mount Hope mine, NW. ¼ Sec. 24, T. 47 N., R. 47 W., Michigan. This mine has a large deposit of ore, situated some 300 feet north across the formation from the underlying quartzite. This body is one of the two large deposits which have been developed above the base of the formation. South of it, and a short distance to the east, is another deposit of ore which rests on the quartzite. (5) The Bonney mine, NE. ¼ Sec. 24, T. 47 N., R. 47 W., Michigan. (6) The Colby mine, NE. ¼ Sec. 16, T. 47 N., R. 46 W., Michigan. This is the second of the two large known deposits which do not rest upon the Quartz-slate formation. Directly south of this body is, however, a still larger one which lies upon the quartzite, and the deeper workings of the mines show that these two deposits approach very close to each other, if they are not actually connected. (7) East of Sunday lake, in T. 47 N., R. 45 W., several mines—including the Brotherton and Sunday lake—which are a considerable distance north of the fragmental quartzites. These mines have peculiarities which distinguish them from other working deposits to the west. The ore bodies lie in isolated and irregular patches, which are generally not more than 10 to 30 feet in thickness. These lenses are separated by barren rock which is at times as much as a hundred feet thick. With the exception of the Mount Hope and Colby none of the above mentioned mines are of large size.

It is not meant to imply that the more numerous class of deposits which have been spoken of as resting upon the foot-wall quartzite have the clean ore always in contact with it. Quite often there is a layer of what the miners denominate "paint rock," or a layer of sand rock between the quartzite and the ore. This latter material is sometimes as much as 20 feet in thickness, although it is usually not more than a few inches, or at most a few feet. The sand rock here found is so friable as to readily crumble between the fingers; in fact, is no more than coarse sand. The paint rock, a commoner material, is a soft red substance, rich in iron, at times carrying more than 50 per cent. It appears like a heavily ferruginous clay, and varies in thickness from a mere film up to 5 feet. Sometimes, also, there is between the ore and the quartzite a mass of greater or lesser thickness of the ferruginous chert or "mixed ore" of the miners. Rarely a thin layer of nearly pure white chert is found between the ore and quartzite. Notwithstanding all these exceptions the south side of the ore never penetrates the quartzite and in a general way follows it, so that it may be spoken of as resting upon it. It will be remembered that this quartzite has an average dip to the north of from 60° to 70°, and it thus furnishes an approximately regular wall, north of which the ore lies, and is consequently always called the foot wall by the miners. While it is true that the average dip of this quartzite is as given, it has subordinate irregularities as great as the ordinary eroded surface of a gently undulatory country. In shafts which follow it the dip is at times as high as 75° or 80°, while in other places it is not more than 45°. Also in horizontal drifts which are following the quartzite this same undulatory character is seen. For instance, one such drift in the Colby mine in following the quartzite bows sharply at one place and runs almost due south for some feet before striking the quartzite, although it has just before been alongside of it.

The so-called "north vein" deposits are described by Mr. J. Parke Channing as always having regular south walls, which dip with the formation and are called by the miners "foot walls." Such walls may be well seen at the open pits of the Montreal, Mount Hope, and Colby mines.

The differences between the foot walls (of the so-called north veins) and the southern deposits will be later considered. For the present it is sufficient to say that whether the ore deposits rest upon the fragmental quartzite or are north of it, they have as their southern boundaries an approximately regular plane, dipping to the north at an average angle of from 60° to 70°.

*Dikes in Iron-bearing member.*—The eruptives of the series are treated in another place. They are known to be very numerous in the Iron-bearing member, although their abundance here does not show that they are not as plentiful in other members of the series; for mining developments have cut this belt in every direction and thus found the greenstones, the presence of which would not have been suspected from natural exposures. As explained in their description (chapter VII), the greenstones of the Iron-bearing member are much altered. Many of them are so decomposed as to be soft friable masses which can be picked to pieces with the fingers and now contain none of the original minerals that make up ordinary basic intrusives. They retain, however, distinctly their diabasic structure and can occasionally be traced into comparatively unaltered phases which are true diorites. These much altered greenstones are known to the miners either as soapstones or as diorite dikes. That they are dikes is manifest from their form as well as by the way in which they cut across the layers of the Iron-bearing member into the foot-wall quartzite. This dike-like character is finely shown by Pls. XXX and XXXI.

One traveling along the iron range is at once struck by the constancy of the association of the iron ores and these so-called soapstones. At every mine, except those east of Sunday lake, a greater or lesser amount of this soapstone is found among the débris from the mines and oftentimes its quantity is large. This association was found to be so constant that Mr. J. Parke Channing, then inspector of mines for Gogebic county, Mich., was employed to work out the relations of the ore bodies and dike rocks. What follows as to the position of the dikes themselves and as to the position of the ore bodies with reference to them is wholly the result of data furnished by his investigations.

The position of the dikes is given with reference to the iron formation in which they occur. This formation has a northern dip and a general east and west strike. As used in reference to the dikes, an east and west direction means parallel with the iron formation; a north and south direction, transverse to it. The important thing for the present purpose is not the absolute direction in which the dikes run, but their relations to the containing formation. The dikes vary a good deal in their dip and strike in different mines, and the same dike at times in the same mine also varies in dip and strike. However, certain of their elements are quite constant. They always dip to the south, and generally this southern dip or its component transverse to the formation is from 20° to 30°. The northern dip of the iron formation is from 60° to 70°. *It follows from this that if the stratified rocks were placed again in a horizontal position the dikes would be vertical.* The true dip of the dikes is, however, usually not exactly transverse to the formation, but east of it, so that a component along the dikes, parallel to the strike of the rocks, has usually an eastern pitch. This pitch may be as high as 35°. From this amount it varies to horizontality or even to a western pitch of 10°. The strike of the rocks of the Iron-bearing member in which the ore bodies occur is, throughout most of the distance, north of east. For a short way in the eastern part of T. 47 N., R. 46 W., Michigan, the strike of the rocks is nearly east and west; but in passing westward the strike begins to vary to west of south and in the western part of the ore-bearing area is from 25° to 30° west of south (Pl. II). If these rocks were turned back to a horizontal position in a direction at right angles to their strike, the strike of the dikes would be the same as the strike of the rocks of the Iron-bearing member at present, when there is no eastern or western component in the dip of the dikes. When the dip component of the dikes along the formation is east, it must be added to the amount that the iron formation now strikes north of east to produce the strike which the dikes would have if the iron rocks were placed in a horizontal position. If, on the contrary, the component along the formation is to the west, it must be subtracted from the amount that the strike of the formation is north of east. The position of these dikes with reference to the foot-wall quartzite will be better understood by an examination of Pls. XXX and XXXI. In one mine in which the pitch of the dike is 10° to the west, the Mount Hope, the strike of the formation is about 10° north of east;

therefore, the strike of the dike, if the iron rocks were turned back to a horizontal position, would be east and west. At the Pence mine the strike of the Iron-bearing rocks is about 25° north of east, while the dike in the mine has an eastern component of 35°. The dike would, then, if the Iron-bearing rocks were turned to a horizontal position, strike about east 60° north. It is for the present assumed that the dikes cut through the iron formation before their uplifting. If this is the case, it would follow that, upon the average, the dip of the dikes was 90°, that is, they were perpendicular to the strata through which they came, and that the strike of the dikes varied from east and west to east 60° north. The average strike of the larger number of dikes would be about northeast and southwest.

The thickness of these dikes varies greatly, running from a few inches to nearly 90 feet. In most of the mines in which the deposits of ore are of any considerable size, the main dikes are generally six or more feet in thickness, while it is noticeable that generally the larger mines have thick dikes, although in the same mines there are often one or more smaller dikes. The main Colby dike is nearly 90 feet thick; the main Norrie dike, 35 feet thick. The only ore deposit west of Sunday lake, the development of which has found no dyke, is the main Ironton-Federal body. This ore body pitches to the east, just as is later seen of the deposits associated with dikes. It is possible that when the workings of these mines penetrate deeper they will come in contact with a dike; one is known to come to the surface 300 or 400 feet west. As to the mines east of Sunday lake, it has already been noted that their character is quite exceptional, and they may for the present be excluded from this discussion.

From the eastern pitch of the dikes, with reference to the rocks of the iron formation, it is evident that they must, if they continue in their observed directions, come to the surface to the west of the workings of each of the mines in which they are found. As the present workings are, in most cases, but a few hundred feet deep, it follows that, when these pitches are high, the dikes would reach the surface but a short distance from the ore deposits. It thus becomes probable that there are as many dikes in the lower horizons of the Iron-bearing member as are seen in all of the different mines, while doubtless there are many more. In quite a number of mines, as, for instance, the Trimble (Pl. XXXI, Figs. 4 and 5), NE. ¼, Sec. 33, T. 46 N., R. 2 E., Wisconsin, there are at least three parallel dikes. In those cases in which there are several dikes in a single mine, one is generally known as the main dike. The smaller ones are, in some cases, clearly offshoots from the larger, the actual connections between them being traced; while in many other cases there is no certain connection between the different dikes in the same mine.

*Position of ore in reference to the dikes.*—The ore has been spoken of as resting upon the fragmental quartzite as a foot wall and in exceptional cases (the so-called "north veins") as resting upon a quartz rock which belongs to the iron formation, but which nevertheless forms a foot wall for the ore deposits dipping north with the formation. From the description of the position of the dikes and the quartzites, it is evident that the two rocks form V-shaped troughs, which have at their apices right angles, and the south arms of which are nearer vertical than the north arms, the first being upon an average 20° to 30° from a vertical, while the second is 20° to 30° from a horizontal position. The relation is that of a right-angled trough tilted toward the north until it lacks 20° to 30° from having its arms in horizontal and vertical positions. In one or two mines, for a short distance these troughs do not incline either east or west, but at most of them, from what has gone before, it is evident that they incline to the east. In one case, however, there is a westward inclination. *Now, the ore bodies lie in the apices of these roughly shaped troughs.* Each deposit of ore in following a trough will evidently be at different depths at different places east and west, the depth depending upon the nearness of the dikes to the surface. All ore deposits in the position described would reach the surface if the underlying dikes pitch to the east or to the west. As a matter of fact, many of them were found at the rock surface, but others were found after cutting an overlying rock. However, at present (October, 1888), the mining developments have traced to the surface all deposits which are large enough to warrant working, with two exceptions, and these exceptions are newly discovered bodies, which, in all probability, will be traced to the surface in the future. As would be expected, it is also true that the development of the deposits which were originally found at the surface has carried them, in every case in which they are of any magnitude, below the surface of the country rock. A practical result of this is that many mines which began as open pits, continued their workings as underground mines as developments went on. Both of these facts, the tracing of the deposits of ore discovered at depths to the surface and those discovered at surface beneath rock, are inevitable deductions from what has preceded as to the position of the ore with reference to the underlying foot-wall rock and dikes. It also follows from the above that an ore deposit upon one property will pass, sooner or later, upon an adjoining property; so that several deposits of ore, one above the other, each bottomed by dikes, will be found at a certain place among a row of mines, provided that the deposits continue to a sufficient depth.[1]

*Rock above the ore.*—The rocks which are found above the ore deposits are the ferruginous cherts, the rocks which have been spoken of as the characteristic ones near the base of the Iron-bearing member throughout the area in which the ores occur. The upper boundary of the deposits differs from the quartzite and dike boundaries in that the change from ore to the cherty rock is a gradual transition instead of an abrupt one. In passing upward through an ore deposit, as its border is reached, the ore becomes mixed with chert until so poor in iron as to become unsalable, although perhaps carrying 50 per cent or more of metallic iron. In passing still farther upwards, the amount of chert becomes greater, until a

[1] Already (July, 1890) the Ashland mine, at the west end of the property, has gone through the first basement dike and a considerable thickness of chert and ore and has struck another ore deposit presumably bottomed by a second dike. The first deposit has been developed quite to the east end of the property, so that the managers of the Norrie felt sure of finding the Ashland deposit by putting a shaft down through the basement dike of the deposit before known. This they have done with the anticipated success. The Aurora mine has at present fully developed the ore deposit lying on its basement dike; so that practically all of it may be said to be in sight. They must soon attempt to find the Norrie deposit. This will necessitate a shaft of very considerable depth, and will when tried be an interesting experiment as throwing light upon the depth to which large deposits may be depended upon with some certainty to extend. The Colby dike, of great size and at first overlain by a great deposit of ore, when followed to the east has been found to break up, with a consequent breaking up and diminution of value of the ore deposit.

The Mount Hope mine has been said to have a westward pitching dike; that of the Aurora is east; that of the Pabst between the two has little pitch. It is nearly certain that this is the same great dike which in the shape of a great half saucer holds the ore deposits of these three mines.

fractured chert and iron ore, known to the miners as mixed ore, is found. In passing up still further, this mixed ore grades into the ordinary ferruginous chert of the lower horizon of the iron formation.

To summarize, then, the boundaries of the ore deposits are to the south either fragmental quartzite or ferruginous quartz rocks in the ore formation, generally the former; under the ore, the dike rocks; and, above the ore, the typical ferruginous cherts of the district.

*Practical deductions to be applied in prospecting and mining.*—The first essential in wise prospecting in the Penokee district is to find the junction of the ore formation and the underlying fragmental quartzite.[1] Having determined the position of the foot-wall quartzite at several places, the next step should be to run a line of test pits east and west just north of the line between the ore formation and quartzite across the property to be explored. Other conditions being equally favorable, the west end of the property should be first examined, for the bodies of ore almost always pitch to the east, and a deposit found upon this part of the property will be likely to remain longer on the land to be explored. If the above preparatory work does not develop an ore body, but a dike rock is struck, the thickness of this dike, its inclination both to the south and to the east or west should be carefully determined. If its dip cannot be made out, assume that it is to the east of south. If, then, the dike is actually found to have or is taken to have an eastern pitch, very careful exploration should be made in the triangular area between the foot-wall quartzite and this dike to a distance of 200 or 300 feet east of the junction of the dike and quartzite and an increasing distance north in passing to the east. For if an ore body exists within a reasonable distance from the surface upon the property in question, this is the place, as shown by the actual position of previously worked deposits, at which it is most likely to be found.

The known existence of a dike just west of a property to be explored would be a second good reason for a thorough exploration upon the west side of the property, based upon the chances of finding an ore deposit which rests upon this dike and the quartzite, which, because of the

[1] The differences between these two classes of rocks have been given in detail, chapters IV and V. They are so unlike that a practical man who has examined the chert in which the ore occurs and the foot-wall quartzite at a few localities can readily distinguish between them at sight.

eastern pitch of the dike in question, may run east far enough to be found upon the adjoining property. A well defined dike thus located would warrant putting down a shaft through a considerable thickness of ferruginous chert, in order to strike an ore body which might be below; but in general a property ought to be well explored by test pits which do not go below the surface of the rock, unless there is a great thickness of drift above it. If heavy drift overlies the rock surface, it is best to make the most of a shaft once down to rock in exploring the area adjacent to it, either by drifts in the rock, or by means of the diamond drill. As a matter of course such explorations are much more expensive than in the cases in which the country rock is near the surface. Under no circumstances should money be expended in exploration south of the fragmental quartzite, or farther north than 400 or 500, or at the outside 600 feet north of it; and work done such distances north of the quartzite should only follow failure to find an ore deposit resting upon the fragmental quartzite.

The large number of the working shafts upon the Penokee-Gogebic range rest upon the foot-wall quartzite, dipping north at its angle. When a shaft thus sunk comes in contact with the underlying dike of the ore body, it is useless to go farther for the purpose of working the deposits under consideration, unless the pitching ore body is to be reached at lower levels by means of long drifts. It is of course the part of wisdom to carry a shaft through the dike a short distance into the underlying rock in order to be sure that it has struck a basal dike. It might be the case that, if the shaft were carried deep enough, it would strike another deposit of ore resting upon another dike, and this would be especially probable if an ore deposit has already been developed within a short distance to the west.[1] It is a good maxim among mining men in exploring work to follow a deposit already found rather than look for others at greater depth. After the deposit thus found has been developed it is advisable to look ahead for

[1] Since the above was written, shafts put down through the first basement dike have, in some cases, struck the ore deposit of an underlying dike after passing through a considerable thickness of ferruginous chert. The most notable instance of this is the discovery of the Ashland ore body by the Norrie mine, which lies to the east. Here, after the base of the original Norrie deposit was reached, 200 or 300 feet of chert was passed before the eastward-pitching Ashland body was found.

future supplies of ore. From the shafts which stop at underlying dikes it is possible to take out all the ore to the west and the ore to the east which lies upon a higher level. That at lower levels to the east can be gotten out by carrying the shaft to a greater depth, and drifting east until the deposit is again found, or by putting in other shafts farther eastward. If the eastern pitch of the dike (and therefore of the deposit) is high enough, the first method is the more economical for a certain distance; but with the low eastern pitch which generally prevails, the second one has in practice usually been followed. Each successive shaft to the east must pass to a greater depth through barren rock before it strikes the ore body; and if the developments of the future show that these ore bodies are of great depth, a deposit will often be found to extend upon the land of an adjoining mining company, as has been shown to be the case with some deposits at the present time. From the shafts thus resting upon the foot wall, drifts are ordinarily run along it east and west at each of the levels, and from these main drifts crosscuts are run north. The drifts running west are continued until the underlying dike is penetrated. Upon passing through this dike, if it is a basal one, the mixed ore or ferruginous chert is found. The drifts running east continue in ore, alternating often with the lean phases and horses of rock, until, on account of the eastern pitch of the ore deposits following the dikes, it reaches the top of them, when it runs gradually into poor ore, mixed ore, and finally ferruginous chert. In general, the horizontal crosscuts to the north are continued until the dikes are reached. Beyond the dikes is found ferruginous chert or the regularly banded red ferruginous slates. Clean ore is not usually continuous in all these directions in any one mine for the distance above indicated, nor are the rocks found at these outer extremities always such as are named above, but the boundaries of the ore deposits are thus defined, at least in a general way.

It is a question whether the present developments have not gone far enough to warrant a radical change in the manner of mining iron ore deposits in the Penokee district. All over the lake Superior country such bodies are well known to be extremely irregular. The deposits of the Penokee range give promise, however, of greater regularity than has been found in other districts. If they could be depended on to continue downward for some distance with the relations which they certainly have in their higher levels, and the dikes are found to have tolerable regularity of dips, inclined shafts, as suggested by Mr. J. Parke Channing, could be sunk in the lower slates close to the quartzite, with crosscuts through the quartzite into the ore.

What has been said in reference to the relations of the ore bodies to the dikes, foot-wall quartzites, adjacent lean material, and methods of mining can be better understood by an examination of Pls. XXX and XXXI.

*Nature of the rocks of the Iron-bearing member adjacent to the ore bodies.*—Before considering the probable origin of the ores, it will be necessary to recall the character of the rocks of the ore-bearing formation adjacent to the ore as compared with the rock in the parts in which ore has not been found, and also the kinds of rocks which occupy the upper horizons of the formation through the area in which paying mines occur.

From the general description of the iron formation, p. 198, and from the tabulations, pp. 215–220, it will be seen that the rocks west of Tylers fork are actinolitic slates. The magnetite and actinolite are important in quantity and the silica is always completely crystallized. Also the rocks east of the Sunday lake mines and west of the Presque Isle river are of the same character, except that the quartz is not always wholly crystallized. The Iron-bearing member east of the Presque Isle is treated in another place. Also these actinolitic slates in the east and west end of the Iron-bearing member constitute, so far as known, the whole mass of the ore formation. The part of the iron formation which bears the ore deposits contains throughout most of its extent no actinolite and magnetite. Its eastern and western extremities do contain a little of these two minerals through the few miles in which they grade into barren actinolitic slates farther east and west. Another strong contrast between the part of the iron formation carrying the ore bodies and the barren portions is found in making a cross section of the member. The nature of the rocks in which the ore deposits actually occur has already been mentioned. Above these ferruginous cherts, which bear bands and shots of ore and which often grade into ore, are in most cases regularly banded red ferruginous slates. These slates have been already described, and here it is only necessary to remember that they are composed of chert and iron peroxide; that they are as regularly bedded as the unaltered carbonates, and that they readily cleave along the bedding. Above these slates for a long distance, and particularly well exposed in T. 47 N., R. 46 W., Michigan, constituting the upper horizon of the ore formation, are partly or wholly unaltered cherty iron carbonates. While the above section is known to occur at several of the more important mines, it can not certainly be said to be common to all of them. Also the respective thicknesses of the ill-defined belts are very different at different mines. A general statement may be made that at most of the mines a cross section of the iron formation shows the proportion of unaltered iron carbonates to increase in passing from lower to higher horizons and appears to be greatest in quantity at the uppermost horizon. It is true, however, that almost solid carbonate occurs in three places at a relatively low horizon, although none of them are known to be at the base of the member, while one is certainly underlain by a ferruginous chert. Also at several localities a completely altered and brecciated chert is found at very high horizons.

*The character of the ore.*—The iron ore of the Penokee-Gogebic range is a soft red somewhat hydrated hematite. By chemical analyses it is shown to be more or less manganiferous. Much of it is so friable that it can be broken down with a common pick, although as taken from the mines a large portion of it is compact enough to hold together in tolerably large lumps. These lumps are porous, often more or less nodular, and often also roughly stratiform. The strata conform in a general way to the strike and dip of the formation. Mingled with this soft hematite in a few mines is a small quantity of aphanitic hard steel-blue hematite, which breaks with conchoidal fracture and is of remarkable purity. In general this exceptionally hard material is found in contact with or close to the diorite dikes of the mines. The following analyses and facts as to composition are mainly taken from a report by Mr. John Birkinbine:[1]

[1] John Birkinbine. The iron ores east of the Mississippi river. Mineral Resources of the United States, 1886, pp. 67–7?

*Analyses of Gogebic iron ores.*

[The analyses from the Colby are averages. The analysis from the Ashland is the average of 48 cargoes.]

| | Colby. | | Mount Hope, formerly Iron King. | | Norrie. | Aurora. | Ashland |
|---|---|---|---|---|---|---|---|
| | North. | South. | North. | South. | | | |
| Iron | 61·00 | 59·30 | 60·85 | 55·74 | 62·83 | 62·93 | 64·50 |
| Manganese | 2·60 | 4·00 | 1·30 | 12·28 | (*) | (*) | (*) |
| Alumina | 1·75 | 1·68 | (*) | (*) | (*) | (*) | (*) |
| Lime | ·11 | ·10 | (*) | (*) | (*) | (*) | (*) |
| Magnesia | ·23 | ·25 | (*) | (*) | (*) | (*) | (*) |
| Silica | 4·50 | 2·50 | 5·44 | 3·47 | 5·18 | 3·65 | 3·65 |
| Phosphorus | ·049 | ·049 | ·027 | ·034 | ·0474 | ·0278 | ·047 |
| Sulphur | ·07 | ·06 | (*) | (*) | (*) | (*) | (*) |

[a] Undetermined.

The south deposits carry upon an average more manganese than the north deposits. The content of manganese in the south Mount Hope is much greater than the average for the district, although some quantity of ore has been taken from the Colby which runs above 30 per cent in metallic manganese. In the mine itself streaks varying from a mere film to those a number of inches in width, composed of almost pure pyrolusite, may be seen intersecting the main mass of the iron ore. "Alumina is found in most of the ores, the amount varying from 0·5 to 5 per cent. The sulphur varies from 0·03 to 0·13 per cent. Water to the extent of 5 per cent exists in the hard ores, and to a greater amount in the softer varieties." It appears that a portion of this water is combined; that is, that the hematites are somewhat hydrated.

The original condition of the rocks of the ore formation, the series of alterations by which they have become changed to a ferruginous chert and to other varieties of rock in the formation, have been fully considered. In several localities the exact facts observed as to these alterations have been recorded. We then have before us the character of the iron ores, the shape of the deposits, their relations to the rocks immediately about them, the nature of the rocks of the iron formation above the ore horizon, and the character of the rocks above and below the iron formation. An attempt will now be made to apply these facts to the changes which have occurred to the particular area of the iron formation in which the ore occurs, and to suggest an explanation of the character and location of the ore bodies.

The shape of the deposits and their relations to the strata of the iron formation, are such as to exclude the idea of original sedimentation in place; neither can they be considered as the result of the oxidation of iron carbonate in place alone. All of the unaltered siderite now found contains a much larger quantity of silica than the ores, so much so as to make these carbonates themselves entirely valueless. Also the red banded slates rather than the ores described (pp. 202–205) give every evidence of being a material which has resulted from the oxidation of such carbonate in place. Further, the large amount of manganese which the ores (especially the south deposits) occasionally contain is much greater than the amount contained in any carbonate from which analyses have been made, and the average content of manganese in the ore is much greater than the average of the carbonates.

While it is thus certain that the ores are not carbonates of iron which have altered in place alone, it is almost as certainly true that the siderite of the belt has been the source whence the iron oxides for these ores have been derived. This statement is based upon the facts furnished by the detailed description of the rocks of the iron formation as a whole and those developed by the discussion which has preceded. That manganese is always present in the iron carbonates, frequently in some quantity, and is yet more abundantly found in the ores, is an additional strong indication that the iron carbonate has been the source whence the ore deposits derived their iron oxide.

Since, then, the iron ores can not be explained by oxidation of carbonates alone in place, and since the carbonate was the source whence they were derived, they are necessarily concentrations of iron oxide, combined perhaps with iron oxide furnished by oxidation of carbonate in place. If this explanation is adopted, however, it is necessary to explain not only the presence of the iron oxide in its peculiar position, but the nature of the whole lower part of the iron-bearing formation. The explanation must account for the great increase in the amount of silica in the lower horizon of the ore formation as compared with the original cherty carbonate; for its almost total absence in the ore; for the concentration of the iron oxide; for the almost complete absence of carbonate at the lower horizons; for the red banded slates and carbonates in the middle horizons; and for the relatively much more abundant unaltered carbonate in the upper horizons.

*A particular occurrence of iron ore.*—Before attempting to give a general explanation of these facts it will first be well to again refer to an occurrence of narrow belts of iron ore upon the bank of Sunday lake outlet, in Sec. 13, T. 47 N., R. 46 W., Michigan. Here the actual transformation from lean cherty iron carbonate to ore is seen in all its phases. In clefts and joints and in partings along the bedding of the exposure are narrow seams of hematite. In passing from the seams the hematite becomes mingled with some chert. This chert increases in quantity until the cherty groundmass contains many rhombohedra of iron oxide. Proceeding farther away from the ore, the iron oxide gradually changes to siderite, the transition from one to the other being quite gradual. The siderite is in perfect rhombohedra, and it is evident in thin section that the iron oxide adjacent is pseudomorphous after it, and now the rock is a sideritic chert; it is of a light gray color, aphanitic texture, and breaks with conchoidal fracture. This rock is manifestly in its original condition at this place. The processes by which the seams of iron oxide now occupy the space once taken by this sideritic chert are plain. The iron carbonate has decomposed in place to iron oxide, the rock becoming a hematitic chert. Along the seams waters bearing iron in solution have passed. These waters have particle by particle dissolved out the chert and replaced it with iron oxide, and where once was lean sideritic rock is rich ore. A portion of the iron oxide is due to the oxidation in place of the iron carbonate, but the larger portion has come from a greater or less distance there to be deposited. These seams of iron oxide at this place are but a few inches in thickness, but it is possible that the process of alteration which has here taken place upon a small scale may upon a large scale explain the concentration of workable ore deposits.

*Chemistry of the process of concentration.*—So far as the iron oxide has formed from iron carbonate in place the process is simply one of oxidation, and it is only necessary to suppose that percolating waters have carried sufficient oxygen in solution to accomplish this work. In the removal of iron as iron carbonate from one place and its deposition as oxide in another place the process was doubtless as follows: Waters having in solution carbon dioxide dissolved the iron carbonate. This carbon dioxide may have been furnished by the oxidation of other iron carbonate, which would relieve the percolating water of oxygen at the same time that it became capable of taking iron carbonate into solution. Such water holding iron carbonate would retain it until some more or less open cleft or passage was reached, by means of which the carbon dioxide could escape, and perhaps oxygen reach these solutions dissolved in other waters, and thus precipitate the iron oxide. The only other chemical change necessary to explain this concentration of ore is that of the solution of the silica, which in part probably occupied the place now taken by the ore. It is now well established that great quantities of silica are carried in solution and deposited in rocks. The large amount of water which has traversed these passages has been able to take the silica into solution at the same time that it oxidized the iron carbonate coming in by lateral secretion, and thus simultaneously precipitated iron oxide and removed silica. There is every reason to believe that these are the chemical changes which have formed the narrow rich seams of ore described. It is most probable that these chemical changes, taking place upon a large scale, have produced the large workable deposits.

*Time at which concentration of the main ore bodies occurred.*—It has been stated that the iron belt rocks are much less altered as a whole in the higher horizons. In passing downwards, it will be remembered that an increasing proportion of the rock varies from its original condition, and at the lowest horizons there is nowhere known any unaltered carbonate. It follows as a deduction from this succession that the series of changes which have so completely altered the lower part of the formation have taken place subsequent to the uplifting of the series. The alterations can only be explained by the action of percolating waters bearing oxygen, and which therefore came from above. If the layers were horizontal when the changes occurred, the waters passing downward would have altered most that part of the formation nearest the surface. The reverse would be the case if the alteration was subsequent to the tilting, for the upper layers of the iron member would partially escape the action of percolating waters, as will be readily seen by glancing at any of the sections across the series in that part of the range under discussion (e. g., Pls. VI, VIII and X;) and considering the nature of the belt of rock above the ore formation. It is a member composed of black and gray clay slates, graywackes, and graywacke-slates; all of which contain a large amount of clay and are practically impervious to water. So strongly clayey is this formation, that a rock underlying any great thickness of it could not be much affected by waters from above. An independent proof of the impenetrable character of this rock is the freshness of the contained greenstones, which, as explained in chapter VII are almost or wholly decomposed in the lower parts of the iron formation. However, when the series had been uplifted and eroded, this upper impervious member would have been removed, and the waters would come directly in contact with the lower horizons of the ore formation, while the upper horizons of the belt would still be somewhat protected.

Before going further it is necessary to consider the porosity of the rocks which underlie the ore formation. This member has been fully described (chap. IV). It consists mainly of a layer of feldspathic quartz-slates. These are interstratified with clay slates, consequently the rocks of this formation are almost impenetrable to percolating waters. Above the feldspathic quartz-slates, and therefore between them and the ore, is a layer, a few feet in thickness, of coarse fragmental quartzite—a rock which was once a sandstone. Before the induration of this sandstone, percolating waters may have penetrated it, but they would have been stopped in their downward passage by the underlying slates. After its change to a quartzite it was itself a barrier to the passage of percolating waters. It is, however, not so perfect a check as the underlying slates, because of the fracturing to which it has been subjected. The joints, so characteristic of a brittle quartzite, do not affect the underlying slates, for these thinly laminated clay rocks are flexible, and under the slight bowing which they have received are almost or quite as impervious to water as when in their horizontal position.

*Process of concentration.*—An attempt will now be made to trace the passage of percolating waters through the inclined layers of the iron formation. Pl. XXXI, Fig. 7, is a section showing the condition of this member at the present time at the surface and illustrating how this state of affairs was reached. The strata of the formation are now exposed by their dipping at a high angle (65°) to the north. The whole Penokee series of which the iron formation is a part is exposed in the same fashion. Therefore thousands of feet of the iron member have certainly been carried away by erosion. The figure assumes that about 2,000 feet have been eroded from this member since it was upturned. However, it would make no difference with the argument if this erosion occurred during the time of the uplifting. The upper part of the figure represents the surface of the iron formation and a part of the underlying and overlying rocks at some past time. Near the bottom of the figure is the present land surface, showing the succession of rocks from north to south which are now actually found. A transition from unaltered cherty carbonates to completely decomposed carbonate is noted. This section is not definitely known to occur at every mine, but it well represents the usual occurrence in that part of the formation which has been productive in iron ore; that is, the presence of more unaltered carbonate at high horizons than elsewhere and in low horizons little or no unaltered carbonate. At the time when the upper supposed land surface was an actual one the present surface would be but little exposed to the action of percolating water. Water could not pass through the slates which overlie the iron formation, neither could it get in through the underlying feldspathic quartz-slates. Therefore most of the water which at that time was able to reach the present land surface must have done so by passing down along and through the layers of the iron formation itself. The dotted broken line represents a perpendicular course which the water would follow were its passage not deflected by the laminæ of the rocks, but this water would have a tendency to follow the bedding, so that, entering the iron formation at its uppermost layer, it would follow the somewhat irregular course marked as the probable line of percolation, and would reach the footwall quartzite at the present surface of the country. It is immaterial to the argument whether this line ought to vary farther from a perpendicular than marked or not, for in any case nearly the whole of the present surface of the iron formation would escape the percolating waters, or, if not this surface, some other yet lower down. It is, however, probable that the lower horizons of the formation would not thus escape until a great depth was reached, for the waters entering the formation would steadily work their way to a greater and greater depth along the foot-wall quartzite until such depths were attained as to prevent its farther penetration.

Now, suppose erosion to gradually sweep away the rocks which are between the old surface of the country and the present surface. Beginning at the base, the rocks of the formation at the present surface would be more and more exposed to the action of percolating waters. These waters would in turn affect the middle and finally the higher layers of the formation until its whole width was subject to the agencies of alteration. There is, then, a gradual increase in the time that percolating waters have acted upon the various horizons of the formation in passing from south to north. The difference in time to which the highest and lowest layers have been subjected to such action is at least the length of time that it has taken erosion to remove the thickness of rock between the old surface of the country and its present surface. Therefore the slower we believe the erosion to have been the greater the difference in time.

Next, suppose that erosion has continued until the surface of the land is at some intermediate point. In tracing the percolating waters in their passage through the formation it is necessary to take into account the deflection to which they would be subject caused by its layers, by the impenetrable character of the underlying slates, and by intersecting dikes. The relative positions of the ore bodies, quartzites, and dikes have already been given. The water which fell upon the layers of the iron formation near its base would readily pass through the rock; it being here already much altered and broken by the long action of water. However, in the most broken cherts there is evidence in the somewhat irregular bands of ore that the path of percolating waters has been influenced by the stratiform character of the formation. Passing through these ferruginous cherts, the water would quickly reach a dike or the fragmental quartzite, and would follow this barrier, deflected to the north if upon the quartzite and to the south if upon a dike, until it reached a trough made by the dike and quartzite, along which it would travel toward the east as it penetrated deeper. Such water would be likely to contain oxygen in solution, and would be capable, if it contained alkalies—which might readily be obtained from the alteration of the basic dikes—of taking up a small amount of silica. Other water falling upon higher layers of the formation would make its way slowly and with difficulty through these less altered parts, and would oxidize iron carbonate until all oxygen had been extracted from it. This oxidation of a part of the iron carbonate would liberate carbon dioxide, which would be taken into solution and added to the carbon dioxide which the water already contained.[1] Such water would take into solution unaltered iron carbonate. It would also, in its upper course, take up what silica it was able to carry. As it penetrated farther and took more carbon dioxide into solution, and consequently also more iron carbonate, it would be less able to carry silica, and would deposit that material as chert in the lower horizons. This water, thus traveling on with an increasing amount of iron carbonate, would finally reach a dike and be deflected toward the foot-wall quartzite. This dike it would follow until the apex of the trough was reached. Here it would mingle with a larger amount of water more directly from the surface, bearing oxygen, and therefore capable of oxidizing the iron carbonate. The iron would then be precipitated in the apex of the trough as more or less hydrated sesquioxide of iron.

Upon the other hand, the silica would here be dissolved, for the carbon dioxide solution containing iron carbonate would be greatly diluted by the large amount of water which bore the precipitating agent for the iron, and the resultant abundant dilute solution of carbon dioxide, bearing perhaps alkalies with it, would be capable of taking up silica, which was either originally present or had been subsequently deposited in the apex of the trough. Such solutions may have furnished the silica which has enlarged the particles of quartz in the foot wall and thus indurated it.[2] The result of this leaching would be to steadily add iron oxide to and to remove the

[1] In this discussion carbonated water is taken as the agent of solution. It is likely enough that organic acids have helped to take the iron carbonate in solution and bear it to the points of precipitation.

[2] The chemistry of the process thus outlined assumes the following: That the oxygen of percolating waters is sufficient to oxidize iron carbonate not in solution and set carbon dioxide free; that the resultant carbonated waters are sufficient to take iron carbonate in solution; that if such waters bearing dissolved carbonates are mingled with other waters bearing oxygen, the iron carbonate or a portion of it will be precipitated; that silica may be carried in percolating waters; that carbon

silica from the apices of the troughs formed by the quartzite and dikes, and thus to form ore bodies. At the same time the other parts of the formation would be steadily impoverished in iron content. Much of that which remained disseminated through the formation would have been changed from carbonate to oxide. The silica which was taken into solution in the upper part of the water's course would be precipitated in its lower part.

The processes thus outlined would penetrate to deeper parts of the formation as erosion steadily advanced until the present surface of the country is reached, where, as shown upon the diagram, the ore bodies thus formed at depth are now found at surface. It follows that a large amount of the iron found in the ore bodies was originally in the rock which has been removed by erosion. So far as the deposits are at the surface, all of the iron oxide except that which came from the oxidation of iron carbonate in place must have been from such a source, while it is probable that a large part of the deposits located at considerable depth have been stored from rock which has been broken down and scattered far and wide. It is a further consequence that it is of no moment whether the amount of iron in the original 800 feet of thickness of the formation was sufficient, if concentrated at its base, to make up the large deposits. These are not so much concentrations of iron oxide which were originally deposited as a carbonate above them, as from the layers which stretched to the southward, but which were subsequently by upturning placed over the ore bodies. Also, the large proportion of silica now found near the surface, and particularly in the southern half of the belt, is probably much greater than was here origi-

dioxide is sufficient to precipitate silica from such solutions; and that a carbon dioxide solution strong enough to precipitate silica by dilution may be made so weak in carbon dioxide that it would be capable of taking silica into solution. All of these facts and principles of chemistry are so well known that no discussion or reference to authorities is needed. However, the following statement of Roscoe and Schorlemmer, vol. I, p. 569, is of interest as bearing upon the solubility of silica and the temperature at which it crystallizes: "In all three conditions silica is insoluble in water. . . . Silica, however, is easily soluble in all alkalies, even in ammonia, and the more easily, the finer its state of division. The amorphous variety, especially if it contains water, also dissolves in alkaline carbonates. . . . When an alkaline solution of silica is heated in a sealed tube the glass is attacked and an acid silicate is formed from which silica separates out on cooling. If the temperature at which the deposition occurs be above 180°, the silica separates out as quartz; if below this point, it crystallizes out as tridymite, whilst at the ordinary temperature of the air it separates in the form of a hydrated amorphous mass."

nally present. As erosion steadily carried away the upturned edge of the ore formation, percolating waters took in solution a part of the silica which it contained, penetrated the deeper parts of the ore formation, and from it silica was precipitated, as explained above, by the ore-forming process. The highly cherty rocks associated with the ores may then represent a concentration from many hundreds or even thousands of feet of rock which has been swept away, just as the ore bodies are concentrations from the iron carbonates which these same rocks contained. A portion of this silica may have come from the alteration of dikes contained in this removed material, but doubtless much of it came from the original cherty carbonate.

*Exceptional localities.*—At three places iron carbonate is found near the base of the formation: Sec. 6, T. 45 N., R. 2 W., Wisconsin, Sec. 13, T. 47 R. N., 46 W., Michigan, and Sec. 18, T. 47 N., R. 45 W., Michigan. At the first of these localities the rock contains a considerable quantity of clayey material. At the second and third, the rocks are exceedingly dense, finely laminated, and bear contortions, as shown in the exposures, without breaking the stratification. In all of these places, then, the original cherty iron carbonate had exceptional characteristics, which prevented ready penetration by water. The presence of an altered carbonate at these low horizons is, however, interesting on two accounts. In the first place, it greatly increases the probability that the whole base of the formation, which now contains so little carbonate, was once a cherty iron carbonate; secondly, one of these exposures shows how completely the presence of a little clay in a rock may prevent the action of percolating waters, even when the remainder of the belt is completely altered by such agencies.

The only other exception to the facts as assumed in the above discussion are the occurrences of iron ore at a higher horizon than the foot-wall quartzite and the ore bodies east of Sunday lake, which so far as present developments go are not known to be associated with dike rocks. It has been said that those ore bodies in the main part of the range which are north of the fragmental quartzite have a well defined cherty quartz foot-wall of a regular character. In these cases this quartz rock has served as the plane which checked the waters on their downward passage before they reached the fragmental foot wall which constitutes the basement of the iron formation. Here the relations of the ore to the dikes and all other of its characters are the same as when the ore is found upon the fragmental quartzite. It is of interest here to note, that in one of the largest mines of the district, the Colby, as shown by Pl. XXXI, Fig. 3, the north and south deposits have as their basement the same great dike, the two ore bodies being separated at the top merely by a gigantic horse of rock, which served as the impervious layer to form the foot wall of the north deposit. The explanation given of the origin of the ore found upon the fragmental quartzites applies perfectly to these north deposits with the modifications above indicated. That there are layers of the iron formation which are not readily pervious, and therefore become basements along which the down-flowing waters passed, is not at all strange. It would be stranger if, in a thickness of water-deposited sediments of 800 feet, there were no layers which, at least for a short distance, were effectual barriers to the passage of percolating waters. The chemistry of the process of concentration of the ore deposits east of Sunday lake is, in all probability, like that of the typical deposits of the range. Their concentration is apparently, however, more nearly analogous to the narrow seams of ore described in the early part of this section than to the typical deposits. The formation here apparently being cut by no impervious dikes, the waters have not been carried over to the quartzite, thus forming main channels of percolation, but the comparatively small ore bodies have developed here and there as favorable conditions for concentration occurred.[1]

The above explanation of the origin of the ore deposits accords well with the facts of their occurrence, and also with the idea that the iron formation was originally an impure cherty carbonate of iron. It explains perfectly the peculiar position of the ore bodies with reference to the dikes and the foot-wall quartzite; it explains their presence in a similar position in the few instances in which the deposits are north of the fragmental quartzite; it explains the flat wedge-shaped character of the ore deposit; it explains the nature of the ore—a soft somewhat hydrated hematite, bearing

[1] As bearing upon the truthfulness of the above theory as a whole, it is an interesting fact that the practical miners, in prospecting, eagerly follow underground water channels, hoping that they will lead to ore deposits.

more or less of manganese; it explains the excess of manganese which the ore carries beyond the amount found in the unaltered carbonates and its relatively greater abundance in the south deposits; it explains the presence of large quantities of unaltered carbonates in the upper horizons of the iron formation, the gradual lessening of this carbonate in passing to lower horizons, and its absence at the base of the formation; it explains the large percentage of silica contained in the greater part of the lower horizons and the low percentage at the apices of the troughs.

The exceptions of carbonate near the base of the formation, the occurrence of ore deposits at horizons above the foot-wall quartzites, and the unusual deposits east of Sunday lake, are all due to exceptional characters at these places. These exceptions, with the ready explanations, are thus rather in favor of than against the general idea of the concentration of the ores.

*Probable extent in depth of ore bodies.*—This explanation of the origin of the ores may throw some light upon the depth to which the ore bodies extend. The fact that all of them have been traced to the erosion surface is favorable, rather than otherwise, to their extending to a considerable depth. The ore bodies at the depth now penetrated must have formed almost wholly before the sweeping away of the rocks of the iron formation above them. They could, then, have received but little of the iron they contain since the end of the glacial epoch, for erosion was then terminated by the mantle of drift dropped over the district. The deposits may be said, with some degree of probability, to continue to a depth at which the agencies of concentration could effectively work. In estimating the depth it must be remembered, in the part of the range in which the ore deposits are close together and parallel dikes consequently not far apart, that the deeper dikes will be screened in part from percolating water by overlying dikes. When the dikes are very deep an overlying dike may penetrate the upper slate to the north before reaching the surface in this direction, and the lower dike can receive iron ore, if it holds any at all, only by the creeping down of the surface waters from the area between the outcrops of the two dikes. Whether the depth of the ore bodies will be found to be measured in hundreds or thousands of feet the data at present are too scant to indicate. I am inclined to believe, however, that they may be depended upon to continue for a considerable depth. While they may extend in unimpaired richness and magnitude to a depth as great as can be penetrated by workings, it is certain that they do not continue to an indefinite distance. There is also a possibility that the deposits may become somewhat poorer comparatively near the surface; for it may be that percolating waters, since the termination of the glacial epoch, have been able to remove from the upper parts of the deposits a small percentage of silica. Such a removal, even to the extent of 5 per cent or less, would have an important influence upon the value of the deposits.[1]

*Emmons on ore deposits.*—In this connection it is of interest to compare the conclusions reached with those of Emmons[2] as to the origin of the silver-lead deposits of Leadville, Colorado. He finds that the ore deposits there did not form in preëxisting cavities, but by a gradual replacement of the rock materials by substances brought in solutions, and also that these solutions did not come up from below, but have reached their immediate locus by passing downward through the rocks above. In his discussion upon ore deposits in general he maintains that a like origin is much more common than has been believed. It will be seen that our own conclusions as to the origin of the iron-ore deposits of the Penokee-Gogebic series, arrived at independently of the publication of Mr. Emmons's monograph, are in exact harmony with his general conclusions.

*Iron ores in other parts of lake Superior country.*—Before closing this chapter some allusion must be made to the nature and origin of the iron ores which are found in other districts of the lake Superior country. Large deposits of ore are found in rocks remarkably like those of the Penokee-Gogebic series in the Vermilion lake, Marquette, and Menominee districts. Recent investigations of these districts have shown that the pitching ore

[1] Since the above was written development has extended in the larger mines to a depth of several hundred feet, and as yet there is no appreciable diminution in the size or richness of the ore deposits.

[2] Emmons, Samuel Franklin: Monograph U. S. Geol. Survey, 1886, pp. 375–379, vol. XII, Geology and Mining Industry of Leadville. Also Structural Relations of Ore Deposits; Trans. Am. Inst. Min. Eng., vol. XVI, 1888, pp. 804–839.

bodies, like those of the Gogebic district, are secondary concentrations produced from carbonates by downward flowing waters and resting upon impervious formations.[1] These impervious formations, known as soapstones, are frequently altered basic eruptives, but in certain places they are clearly sheared clayey phases of sedimentary rocks. It is an interesting illustration of the uniformity of nature's processes that later investigations have shown that the iron-ore bodies in the other districts of the lake Superior country have an origin like those of the Penokee-Gogebic series.

*Summary of more important conclusions.*—The Iron-bearing member is separated from the Quartz-slate member below it and the Upper slate member above it because it is nonfragmental, while they are fragmental sediments.

It consists of three main types of rock: (1) cherty iron carbonate; (2) ferruginous slates and cherts, and (3) actinolitic and magnetitic slates.

The cherty iron carbonates represent the original condition of the whole member, the other types having reached their present condition by a series of subsequent alterations.

In the change of cherty iron carbonate to ferruginous slates and cherts the siderite has been oxidized, and to some extent taken into solution and redeposited in other places. The silica originally present has been rearranged, and in many places additional silica has entered.

In the alteration of the cherty iron carbonate to actinolitic slates the oxidation of the protoxide of iron in the carbonate has not been complete, and thus magnetite has been formed. At the time of the rearrangement and introduction of silica a portion of it has united with the bases present and has formed actinolite.

The iron ores are found in the lower horizons of the Iron-bearing member, most of the deposits resting upon the upper quartzite of the quartz-slate formation. Those deposits which are not at the base of the member have also somewhat regular foot walls, which dip to the north like the quartzite

[1] Van Hise, C. R.: The Iron Ores of the Marquette District of Michigan; Am. Jour. Sci., 3d series, vol. 43, 1892, pp. 116–132. Also The Iron Ores of the Lake Superior Region; Wis. Acad. Sci., Arts, and Letters, vol. 8, pp. 219–228.

at an angle of 60° or 70°, consisting of the ferruginous chert of the Iron member itself. These foot walls form the southern boundary of the ore bodies.

The formations are cut at right angles by a series of dikes, which are in such a position that the same dike is generally at a greater depth as it is followed eastward, i. e., pitches to the east.

The ore bodies rest in the right-angled troughs formed by the junction of the dike rocks and foot walls.

The iron carbonate is the source of the ore deposits.

The ores have not been chiefly produced by the oxidation of the carbonate in place, but by concentration from the lean carbonates of the formation.

The concentration has taken place during or subsequent to the uplifting of the series.

Percolating water was the active agent of concentration. It has taken the carbonate into solution, and in its passage downward has been deflected into the troughs by the impervious quartz-slate formation and the dikes.

In the apices of these troughs other waters more directly from the surface, bearing oxygen, have precipitated the iron as an oxide.

# CHAPTER VI.

By C. R. Van Hise.

## THE UPPER SLATE MEMBER.



### SECTION I.—DETAILS.

*Name and basis of separation.*—All the rocks of the Penokee series above the Iron-bearing member are placed together, although their thickness is for a distance of many miles several times as great as the three lower formations of the series combined. Lithologically the great mass of the rocks are slates. Frequently the slate becomes somewhat massive and occasionally becomes a quartzite; also in certain localities it becomes quite schistose; but all these phases may be said to be exceptional. It is not meant to imply by the term "slate" that any of the rocks have a slaty cleavage. The direction of the easiest parting and bedding always correspond, and none of the rocks possess the uniformity of composition and parting requisite for roofing slates. The formation is given the name "Upper slate member," which at once shows its stratigraphical position and lithological character, and distinguishes it from the Quartz-slate member, which is below the Iron-bearing member.

This Upper slate is a belt of fragmental rocks, or rocks which were originally fragmental. It has the same basis for separation from the sediments of the Iron-bearing member that the fragmental Quartz-slate below it has. In general the fragmental character of the thin sections of these rocks is recognizable at a glance, although, as will be seen later, certain portions of the belt have by subsequent alterations taken a crystalline character. These rocks both in hand specimen and thin section are separated with certainty and ease from those of the underlying Iron-bearing member; for they are fundamentally unlike in texture and mineral content.

*Transition from Iron-bearing to the Upper slate member.*—The change from the Quartz-slate to the Iron-bearing member has been shown to be abrupt, taking place usually without any transition belt. In the few localities in which the transition from the Iron-bearing to the Upper slate member is exposed the change is quite gradual. Beginning at the west, the first known exposure of this sort is in the extreme southern part of the SW. ¼ of Sec. 11, T. 44 N., R. 3 W., Wisconsin. Here, at the foot of the northern slope of a large bluff belonging to the iron-bearing formation, is found a rock (described later) which in its characteristics is intermediate between the black slates found in the upper belt at this locality and the biotitic actinolite-slates of the Iron-bearing member. Its location in either formation is somewhat arbitrary, but it is placed in the tabulations of the Upper slate member. In the west part of Sec. 6, T. 45 N., R. 2 E., Wisconsin, and near by, exposures in the Iron-bearing and in the Upper slate members are found quite close to each other. That in the latter is a transition rock, as it contains iron oxide as a chief constituent, a large part of which is magnetite, although it is nearer the slates than the iron-belt rocks. At the Black river, in the southern part of Sec. 12, T. 47 N., R. 46 W., Michigan, there is a continuous exposure of 200 feet of rock at the horizon in which the change from the Iron-bearing to the Upper slate member occurs. Here is a transition, and the location of the line between the two belts is more or less arbitrary. Just south of this line, although the specimens contain fragmental material in considerable quantity, the nonfragmental material is preponderant; and at the southern end of the exposure, 150 feet south of this line, the fragmental material is still tolerably abundant. North of the line separating the formations the exposure is strongly clayey, and contains a preponderating amount of fragmental material. The exposure does not continue far enough northward for the rock to become completely fragmental. It thus appears that the passage from the nonfragmental iron-bearing rocks to the fragmental rocks of the upper slates is not complete in a surface distance of 200 feet, which, at a dip of 57°, which here prevails, corresponds to a thickness of rock of about 170 feet. This is the only locality in which the actual change from one belt to the other is so well exposed. It is of course possible that in other localities the change is more abrupt, although, as will be seen, the nature of the rocks at the base of the upper slate belts are such as to render it probable that the change is often a transition.

*Geographical distribution.*—The westernmost exposure found in the upper slates is near the center of Sec. 18, T. 44 N., R. 3 W., Wisconsin, while the easternmost exposure is at Black river, Michigan, Sec. 12, T. 47 N., R. 46 W. Probably the rocks of the member extend somewhat beyond these points before being cut off by the Keweenaw rocks. At the western extremity of the belt the rocks on the map are carried to near the north and south quarter line of Sec. 14, T. 44 N., R. 4 W., Wisconsin. Whether they extend beyond this point is not known. At the east end of the belt the Keweenaw rocks upon the map are represented as cutting off the upper-belt rocks about $1\frac{1}{4}$ miles east of Black river, near the east line of Sec. 7, T. 47 N., R. 45 W., Michigan. While it is not certain just where the Upper slate member first emerges from the Keweenawan eruptives at the west, it is certain that the belt rapidly widens until it attains a great breadth and thickness. At a short distance east of Penokee gap the surface width of the belt is about $1\frac{3}{4}$ miles, or nearly 9,240 feet. The dip is here about 70°. This surface width therefore represents a thickness of 8,630 feet. From this place the width of the member gradually and uniformly increases, until at the east line of Range 2 W., Wisconsin, the distance across the belt north and south is about $2\frac{1}{2}$ miles, which represents a width perpendicular to the strike of the rocks of about $2\frac{1}{4}$ miles. Through R. 1 W., Wisconsin, this width is about the average. At Tylers fork the width reaches its maximum, and 2 miles east of Tylers fork falls somewhat below its average through the township. The surface width at Tylers fork is almost 2½ miles (more accurately is about 12,800 feet.) The dip at this locality is from 70° to 80° (upon an average it may be taken as 75°), and the surface width then represents an actual thickness of rock of 12,360 feet. Through the township R. 1 W., Wisconsin, the average thickness of the belt is not far from 11,000 feet, and nowhere does it fall below 10,000 feet. Though R. 1 E., Wisconsin, the belt gradually and quite uniformly narrows, and at the east line of this range has a surface width of about 1⅜ miles, or 7,260 feet. As the dip is here upon an average close to 80°, this width represents a thickness of about 7,150 feet. This width and thickness is maintained with considerable uniformity through R. 2 E., Wisconsin, to the Montreal river. From the Montreal river, the boundary between Michigan and Wisconsin, there is a continuous narrowing of the member through Ranges 47 W. and 46 W., Michigan, until at the Black river the surface width is but 1,650 feet, and as the dip is here but 65°, this represents a thickness of only 1,495 feet. Here, as before stated, are the last exposures of this formation, and a short distance east the whole member is cut out by the Keweenawan greenstones.

As the rocks of the Upper slate, Iron-bearing, and Quartz-slate members are entirely conformable, there is exposed throughout the whole extent of the rocks of the upper member the full thickness of the lower members of the series. However, a very considerable portion of the area which should be occupied by the slates of the upper formation is taken by the Keweenaw series. It is not certain, even at Tyler's fork, where the maximum thickness of the formation is exposed, that its total thickness is really shown. If at Tylers fork we have the full thickness of this member, the surface which the upper formation rocks cover in the area in which they occur at all is about one-half of the area which they would cover had they not been removed by erosion before the beginning of Keweenaw time; for at Tylers fork the member gradually and quite uniformly narrows both east and west until it disappears. The surface then covered by this member may be roughly compared to a triangle, the area of which is one-half that of a rectangle of the same base and altitude which these rocks would extend over were they not cut off by the Keweenaw series. When it is considered that in all probability this upper member of the series once extended east and west as far as the lower members, the proportion of this formation that is removed must be concluded to be much greater than one-half.

Throughout the area which the member covers, the exposures, with the exception of a few localities, are not particularly numerous, and yet a sufficient number have been found and mapped to give a clear idea of the nature of the rocks of the entire area. Nowhere are there full sections. At Penokee gap the exposures are most numerous, but even here little more than one quarter of its total thickness is uncovered. At Tylers fork the exposures are also numerous, but here not more than one-fifth or one-sixth of the member is shown. The conception of the member as a whole is formed by uniting and correlating the results obtained from many detached exposures.

The rocks of the upper formation have been said to strike across the country in perfect conformity to those of the Iron-bearing member (Pls. v to xii). In the vicinity of Penokee gap and English lake the rocks of the upper belt strike nearly east and west, and here the strikes of the iron-bearing belt are approximately in the same direction. In the west part of R. 2 W., Wisconsin, the iron-bearing formation begins to take a northern trend and the strata of the upper belt conform to it. Through Ranges 1 W. and 1 E., Wisconsin, the iron-bearing horizon has a strike from E. 25° N. at the east side of R. 1 W. to about E. 30° N. at the east side of R. 1 E., and to these strikes the slates above almost exactly correspond. In R. 2 E., Wisconsin, and R. 47 W., Michigan, in passing eastward there is a gradual bowing towards a more easterly course in the rocks of the iron formation, and the upper-belt rocks also show a corresponding bowing; and finally, when Black river is reached, on the east side of T. 47 N., R. 46 W., Michigan, the Iron-bearing and Upper slate members both strike nearly due east and west. This exact correspondence of strike between the two members is accompanied by as noticeable a correspondence in their dips, as will readily be seen by an examination of the plates referred to. The foregoing facts could hardly be explained upon any other hypothesis than that of a continuous conformable series, which has, as a whole, undergone the same process of tilting, and which has resulted, in connection with erosion, in giving the series its present surface distribution.

*Topographical features.*—The topography of the Penokee district (Pls. VII, IX, and XI) shows in a general way the boundaries of the Upper slate member. The ridge known as the Penokee range has been described in detail, pp. 145–146. It is always found within the Quartz-slate or Iron-bearing members, or in the granite just to the south. North of the iron formation the ground slopes rapidly in most cases to a nearly level plain, which ordinarily has a gentle slope northward, as is shown by the direction of the flow of the streams (Pl. II). A considerable portion of the ground is of a swampy nature, and the part not a swamp is largely low, rich, heavily timbered and thick with underbrush. The northern boundary of the Upper slate is for much of the distance defined by the trap range, which constitutes the base of the Keweenaw series. In traveling from the iron range north across the slate belt to determine its northern limit, the approach to this line is indicated by a rise in the ground. Ascending the swell for a short distance, one is pretty sure to find the eruptives of the Keweenaw series, and oftentimes in the form of a series of bold bluffs, which are a prominent topographic feature of the region. In general, then, the Upper slate member lies in a valley, bounded by the Penokee range on the south and the trap range on the north. At many points on both of these ranges the valley may be overlooked. The tree tops are seen stretching as an almost level mass of forest for miles both east and west. This forest is now rapidly disappearing under the necessities of the neighboring mines.

Within the belt the exposures are usually low and small. This results from the soft character of the slate. It is to be presumed that the judgment made up from the known exposures conveys a somewhat erroneous impression with reference to the character of the member as a whole; that is, the rocks which have a certain amount of the more resistant massive graywacke or quartzite are more apt to be exposed than the softer slates. In the vicinity and a short distance west of Bad river the exposures are quite numerous; also a little way west of this locality, east of English lake, there are again frequent exposures. This unusual number is here probably due to the fact that the rock in large measure becomes a somewhat resistant mica-schist, which is interstratified with quartzites and massive graywackes. East of this locality the exposures are not numerous until Tylers fork is reached. Here, while they are large, they are in a good measure due to the cutting action of the river. No bluffs and hills of slate are found, as west of Bad river. Numerous large exposures are in the south part of Sec. 12, T. 45 N., R. 1 E., Wisconsin, just south of a small lake. The slates and graywackes here are the north slope of a steep bluff which rises rapidly from the water of the lake. The only remaining large exposures in the belt are those along the railroads in the west part of Sec. 28, T. 46 N., R. 2 E., Wisconsin. The slates and graywackes are here a prominent landmark, rising in a bluff of some size in the valley between the iron and trap ranges.

*General petrographical character.*—It has already been said that the rocks of the member under consideration are distinctly clastic, or at least are rocks which can be shown to have been once fragmental. While they are alike in this fundamental point there is great variety in minor characteristics. The varieties may be grouped under the heads: (1) *Mica-schists and mica-slates;* (2) *Graywackes and graywacke-slates;* (3) *Clay-slates or phyllites;* (4) *Quartzites and conglomerates.* Each of these main types has the various phases shown by the following tabulation:

| | | |
|---|---|---|
| Mica-schist and mica-slate | Micaceous | Muscovitic. |
| | | Biotitic. |
| | | Muscovitic and biotitic. |
| | Micaceous and chloritic | Chloritic and biotitic. |
| | | Chloritic and sericitic or muscovitic. |
| Graywacke and graywacke-slate | Micaceous | Biotitic. |
| | | Biotitic and muscovitic. |
| | Micaceous and chloritic | Chloritic and biotitic. |
| | Chloritic | Chloritic. |
| | | Magnetitic and chloritic. |
| | | Ferruginous and chloritic. |
| Clay-slate or phyllite | | Chloritic. |
| | | Chloritic and magnetitic. |
| Quartzite and conglomerate | | Clayey. |
| | | Feldspathic. |

In the subsequent detailed descriptions of the rocks of this member they are grouped into several areas geographically. The distribution corresponds in a loose way to the classification of the rocks above given. At the west end of the member the mica-schists and mica-slates are the only rocks found. At Bad river and vicinity these rocks greatly predominate. In passing eastward micaceous graywackes and graywacke-slates, chloritic graywackes and graywacke-slates, and clay-slates are each in turn the preponderating rocks. In the transition from one type of rock to the next one there are cross sections in which two or more of these kinds may be found.

Before passing to the petrographical characterization of the types of rocks of this group, it will perhaps be well to give the kinds of rocks found in the geographical divisions as given in the tabulations. All the rocks of the English lake, Penokee gap, and Mellan junction sections, and also the exposure in Sec. 18, T. 44 N., R. 3 W., Wisconsin, have as their chief constituents quartz, feldspar, and mica. The rocks in Sec. 18 and those in the English lake section are all mica-schists and mica-slates. At Penokee gap are some graywackes and thin belts of quartzite, but both are micaceous. At the Tylers fork section the mass of the rocks are graywackes and graywacke-slates. However, in exposure all show lamination with sufficient plainness to enable one to readily determine strike and dip. The difference, then, between graywackes and graywacke-slates is of minor importance, and is used only for convenience to show relative degrees of massiveness. The rocks at the section between Tylers fork and Potato river and at the section in the vicinity of Potato river differ in no respect from those at the Tylers fork section, with the exception that biotite is less and chlorite more plentiful. Also, at one exposure in the extreme northern part of the member are found some conglomerates and quartzites, which will be further referred to. The rocks in the section located in the north part of T. 45 N., R. 1 E., and along the west range line of R. 2 E., Wisconsin, are mostly chloritic graywackes, although there are also found magnetitic clay-slates. The rocks, then, differ from those found at Tylers fork and Potato river in that biotite has almost entirely disappeared and chlorite has become the predominant mineral aside from the quartz and feldspar. At the extreme east end of this area appear the first exposures found of the clay-slates. These clay-slates or phyllites differ chiefly from the finer grained graywacke slates, into which they grade apparently only in that a portion of their mineral constituents are so fine grained as to make exact determinations impossible in many cases. The rocks in the section between the east range line of R. 1 E. and West branch of the Montreal, the section between the west branch of the Montreal and Montreal river, and the section at the Montreal river and vicinity extend over a distance east and west of about 6 miles. The westernmost exposure placed in these areas is about 3 miles west of the west branch of the Montreal, while the easternmost exposure is just east of the Montreal river. In this locality the exposures are more numerous than in any of the previous ones except those at Bad river and Tylers fork. Also, some of the exposures are of large size. The rocks here included are wholly graywackes and graywacke-slates, which are always chloritic. Only in one or two of them is any biotite found, and then only in subordinate quantity. Some of them are ferruginous in appearance. The slates differ but little from those of the Potato river and Tylers fork sections. The areas west of Black river and at Black river include, with a single exception, all the exposures found in Michigan. They are widely scattered, few in number, and are, with one exception, small. While graywackes and graywacke-slates are found among them, they are very fine grained and approach closely to clay-slates, of which the greater number of the exposures are composed. Mica is found only in a single exposure and in subordinate quantity.

*Petrographical characters of the four types of rock.*—In giving a characterization of the rocks of the Upper-slate member the following order will be followed: (1) The quartzites and conglomerates; (2) The clay-slates or phyllites; (3) The graywackes and graywacke-slates; (4) The mica-slates and mica-schists. This order is that of alteration, the first mentioned being nearest its original condition of deposition. By following this order the sections will in the main come from exposures in a direction from east to west.

The only exposure of *quartzite* and *conglomerate* of any magnitude is in Sec. 11, T. 45 N., R. 1 W., Wisconsin. At this place the rocks of the Copper series lie immediately to the northward, there being between the quartzites and greenstones an interval of but a few feet. The rocks of this exposure, described in the tabulations, are feldspathic. They are notable in showing nicely the alteration of fragmental feldspar to both muscovite and biotite with a simultaneous development of quartz, which is thus inclosed in the feldspar and mingled with the other secondary products. (Pl. XXXII, Fig. 1.) The rather unusual alteration of feldspar to actinolite is also here illustrated. This actinolite occurs in the enlargements of the quartz grains, but not in their cores, thus showing that it has formed subsequently to the deposition of the fragments of the rock.

The *clay-slates* or *phyllites* are not numerous, being found in but a few localities in the eastern part of the Upper-slate member. It is probable that these rocks make up a greater part of the upper belt than would be inferred from the few exposures, for they are so soft that they would rarely outcrop even if widespread. The known exposures of clay-slates are in Secs. 11, 12, and 17, T. 47 N., R. 46 W., Michigan; Sec. 13, T. 47 N., R. 47 W., Michigan; and near the line between Sec. 1, T. 45 N., R. 1 E., and Sec. 6, T. 45 N., R. 2 E., Wisconsin. Among the clay-slates are placed only rocks, which are excessively fine grained, the particles that compose them being so minute as to make the determination of their mineral composition in part uncertain. A portion of each thin section is sufficiently coarse grained to certainly show that it contains small fragmental particles of quartz and feldspar. It can also be seen that it contains much chlorite, kaolin or sericite, finely crystalline quartz, and iron oxides. As the minerals thus known to be present are the same that ordinarily constitute clays, and as they are those which compose the graywackes and graywacke-slates with which the clay-slates are closely associated, there is little doubt but that the greater number of them are thus chiefly constituted. One of the slates contains a small quantity of biotite. The iron oxide in the slates along the line of Sec. 1, T. 45 N., R. 1 E., and Sec. 6, T. 45 N., R. 2 E., Wisconsin, is so abundant as to be one of the chief constituents of the slate. This iron oxide is very largely magnetite in minute crystals. One of the slates has a peculiar mottled appearance when viewed under the microscope, resembling that presented by raindrops on shale, but the spots are indefinitely smaller. They seem to be due to the relative proportions of the minerals which compose them. This arrangement may be caused by the decomposition of feldspar, each one of the lighter spots perhaps representing a rounded fragment of that mineral.

In order to reenforce the microscopical determination of the minerals in these obscure slates, analyses of two of the magnetitic ones were made in the U. S. Geological Survey laboratory by Mr. L. G. Eakins, with the result of confirming fully the observations made. The first specimen is from NW. ¼ Sec. 6, T. 45 N., R. 2 E., Wisconsin; the second from NE. ¼ Sec. 1, T. 45 N., R. 1 E., Wisconsin. The amount of magnetite would appear in both cases to be as much as 15 per cent.

*Analyses of slates.*

| | I. | II. |
|---|---|---|
| $SiO_2$ | 53·44 | 52·58 |
| $Al_2O_3$ | 19·62 | 20·76 |
| $Fe_2O_3$ | 11·38 | 12·17 |
| FeO | 5·35 | 4·08 |
| MnO | trace | ·21 |
| CaO | ·42 | ·30 |
| MgO | 1·58 | 1·33 |
| $K_2O$ | 1·73 | 4·87 |
| $Na_2O$ | 2·61 | ·37 |
| $Li_2O$ | trace. | trace. |
| $H_2O$ | 4·07 | 3·43 |
| $P_2O_5$ | trace. | .......... |
| Total | 100·20 | 100·10 |

The *graywackes* and *graywacke-slates* cover much the largest territory of any class in the Upper slate member. The graywackes[1] have always as chief constituents fragmental quartz and feldspar. The strength of the

[1] The term graywacke is here used in a lithological sense, in accordance with the definition of the term given by Geikie, Text Book of Geology, 2d ed., p. 162: "A compact aggregate of rounded or subangular grains of quartz, feldspar, slate, or other minerals; or rocks, cemented by a paste, which is usually siliceous, but may be argillaceous, feldspathic, calcareous, or anthracitic. Gray, as its name denotes, is its prevailing color; but it passes into brown, brownish purple, and sometimes, where anthracite predominates, into black. The rock is distinguished from ordinary sandstone by its darker hue, its hardness, the variety of its component grains, and above all by the compact cement in which the grains are embedded."

rock is usually given by "siliceous paste," although much of the cement is frequently in the form of quartz added to the rounded fragmental grains. There is frequently "argillaceous and calcareous" and occasionally carbonaceous material present as accessories. There is also found in all of these graywackes abundant chlorite or mica, or both. The mica is chiefly biotite, although muscovite or sericite, or both, are plentiful. In importance, these minerals are secondary only to quartz and feldspar. The class of rocks in this district—graywackes and graywacke-slates—has been divided into three phases—micaceous, micaceous and chloritic, and chloritic. These divisions have a geographical significance as well as a lithological one. All of the graywackes and graywacke-slates in Michigan and Wisconsin as far west as the Potato river are chloritic; the Potato river rocks are mostly micaceous and chloritic, these two minerals being in about equal quantity; about half of the rocks in the vicinity of Tylers fork are both chloritic and micaceous; the remaining half micaceous only; west of Tylers fork and vicinity the graywackes and graywacke-slates are micaceous only. We have thus a series of graywackes which at the east end are wholly chloritic; in passing to the west mica appears with the chlorite, becomes more and more plentiful, and ultimately entirely replaces the chlorite. How gradual and complete this transition is will be readily seen by turning over the tabulations of these rocks on subsequent pages. The graywackes and graywacke-slates are so closely associated, both stratigraphically and lithologically, with the mica-slates and mica-schists, that a more detailed characterization of them will be deferred until the general character and distribution of the latter are given.

The *mica slates* and *mica-schists*[1] (Pls. XXXIII and XXXIV) of the district have always as a chief constituent quartz, and usually this mineral is the most abundant of all. Feldspar, as in the graywackes, is almost always present, but its quantity is much less, and in the typical slates and schists is almost wholly absent. Biotite, muscovite, sericite, and rarely chlorite, or two or more of these minerals, are always plentiful, the individuals generally being in well defined folia. The accessories present are the same

[1] Although in one place chlorite is, aside from the feldspar, the chief constituent, they will all be called mica-schists and mica-slates, to distinguish them from the graywackes and graywacke-slates.

as in the graywackes—ferrite, pyrite, some carbonate, and rarely carbonaceous matter. As biotite is usually the prevalent mica, the slates and schists have as a whole a darker color than the graywackes, ranging from very dark gray to black. The fundamental differences, however, which separate them from the graywackes are their crystalline appearance and absence of feldspar. Very many of them when viewed under the microscope, unless closely examined, taken by themselves, show no trace of a clastic origin; although the greater number, upon closer examination, are seen to have something of a fragmental character. The distinction made between mica-schists and mica-slates is based upon structure and coarseness of grain. Most of the coarser grained upper member mica rocks have a well developed schistose structure parallel to the bedding of the rock—a structure which could fairly be called foliated in some places. They never become very thinly foliated, or contorted with a brilliant sheen upon the foliation surface, as do some of the most crystalline mica-schists. A few exposures have a dark and light banded appearance, suggestive of a fine grained gneiss, which in fact they are when the feldspar is a chief constituent. The rocks called mica-slates are generally finer grained than the mica-schists; they cleave with a very smooth slate-like parting parallel to the bedding. Many of them have a black color, due to abundant dark biotite, particles of ferrite, and in some places to carbonaceous material. Like the graywackes and graywacke-slates, the mica-slates and mica-schists have been divided into three divisions: those in which chlorite is the chief constituent aside from the quartz and feldspar; those in which mica takes this place; and those in which both chlorite and mica are abundant. The first division is represented by but a single exposure. The chloritic and micaceous schists and slates are quite plentiful, but by far the greater number of the slates and schists are micaceous only. As with the graywackes and graywacke-slates, their classification corresponds to geographical distribution, and the distribution is of the same sort as that of the graywackes and graywacke-slates. The one exposure of sericitic chlorite-schist is but a short distance west of the Montreal river, in Sec. 14, T. 46 N., R. 2 E., Wisconsin. In passing to the west, the mica-slates at the Potato river first appear. At this locality only one exposure is known which falls under this head. At Tylers fork and vicinity there are quite a number of exposures of chloritic and biotitic slates and but a single one of pure chloritic slates. West of Tylers fork the schists and slates are almost wholly micaceous, although chlorite is yet occasionally found. There are, then, precisely the same stratigraphical relations with reference to chlorite and mica in the slates and schists that there are in the graywackes and graywacke-slates. The two classes of rocks are also interlaminated with each other. In Sec. 14, T. 46 N., R. 2 E., a chlorite-schist is but a short distance from an exposure of typical graywacke. At Potato river again the one biotite-slate there found is interstratified with graywackes and graywacke-slates. At Tylers fork the graywackes and graywacke-slates and the mica-schists and mica-slates are interstratified in the most intimate manner, both rocks occurring at times in the same exposure. Beginning at the top of the Upper slate member, the order of succession of the different phases of rock as here found, as taken from the tabulations, are biotite-slate, chloritic graywacke, chloritic biotite-slate, biotitic graywacke, biotitic graywacke-slate, chloritic graywacke-slate, chloritic graywacke. At Bad river, the order, beginning at the top, is as follows: mica-schists, micaceous graywacke, biotite-schists, micaceous graywacke, mica-slates. West of Bad river, in the vicinity of English lake, mica-schists and mica-slates only are found.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.

*Exposure in Sec. 18, T. 44 N., R. 3 W., Wisconsin.*

1. Biotite-slate. Specimen 167 Wr., from 1,000 N., 1,250 W., Sec. 18, T. 44 N., R. 3 W., Wisconsin.[1]

The rock contains, in an aphanitic background, very numerous small crystal surfaces which feebly reflect the light, is black, and cleaves somewhat irregularly parallel to the bedding.

The thin section is composed of a finely crystalline background and individuals and clusters of individuals of feldspar, in about equal proportion. The background consists of finely crystalline quartz, small brown folia of biotite, very numerous black particles of ferrite or biotite, or both, and probably also some carbonaceous material.

[1] The numbers of specimens and slides are usually those of the collection of the lake Superior division. Specimens with Wr. after the numbers are from the collection of the late Mr. Charles E. Wright. Specimens with Wis. after the numbers are from the collection of the Wisconsin Geological Survey. Locations are given from the southeast corner of the section in steps of 2,000 per mile.

The feldspar areas are rounded and are decomposed to a greater or less extent, the secondary products being biotite and quartz. This alteration is more extensive upon the outside than in the interiors of the particles. These feldspars also include ferrite.

*From the section at east end of English lake.*

2. Biotite-slates from a middle horizon. Specimen 126 Wr., from 1,300 N., 200 W., and specimen 128 Wr., from 1,600 N., 600 W., Sec. 9, T. 44 N., R. 3 W., Wisconsin.

These rocks are dark gray to black, fine grained, quite massive, mottled, the mottling being due to numerous small cleavage surfaces.

In the thin section the cleavage areas are seen to be well rounded, altered grains of feldspar. They are set in the groundmass, which consists of intimately mingled small grains of quartz and small, brown particles of biotite, with a considerable quantity of ferrite. The partial decomposition of the clastic feldspars has resulted in the formation of very numerous small folia of biotite and a few larger ones of muscovite, the transition to these minerals being beautifully shown. In places also the feldspar is replaced by saturating quartz. In each of the feldspar areas the secondary biotite and muscovite are found most plentifully at or near the exterior of the grain, although in almost every case the alteration has proceeded in a greater or less degree quite to the center. In the matrix it is impossible to determine which part, if any, of the quartz is fragmental. The biotite of the matrix is precisely like that found in the feldspar; it is all deep brown, very strongly dichroic, and therefore probably bears a large percentage of iron. This biotite has doubtless been furnished its iron by the abundant oxide present. The peculiar spotted appearance of the section when held up to the light, taken in connection with its appearance under the microscope, gives a clear idea of the manner in which the rock reached its present condition. (Pl. XXXIII, Figs. 2, 3, and 4.)

3. Muscovitic biotite-schist from an upper middle horizon. Specimen 73, Wis. (slide 24), from south shore of English lake, Sec. 9, T. 44 N., R. 3 W., Wisconsin.

The thin section is a rather fine grained, apparently completely crystalline, typical mica-schist. The groundmass consists chiefly of quartz, mingled with which is feldspar, both orthoclase and plagioclase. Biotite in rather small fine folia of uniform size is very plentiful; muscovite is much less abundant. That all the mica is a secondary alteration of feldspar can not be proven, but a portion of it is certainly of this nature. Many grains of feldspar are partly surrounded and cut by folia of mica, while many of the larger particles of feldspar contain numerous flakes of mica, which in magnitude and appearance are precisely like the great mass of the mica in the section. Quite numerous black grains and crystals of a mineral which is taken to be pyrite are included alike in the quartz, feldspar, and mica.

4. Muscovitic biotite-schists from an upper horizon. Specimen 78 Wis. (slide 26), specimen 79 Wis. (slide 27), from SW. ¼ of Sec. 4, T. 44 N., R. 3 W., Wisconsin.

These sections are like 3, except that they are somewhat coarser grained and contain more muscovite and approach nearer (especially slide 27) to a typical mica-schist.

5. Biotite-schist, from an upper horizon. Specimen 153 Wr., 335 N., 1,050 W., Sec. 4, T. 44 N., R. 3 W., Wisconsin.

The rock is dark gray, of a rather fine, uniform grain, finely laminated, yet so compact as to break quite readily across the plane of lamination. The rather large black abundant flakes of mica give the specimen the appearance of a typical mica-schist.

The thin section shows this rock to be a mica-schist. It has an interlocking quartzose background, mingled with which in subordinate quantity are both orthoclase and plagioclase. Contained in this background is much biotite in tolerably wide, long, well defined blades, which cut through both quartz and feldspar. No grains of quartz are found which are plainly enlarged. This rock is the most completely crystalline of any mica-schist in the formation. It contains the merest trace of old feldspar grains, no quartz which can be shown to be fragmental, and a considerable quantity of fresh feldspar. In short, if this schist has formed, as from its position we are obliged to believe, from a fragmental rock, no trace of the alteration is discoverable. The fresh feldspars in all probability, in this, as in other cases where they are present, are of secondary origin, not original fragmental particles. (Pl. XXXIV, Fig. 2.)

6. Biotite-schist, from an uppermost horizon. Specimen 154 Wr., 500 N., 1,000 W., Sec. 4, T. 44 N., R. 3 W., Wisconsin.

This rock differs only from 153 Wr. in that it is finer grained.

In section the chief constituents are quartz, biotite, and feldspar, the first being preponderant, and the last comprising both orthoclase and plagioclase. The section contains also quite a quantity of black opaque material. Many of the grains of quartz have undergone secondary enlargement. That all the biotite is secondary is probable, although only a portion of it can be shown to be of this nature.

*From the section at Bad river and vicinity.*

7. Garnetiferous biotite-slates, from west side of fault at base of formation. Specimen 9552 (slide 3187), 0 N., 1,800 W.; Specimen 9554 (slide 3189), 0 N., 1,750 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

These rocks are of a reddish or greenish black color, aphanitic, finely laminated, and readily cleave along the plane of lamination. The cleavage surfaces are lustrous and covered by many small protuberances, which are taken to be due to contained garnets.

The sections are mostly composed of small flakes of biotite with particles of a black substance set in a fine quartzose groundmass. The quartz is in fine and closely fitting grains. Whether any of it is fragmental is difficult to say. A few grains are found which are larger than the remainder of the mineral, and these are clear and appear to be clastic. Biotite in very small flakes, with the greatest diameters ordinarily in a common direction, compose fully one-half of the section. Mingled with this biotite, and giving the rock its color, are large quantities of the black or very brown material before mentioned. This is not magnetite, but appears to be a very dark colored ferrite, or such ferrite mingled with pyrite or carbonaceous material, or both. In each section there chances to be but one or two garnets. Included in each of the garnets are all of the remaining constituents. In the main the garnets are not crystal outlined, but in places they are, and here biotite blades often abut sharply against the garnets and abruptly terminate. These rocks are plainly intermediate between the Iron-bearing and Upper-slate members.

8. Biotite-slate, from east side of fault and near base of formation. Specimen 9568 (slides 4497 and 4498), 1700 N., 1000 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

This rock is black, very fine grained, massive, breaks with hackly subconchoidal fracture, contains many grains of colorless and flesh-colored feldspar, which upon the broken surface of the rock show well developed cleavage planes.

The thin sections are composed of comparatively coarse fragmental particles of feldspar set in a much more abundant matrix, consisting largely of biotite, quartz, and feldspar. The larger fragments are mostly more than 1 mm. in diameter. They vary in magnitude from this to those so fine as to be lost in the matrix, their numbers increasing as their magnitudes diminish. These sections differ from any of the other biotite-schists and biotite-slates in the remarkable freshness of the larger feldspars. They are in their interiors generally clouded but slightly, and the plagioclase gives sharp twinning bands. The greater part of the feldspar is, however, orthoclase. The smaller feldspars have all largely and some of them wholly altered to biotite and quartz, and even the larger feldspars are often affected more or less deeply upon their exteriors by this biotitic decomposition, and sometimes complex areas of biotite are found quite a distance in the feldspars. Every stage of this change is seen from perfectly fresh unaffected feldspar to that in which but a trace of feldspathic material remains in a fine aggregate of biotite and quartz. The amount of fragmental quartz is very small, not more than from a tenth to a twentieth as plentiful as the feldspar. The biotite is in small dark brown folia intimately mingled with finely crystalline quartz, and all the particles of these two minerals have without doubt formed by the decomposition of the feldspar. The absence in many cases of large fragmental grains of quartz in the more altered mica-schists and mica-slates is explained by this section. Here are abundant fresh large fragmental feldspars and but few small fragmental quartzes. It is plain that this rock was once mainly a feldspathic sediment, the metasomatic alterations of which have formed a dark colored mica-slate. Doubtless the greater mass of the fragmental material was finer grained than the unaltered large grains of feldspar. It would seem from this section that the fine grained mica-schists in which the feldspar is decomposed to a much greater extent than in this rock, and which contain no large fragments of quartz, must originally have been feldspathic sediments.

9. Black biotitic slate, from east side of fault and near base of formation. Specimen 9569 (slide 3378), from 1700 N., 1000 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin.

A black fine grained compact rock, which breaks with a conchoidal fracture.

Very small clastic particles of quartz and feldspar compose one-half of the area of the section. The quartz grains are ordinarily distinctly enlarged, while quite a good many of the grains of feldspar are tolerably fresh. The greater number of them are altered to some extent to biotite, while frequently they are almost completely thus altered. All stages of this process are seen, and while the particles of feldspar and secondary folia of biotite are very small, the transformation is distinctly made out. The interstitial material composing the other half of the section consists of exceedingly fine crystallized quartz, of minute folia of biotite, and of an abundant black opaque material which is doubtless ferriferous and possibly also carbonaceous. All of the biotite in the section is believed to be of secondary origin.

10. Black biotitic slates, from west side of fault and at the lower middle horizon. Specimens 9550 (slide 3322) and 1480 Wis., (slide 267), from 500 N., 1400 W., Sec .11, T. 44 N., R. 3 W., Wisconsin.

Fine grained and finely laminar rocks, which cleave readily along the planes of lamination. Contained in the fine material are numerous roundish black lustrous cleavage areas, which are taken to be large fragmental particles of feldspar. A lens shows very numerous minute crystals of pyrite or pyrrhotite, probably the latter, for the rock gives, finely pulverized, a magnetitic powder, which may, however, be due to magnetite.

The thin sections show the rocks to consist of two parts, a finely crystalline matrix and coarse well rounded fragmental feldspars. These feldspars have always altered to a greater or less degree, the alterations resulting in the formation of the biotite, many small folia being always found in a single individual of feldspar. Every gradation of the change is seen from grains of feldspar which contain but few folia of biotite to those in which the remaining feldspar is just sufficient in quantity to enable one to perceive that the detached areas are parts of one individual. Doubtless also the alteration to biotite and quartz has completely taken place in many cases, when the outlines of the original clastic areas would be entirely lost. Accompanying the biotite secondary to the feldspar is a large amount of black opaque material in minute particles. This is in all probability also secondary, as its amount increases as the quantity of biotite increases. The black roundish spots spoken of under the macroscopic descriptions are evidently these altered fragmental feldspars. The matrix of the rock is composed of intimately mingled quartz, feldspar, biotite, and black opaque material, which is mostly somewhat altered pyrite or pyrrhotite, but which may also contain carbonaceous material. A portion of the matrix is certainly fragmental, as is shown by secondary enlargements of the quartz grains. The biotite is all believed to be due to the alteration of feldspar; much of it is certainly of this nature.

11. Black chiastolitic biotitic slates, from west side of fault at lower middle horizons. Specimen 9576 (slide 3381), 650 N., 1350 W.; specimen 9574 (slide 3380), 670 N., 1350 W.; specimen 9572 (slide 3379), 680 N., 1350 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

The rocks are black, and exceedingly fine grained to aphanitic. Specimen 9572 breaks with a conchoidal fracture and 9574 and 9576 are finely laminar. In 9576 are large cleavage areas like those described in 10. In the specimens numerous crystals of pyrite are contained.

The thin section 3381 is almost precisely like the thin section 3322 in 10, above described, the only difference being that the decomposition of the large fragmental feldspars has proceeded somewhat further. Thin section 3380 differs from 3381 in that the large feldspars have been less numerous apparently and the alteration of those present has not gone so far. The appearance of the rocks as seen in hand specimens corresponds with their appearance under the microscope, the extent of the alteration of the feldspars as determined by the thin sections corresponding exactly with the condition of the large feldspars as seen macroscopically. In specimen 9550, in which the areas of feldspar are generally well developed and show distinct cleavage surfaces, the biotitic alterations characteristic of these rocks have taken place to but a comparatively small extent. In specimen 9574 the obscurely outlined feldspars and irregular cleavage surface are accompanied by extensive biotitic alteration. The section of 9572 is much like the finer parts of 9550 (in 10) and 9576. Scattered sparsely through the finer material of 9572 and 9574 are quite large crystals and intersecting clusters of crystals of chiastolite. These chiastolites often include such a quantity of the other minerals of the section as to be almost indistinguishable in ordinary light. The clouds of inclusions are arranged in parallel lines, which correspond to the somewhat obscure slaty cleavage of the rock. Pyrite is an abundant accessory.

12. Biotite-slate, from west side of fault at a lower middle horizon. Specimen 1440 Wis., (slide 261), 700 N., 0 W., Sec. 10, T. 44 N., R. 3 W., Wisconsin.

The thin section is very fine grained, and consists of intimately mingled quartz, feldspar, biotite, and minute particles of dark opaque material a portion of which is doubtless pyrite. The biotite composes about one-third of the rock. A portion of this mineral is certainly secondary to feldspar, and all of it is probably of this origin.

13. Biotitic and muscovitic slates, from west side of fault, at a lower middle horizon. Specimens 129 Wr. and 130 Wr., 850 N., 200 W., Sec. 10, T. 44 N., R. 3 W., Wisconsin.

Specimen 129 Wr. is like 9576 in 11, above described. Specimen 130 Wr. differs from 129 in being of a dark gray color, and in that it shows but few cleavage surfaces.

The thin section of 129 Wr. resembles very closely 3322 in 10 and 3381 in 11; the only point of difference being that pyrite and black material in minute specks are particularly abundant. In 130 Wr. the alteration of large fragmental feldspar to muscovite and biotite is nicely shown. The flakes of muscovite, which are of a greater magnitude than those of biotite, are clustered about and penetrate the particles of feldspar. The section is unusually free from black material. In other respects it does not differ from the other mica-slates of the vicinity. (Pl. XXXIV, Fig. 3.)

14. Black biotite-slates, from west side of fault, at a middle horizon. Specimens 9549 (slide 3321), 1050 N., 1600 W.; 9548 (slide 3320), 1070 N., 1600 W.; 9547 (slide 3094), 1090 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

The rocks are black, exceedingly fine grained, finely laminar, and cleave readily along the plane of lamination. As in 9550 in 10, and 9576 in 11, which they are almost precisely like, numerous rounded cleavage areas are contained in the fine material. Pyrite in small crystals is an accessory.

The thin sections are almost precisely like 3322 in 10, the only difference of importance being that in them the biotitic alteration of the fragmental feldspars has taken place more largely than in 3322. The correspondence between the appearance of hand specimens and thin sections described as applying to 10 and 11, due to feldspar decomposition, is here equally well seen.

15. Muscovitic graywacke, from west side of fault, at a middle horizon. Specimen 9546 (slide 3093), 1100 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

The rock is a light gray, medium grained one, with uniform texture, which cleaves irregularly along a schistose plane.

The thin section is composed of coarse grains of quartz, having generally oval or roundish forms set in a fine matrix, which also appears to be chiefly quartzose, although with it are feldspar, chlorite, and muscovite. While there is a wide gradation in the size of the quartz grains, there is an approximate separation of the coarse and fine quartz. At first sight the section appears to have but a small amount of coarse fragmental feldspar. However, upon closer examination it is seen that the remnants of many such feldspars are present. In some cases these grains are honeycombed by saturating quartz, many detached areas often being in a single individual. Again a feldspar area contains many small individuals of quartz mingled with chlorite and muscovite, and occasionally a feldspar particle is found which is tolerably fresh. Evidently this rock was originally mostly composed of rounded fragmental particles of quartz and feldspar. The fragmental quartz grains are enlarged, and thus are now sharply angular. The particles of feldspar are largely replaced or decomposed, as above described, and consequently the rock has now become at first sight an almost completely crystalline one. Had the process continued until all the feldspars had been thus decomposed, the only trace of any original fragmental material would be the general oval or roundish character of the larger particles of quartz.

16. Biotitic and muscovitic graywacke, from west side of the fault, at a middle horizon. Specimen 9544 (slide 3092), 1105 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

A gray, coarse grained, massive rock, having a conchoidal fracture.

Large fragmental grains of quartz and feldspar, with the alteration and replacing products of the latter, make up the mass of the thin section. The areas of quartz are enlarged, and consequently minutely angular, although still retaining their general roundish form. The feldspar is much fresher than in 15, many individuals showing no alteration influence except a little kaolinization. Other individuals, however, include many grains of quartz or large reticulating quartz individuals with numerous flakes of muscovite. Here these minerals are plainly alteration products of the feldspar. In many cases this alteration has proceeded so far as to leave irregular cores, which are entirely surrounded with the secondary quartz, biotite, and muscovite. Again in other cases the original rounded outlines of the feldspar are distinct, the alterations having occurred in spots through the grains. The finer portions of the rock are composed of quartz, biotite, and muscovite, often without any feldspar. These portions are also probably alteration products of feldspar, the individuals perhaps being small, or at any rate are alteration products of feldspar mingled with detrital quartz. Through the finer grained portions of the rock are numerous small particles of black opaque material. (Pl. XXXII, Fig. 2; Pl. XXXIII, Fig. 1.)

17. Biotitic graywacke, from the west side of fault at a middle horizon. Specimen 9545 (slide 3319), from 1100 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

The rock is gray, coarse grained, massive, and has a conchoidal fracture. It contains numerous particles of limpid quartz and less plentiful ones of white or pale pink feldspar, which are so large as to enable one to easily see their rounded forms. The rock in appearance approaches that of a gray quartzite.

In the thin section very large, rounded, often complex areas of quartz are very numerous. These grains as to general form are well rounded, but their outlines are minutely irregular, and these irregularities are doubtless due to enlargements. The feldspar also is found in rounded areas. It is often more or less decomposed, the method of alteration and the products produced being precisely as in 16. Contained in the section are large areas composed almost entirely of finely crystalline quartz, brown folia of biotite mingled with small remnants of feldspar, each of which without doubt represents a single fragmental feldspar.

18. Biotitic schists, from west side of fault at middle horizon. Specimens 9543 (slide 3318), and 1491 Wis. (slide 273), from 1110 N., 1600 W., Sec. 11, T. 44 N., R. 3 W., Wisconsin.

A dark gray mottled, fine grained, and quite massive rock.

At first sight the sections appear like ordinary biotite-schists. They contain groundmasses of quartz, through which are plentifully and uniformly scattered brown folia of biotite and less numerous flakes of muscovite. On closer examination many of the larger grains of this quartz are plainly fragmental, and they have often been enlarged. The biotite is to a large extent secondary to feldspar, many flakes of this mineral being found mingled with a small quantity of feldspathic material, which throughout a considerable area acts as a unit. In a few places fragments of orthoclase and plagioclase are found, in which the mica-schist decomposition is but begun, but in the greater part of the sections but little of the original feldspar remains. We have now the explanation of the vaguely outlined spots seen in the hand specimens. They represent original fragmental feldspars, which once composed a very large proportion of the rock; but now in most cases they have so completely altered to biotite, muscovite, and quartz that only here and there in the thin section is an area well outlined. This rock was then originally like 2, but now approaches very closely to a typical mica-schist. In 2 there is everywhere a plain distinction between the feldspathic and nonfeldspathic areas. The larger portion of the sections resembles the fine grained matrix of 2. Oxide of iron in small particles is an abundant inclusion in the biotite, feldspar, and much of the quartz. The quartz containing such quantities of this oxide of iron is taken to be secondary, the larger plainly fragmental grains being free from this ferrite.

19. Muscovitic and biotitic graywacke, from west side of fault at an upper middle horizon. Specimen 9540 (slide 3316), from 1600 N., 0 W., Sec. 10, T. 44 N., R. 3 W., Wisconsin.

A light gray, fine grained rock, which is quite massive, but which breaks most readily along its obscure schistose plane.

The section is chiefly composed of particles of quartz and feldspar of greatly varying sizes and quite deeply interlocking. At first sight the only indication of a fragmental nature is the general rounded contours of the larger particles of quartz and feldspar, these grains being minutely and sharply angular upon their borders. Upon close examination many of the grains of quartz show indications of enlargement. The lines between the supposed nuclei and their enlargements are in no case so distinct as in the ferruginous fragmental quartzites, but consist of small detached particles of chlorite, kaolin, air bubbles, and sometimes iron oxide. In a few cases the cores of the quartz grains are clearly made out. Oftentimes there are considerable breaks in the lines, and the whole line in most grains might be taken to be ordinary inclusions. However, the constancy of the oval or rounded forms of the inclusions and their positions near the exteriors of the large grains lead to the conclusion that they mark the outlines of true fragmental cores which have become enlarged until they interlock. The irregularity of the exterior of the grains of feldspar is due to another cause, their partial alteration to chlorite, muscovite, and biotite, with consequent separation of silica. These minerals are not plentifully present, but are so situated with respect to the feldspars as to leave little doubt of the connection between them. A portion of the finer grained quartz is certainly secondary.

20. Biotite-schist, from west side of fault at an upper middle horizon. Specimens 9539 (slide 3315), 1442 Wis. (slide 262), from 1650 N., 0 W., Sec. 10, T. 44 N., R. 3 W., Wisconsin.

The rocks are like 2.

The thin sections are like those of 2.

21. Muscovitic biotite-schists, from west side of fault at a middle horizon. Specimens 9537 (slide 3314), 50 N., 1950 W.; 2001 Wis. (slide 281), 30 N., 1950 W.; 2002 Wis. (slide 282), 130 N., 1950 W.; 9536 (slide 4223), 150 N., 1950 W., Sec. 2, T. 44 N., R. 3 W., Wisconsin.

The rocks are gray or green, fine grained, quite massive, yet showing a more or less obscure schistose structure.

The thin section 4223 resembles very closely those of 3 and 4. It differs from them in that the alterations have not gone quite so far, and consequently the original fragmental nature of the rock is clearly made out. Many of the more angular grains of quartz are distinctly seen to be widely enlarged. In places saturating quartz has penetrated through and through large grains of feldspar. In this manner large secondary individuals of quartz have formed, no part of which is fragmental. The mica is abundant and much of it is secondary to feldspar, while there is little doubt that all or nearly all of the biotite, muscovite, and enlarging quartz are secondary products, having resulted from decomposition of the feldspar. The section 3314 differs from 4223 in that the alterations of feldspar and enlargements of quartz are not so easily traced, and in that a considerable quantity of chlorite has resulted from the decomposition of the feldspar. The thin sections 281 and 282 contain numerous well rounded somewhat coarse particles of quartz and feldspar, so that they are much nearer their original condition than 4223 and 3314 from the same locality. In them the alterations of feldspar have also produced chlorite and kaolin as well as biotite and muscovite.

22. Biotite-schist, from west side of fault at the uppermost known horizon, 134 Wr., from 250 N., 0 W., Sec. 3, T. 44 N., R. 3 W., Wisconsin.

The rock is like 9536 in 21, except that it is very plainly schistose and in places biotite is very prominent.

In essential points this section is like 4.

*Section east of Mellen junction.*

23. Biotitic and chloritic graywacke-slate, at a middle horizon. Specimens 12764 (slide 5459), 12765 (slide 5460), NE. ¼ of NE. ¼ Sec. 8, T. 44 N., R. 2 W., Wisconsin, on the Wisconsin Central Railroad.

The rocks are dark gray, fine grained, finely laminated. In them are numerous roundish spots of a darker color than the remainder of the rock. Pyrite is a plentiful accessory.

The thin sections show both fine grained and coarse grained materials. Rather small well rounded grains feldspar compose more than one-half of the coarser parts, while the particles oı this mineral, although of very small size, are abundant in the finer portions. The grains of quartz are frequently enlarged. The feldspar comprises orthoclase, microcli e, and plagioclase. Many of its grains are much altered chlorite, biotite, and quartz, resulting from their decomposition. In the finer parts of the sections are plentiful chlorite, biotite, and finely crystalline quartz, which may in part be fragmental, and many fine particles of a dark colored substance, which is probably carbonaceous material. In the coarser portions of the rock much of the chlorite and biotite are in well defined flakes. The dark colored roundish spots, seen macroscopically when examined in ordinary light, appear to be but little different from the finer grained parts of the remainder of the rocks, but in polarized light they almost completely extinguish the light.

24. Biotitic graywacke, from a middle horizon. Specimen 9582 (slide 3326), 220 N., 0 W., Sec. 5, T. 44 N., R. 2 W., Wisconsin.

The rock is light gray, fine grained, quite massive, and breaks with a conchoidal fracture.

The thin section is composed largely of fragmental particles of quartz and feldspar of varying sizes, which are set in a finely crystalline matrix, consisting mostly of quartz. Biotite in minute folia is scattered between the fragments and through the fine matrix. A portion of it is certainly secondary to feldspar, and probably all of it is of this nature. The grains of quartz are frequently enlarged. Much of the finer grained interstitial quartz is probably secondary.

25. Black biotite-slate from a middle horizon. Specimen 9581 (slide 3327) from 600 N., 0 W., Sec. 5, T. 44 N., R. 2 W., Wisconsin.

The rock is almost black, aphanitic, cleavable, and contains numerous black, obscure areas which give it a faint mottled appearance.

The thin section consists of excessively minute particles of quartz, biotite, chlorite, kaolin, and pyrite. A few grains of quartz somewhat larger than the remainder have a fragmental appearance. Biotite is very abundant. Contained in this fine material are rounded areas which appear to be almost completely decomposed feldspar, the minerals formed by this alteration being the same as those in the remainder of the section.

26. Black biotite-slate from an upper horizon. Specimen 9592 (slide 3330), 1950 N., 1750 W., Sec. 4, T. 44 N., R. 2 W., Wisconsin.

The specimen is like 9550 in 10 and 9576 in 11, except that the cleavage areas which give the rock a mottled appearance are less distinct than in them. Composi tion: Silica, 59·73; alumina, 22·78; iron sesquioxide, 0·11; iron protoxide, 5·98; manganous oxide, 0·09; calcium oxide, 0·53; magnesium oxide, 2·94; potassa, 3·48; soda, 1·41; water, 3·28 = 100·33.

The section of this rock is much like 3322 in 10. The chief differences are, that much of the large fragmental feldspar shows the distinct twinning bands of plagioclase, and that none of these large feldspars have altered to such a degree as a part of them have in the section referred to.

27. Chloritic biotite-schists; the uppermost horizon shown at this point, the rock being mingled with the eruptives of the Keweenaw series. Specimens 9586 (slide 3329), 1980 N., 540 W.; 9590 (slide 4425), 1850 N., 640 W.; 9591 (slide 4426), 1940 N., 585 W., Sec. 5, T. 44 N., R. 2 W., Wisconsin.

The rocks are light to dark gray, break with a conchoidal fracture, and are quite massive, although showing traces of lamination.

In the thin sections fragmental quartz and feldspar are the most plentiful constituents. Mingled with these minerals are much biotite, chlorite, and muscovite, the biotite being far the most abundant. Many of the larger of the quartz grains have taken a second growth, as a result of which their exteriors are minutely angular. Much of the feldspar is quite fresh, although in many places it has largely altered to muscovite, chlorite, and biotite. Less frequently the feldspar is replaced by saturating quartz. While much of the mica and chlorite are secondary to feldspar, this statement could not with certainty be made of all of it. Quite plentiful black particles of ferrite are scattered through the sections. In the interstices is finely crystalline quartz.

28. Muscovitic biotite-schist. The uppermost horizon shown here—higher than the preceding. Specimen 2039, Wis., NW. ¼ of NE. ¼ Sec. 6, T. 44 N., R. 2 W., Wisconsin.

The section has a fine grained groundmass of quartz and feldspar, in which are abundantly found muscovite and biotite. Many of the larger quartz grains include numerous folia of mica. The feldspar areas are reticulating and include quartz and both the micas. The muscovite and biotite, besides being found in the small folia thus included in the quartz and feldspar, are present in numerous large blades. This section, taken by itself, would be considered a completely crystalline mica-schist in which the interlocking and mutual inclusions of the different minerals are of the most intricate sort. But, like the other mica-schists of the Upper slate, it is believed to be an ordinary clastic rock in which the series of metasomatic changes have been great. The large areas of quartz including folia of mica represent clastic individuals of feldspar. As these feldspars have altered to mica the excess of silica has separated out as quartz, and the areas, as stated above, which were once orthoclase or plagioclase—in most cases the former—are now complex, most intricately interlocking areas of quartz and mica. Frequently the alteration of a single feldspar has resulted in the formation of a single individual of quartz, in which case the more or less detached areas polarize together. In other cases the decomposition of a feldspar has resulted in the formation of many grains of quartz as well as numerous folia of mica. The proof of these alterations in the single section is not complete, but taken in connection with the other mica-schists of the formation it is conclusive. A reticulating area of saturating quartz often contains detached cores of feldspar, which polarize as a unit. Sometimes these feldspars have not altered to such an extent as described above. In almost every case their rounded exteriors are lost, but irregular areas of considerable size quite frequently remain, which include few folia of biotite and little saturating quartz. It is possible that a portion of the silica composing the saturating quartz comes from extraneous sources. (Pl. XXXIV, Fig. 1.)

29. Chloritic and muscovitic graywacke, from a high horizon, higher than the preceding, although not here an uppermost horizon. Specimen 3164 (slide 322), Wis. 0 N., 1,000 W., Sec. 27, T. 45 N., R. 2 W., Wisconsin.

The thin section was originally composed of rather small clastic particles of quartz and feldspar. The quartz grains are mostly enlarged. Secondary interstitial quartz has appeared. The feldspars have largely decomposed, their places now being occupied by chlorite, muscovite, saturating quartz, and to a small extent biotite.

*Section at and west of Tylers fork.*

30. Black biotite-slate, from a low horizon. Specimen 12770 (slide 5461); short distance east of north quarter post, Sec. 1, T. 44 N., R. 2 W., Wisconsin.

The rock is black, aphanitic, finely laminated, very soft, and apparently carbonaceous.

The thin section shows an exceedingly fine grained background, composed of flinty and perhaps amorphous quartz, of kaolin, and of black material which may be carbonaceous. Contained in this background are numerous small fragments of quartz and feldspar and dark brown folia of biotite.

31. Biotitic graywacke-slate, from a low horizon. Specimen 12771 (slide 5462), SE. ¼ of the SW. ¼ of Sec. 31, T. 45 N., R. 1 W., Wisconsin, on the Wisconsin Central Railroad.

The rock is dark gray, very fine grained, cleavable, and shows here and there lustrous flakes of white mica.

The thin section consists of very small particles of quartz, feldspar, biotite, chlorite, brown iron oxide, and apparently some kaolin. Much of the quartz is fragmental. The feldspar fragments are much altered, the resultant products being chlorite, biotite, and quartz.

32. Chlorite graywacke-slates, from a middle horizon. Specimens 12772 (slide 5463), 12773 (slide 5464), NE. ¼ of the NW. ¼ Sec. 32, T. 45 N., R. 1 W., Wisconsin.

The two specimens differ in appearance. The first is almost black, fine grained, and finely laminated. The second is gray, coarser grained, and massive. Both contain shining flakes of white mica.

In slide 5463 rather small fragmental particles of quartz and feldspar, with a few flakes of white mica, compose two-thirds of the section. The quartz grains are often enlarged. The feldspar comprises orthoclase, microcline, and plagioclase, the latter very plentiful. All the feldspars have altered considerably to chlorite, sericite, biotite, and quartz, chlorite being the most abundant. The remaining one-third of the section is apparently composed of the same minerals as the coarser parts, with the addition of pyrite, opaque iron oxide, and a little of some carbonate. Slide 5462 differs from 5463 in that its fragmental quartz and feldspar are in much smaller particles, in that the latter is more altered; and in containing more ferruginous and perhaps some carbonaceous material.

33. Chlorite graywacke-slate, from a middle horizon. Specimen 12776 (slide 5466), near center SW. ¼ of SE. ¼ Sec. 29, T. 45 N., R. 1 W., Wisconsin, on Wisconsin Central Railroad.

The rock is precisely like 12773 in 32.

The thin section is in no important point different from 5463 in 32.

34. Chloritic graywackes, from a middle horizon. Specimens 2108 Wis. (slide 387), 1000 N., 784 W.; 9611 (slide 3341), 1000 N., 800 W.; 2104 Wis. (slide 306), 1060 N., 784 W.; 9613 (slide 3342), 1150 N., 775 W., Sec. 28, T. 45 N., R. 1 W., Wisconsin.

The rocks are light gray, rather fine grained, and cleave most readily along the plane of stratification, although easily breaking across this plane with a conchoidal or subconchoidal fracture.

In thin sections, well rounded clastic particles of quartz and feldspar are set in a fine matrix, consisting generally of quartz and chlorite, but containing some kaolin, biotite, and brown and black material which is taken to be ferrite, mingled perhaps with pyrite and organic matter. The fragments of quartz are frequently enlarged. The feldspars are often quite fresh, but much of this mineral is altered to chlorite, kaolin, and biotite, with simultaneous separation of silica.

35. Biotitic graywacke-slate, from a middle horizon. Specimen 9627 (slide 3343), 1550 N., 0 W., Sec. 29, T. 45 N., R. 1 W., Wisconsin.

A dark gray aphanitic banded rock.

The thin section is exceedingly fine grained. It consists of a confused mass of quartz, feldspar, chlorite, biotite, and ferrite, with perhaps some sericite.

36. Chloritic biotite-slates, from an upper middle horizon. Specimens 9609 (slide 4428), 100 N., 1525 W.; 9610 (slide 4429), 140 N., 1540 W.; 2098, Wis. (slide 304), south line Sec. 21, at point where intersected by Tylers fork, Sec. 21, T. 45 N., R. 1 W., Wisconsin.

The rocks are black, fine grained to aphanitic, and break readily across the slaty cleavage with a subconchoidal fracture.

The thin sections consist of intimately mingled minute particles of quartz, feldspar, biotite, chlorite, and dark opaque patches of ferrite or altered pyrite. In these, as in the previously described sections, the biotite and chlorite are in part at least plainly secondary to feldspar. These slates are somewhat coarse grained, and therefore show more plainly their fragmental character than do most of the slates of the district.

37. Chloritic biotite-slate, from an upper middle horizon. Specimen 9608 (slide 3340), 475 N., 910 W., Sec. 21, T. 45 N., R. 1 W., Wisconsin.

The rock is like 36.

The thin section is finer grained than those in 36, but is otherwise like them.

38. Biotite-graywacke, from an upper middle horizon, interstratified with 9608. Specimen 9607 (slide 3339), 550 N., 910 W., Sec. 21, T. 45 N., R. 1 W., Wisconsin.

The rock is dark gray, of a uniform medium grain, massive, and breaks with a subconchoidal fracture.

In thin section this rock differs from 387 in 34, in that the chlorite is less and biotite more abundant. They were originally of the same composition. The difference at the present time is due to the fact that the feldspars underwent different alterations in the two cases. Pyrite is present in abundant small grains and crystals.

39. Chloritic graywacke, from an upper middle horizon, interstratified with 9607 and 9608. Specimen 9606 (slide 4427), 715 N., 885 W., Sec. 21, T. 45 N., R. 1 W., Wisconsin.

The rock is like 38.

The thin section resembles closely 3341 and 3342 in 34. It differs from them chiefly in containing a smaller proportion of finely crystalline interstitial material, and in that the fragmental quartz and feldspar are in larger grains. The almost complete decomposition of the feldspar and the resultant formation of chlorite, biotite, muscovite or sericite, and finely crystalline quartz are nicely shown.

40. Biotite-slate, from an upper middle horizon. Specimen 9605 (slide 3338), 740 N., 885 W., Sec. 21, T. 45 N., R. 1 W., Wisconsin.

The rock is dark gray, exceedingly fine grained; contains numerous minute particles of pyrite, and is given a mottled appearance by cleavage surfaces of feldspar.

The thin section consists chiefly of biotite, quartz, and feldspar, the latter mineral now being much less abundant than the other two. The little remaining feldspar is in the last stages of alteration, its resultant products being mainly biotite and quartz. The decomposition of each grain of feldspar produced many particles of quartz and folia of biotite. In many cases polarized light is necessary to discover the remaining feldspar of a partly decomposed individual, so closely do its alteration products resemble in appearance the remainder of the section. It is quite probable also that in most cases the decomposition of the feldspars has been complete, and that all of the biotite and much of the quartz are secondary products. Scattered uniformly through the section are rather plentiful grains and crystals of pyrite.

41. Chloritic sericite-schist, from an uppermost horizon, mingled with Keweenaw greenstones. Specimens 9629 (slide 4430); 9630 (slide 3345), 120 N., 150 W., Sec. 17, T. 45 N., R. 1 W., Wisconsin.

The rock is light gray, moderately fine grained, banded, and breaks with a subconchoidal fracture.

The thin section has a groundmass of small blades and fibers of pale green chlorite and colorless sericite, with a little biotite, which contains numerous small fragmental grains of quartz and fewer of feldspar. The individuals of the latter mineral are usually badly decomposed, the alteration products being chlorite, sericite, and biotite. In some cases cores of feldspar surrounded by these secondary products are comparatively fresh.

*Section between Tylers fork and Potato river.*

42. Chloritic graywacke-slate, from a lower middle horizon. Specimens 12777 (slide 5467); 12778 (slide 5468), the SW. ¼ Sec. 24, T. 45 N., R. 1 W., Wisconsin, on the Wisconsin Central Railway.

These rocks are almost precisely like 32, the only differences being that 12778 is slightly schistose, while 12773 is massive and white mica flakes are plentiful.

In thin section these rocks are almost precisely like those of 32. The only differences are that fragmental white mica (sericite) is more, biotite less, and pyrite more plentiful than in that number.

43. Chloritic graywacke-slate, from a lower middle horizon. Specimen 12779 (slide 5469), NE. ¼ of the SW. ¼ Sec. 24, T. 45 N., R. 1 W., Wisconsin, on the Wisconsin Central Railway.

This rock is like 12773 in 32, except that it is of a darker color.

The thin section is like 5463 in 32, except that the amount of black material, either impure iron oxide or iron oxide, pyrite, and carbonaceous material is greater.

44. Biotite-graywacke, from an upper horizon. Specimen 9598 (slide 3334), 0 N., 600 W., Sec. 15, T. 45 N., R. 1 W., Wisconsin.

The rock is of a dark gray color, medium grained, uniform texture, and breaks with conchoidal fracture.

This section is coarser grained than that of any of the previously described biotitic graywackes, but resembles them in essential points. Clastic particles of quartz and feldspar, well rounded, compose two-thirds or more of the mass of the rock. A few of the quartz grains are finely complex, and nearly all of them are distinctly enlarged. The alteration of feldspar to biotite is very nicely shown. The freshest of the feldspar grains are surrounded by and more or less deeply intersected with secondary biotite. These grains yet retain their well rounded form, but in many cases the original exteriors of the feldspar grains are lost. Often the entire surfaces of the feldspars include very numerous particles of the biotite, there remaining throughout such areas here and there little spots of feldspar, which together polarize as units. The rather sparse matrix of the rock consists of finely crystalline quartz, of feldspar, and of biotite. Much of this fine quartz is doubtless a secondary infiltration material and the biotite is believed to be secondary to feldspar.

This section is one of the finest yet described to show the alteration of feldspathic areas into numerous small folia of biotite. (Pl. XXXII, Fig 3.)

45. Biotitic graywacke, from near the top of the series. Specimen 9595 (slide 3332), 700 N., 1940 W., Sec. 14, T. 45 N., R. 1 W., Wisconsin.

The rock is dark gray, rather fine grained, massive, and breaks with a subconchoidal fracture.

In thin section medium sized clastic particles of quartz and feldspar are set in a finer matrix, which consists of particles of these minerals mingled with much biotite in small folia and with less plentiful white mica (sericite). As in the mica-schists previously described, many of the feldspar particles are altered to biotite to a greater or less degree.

*Section at Potato river and vicinity.*

46. Chloritic graywacke-slate, from a lower middle horizon. Specimen 9107 (slide 2789), 1925 N., 1990 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin.

The rock is dark gray, exceedingly fine grained, finely schistose, and shows upon the cleavage surface numerous minute particles of pyrite.

In thin section small fragmental particles of quartz and feldspar are set in an exceedingly fine matrix, consisting chiefly of quartz and chlorite. Mingled with the chlorite are flakes of sericite or kaolin. Throughout the section are many small areas of dirty somewhat altered pyrite.

47. Biotitic and chloritic graywacke, from an upper middle horizon. Specimen 9109 (slide 4418), 1800 N., 0 W., Sec. 13, T. 45 N., R. 1 W., Wisconsin.

The rock is dark gray, medium grained, massive, and breaks with conchoidal fracture.

The thin section is almost precisely like that of 38. The particles of quartz are distinctly enlarged; many of them are notable for the very numerous partly liquid filled cavities which they contain. (Pl. XXXII, Fig. 4.)

48. Biotitic and chloritic graywacke, from an upper horizon. Specimen 9110 (slide 2902), 390 N., 1980 W., Sec. 7, T. 45 N., R. 1 E., Wisconsin.

The rock is like 47.

In thin section the rock is almost precisely like that of 47.

49. Biotitic graywacke-slate, from an upper horizon. Specimens 9111 (slide 2790); 9112 (slide 2923), 35 N., 940 W., Sec. 12, T. 45 N., R. 1 W., Wisconsin.

The rock is dark gray, fine grained, and varies from massive to finely laminar.

In all essential points the thin section is like 3329 in 27. As in it, there is much biotite, which is certainly secondary to feldspar.

50. Biotite-slate, from near top of series. Specimen 9113 (slide 2903), 300 N., 940 W., Sec. 12, T. 45 N., R. 1 W. Wisconsin.

The rock is dark gray to black, aphanitic, finely laminated, and mottled by very numerous black cleavage areas.

The thin section, with the exception that black opaque material and pyrite are sparsely present, is exactly like 3322 in 10. (Pl. XXXIV, Fig. 4.)

51. Feldspathic quartzites and conglomerates from top of series, mingled with Keweenawan greenstones. Specimens 9115 (slide 4419), 9116 (slide 2905), 470 N., 30 W.; 9118 (slide 2906), 9119 (slide 3298), 470 N., 65 W., Sec. 11, T. 45 N., R. 1 W., Wisconsin.

The rocks vary from coarse grained gray vitreous quartzite to a conglomerate containing numerous pebbles several inches in diameter.

In thin sections large fragmental grains of quartz compose a good portion of these rocks. Mingled with the quartz is a considerable quantity of fragmental feldspar, also in large individuals. The quartzes are usually enlarged, this fact generally being easy to discover. Between the fragmental particles is finely crystalline quartz and other accessories in large quantity. In slide 2905 the finely crystalline quartz is mingled with actinolite, being cut through and through in every direction by it. The actinolite needles are also always included in the enlargements of the clastic quartz grains, but never in the cores. It is, then, plainly a secondary mineral, and about it the infiltrated quartz has crystallized. Some of the feldspars have decomposed, and in them is found, as secondary and replacing product, actinolite and quartz. In slides 2906 and 3298 the feldspars are badly decomposed, the secondary products being kaolin, large brilliantly polarized flakes of muscovite, and many smaller ones of biotite. These minerals are also included in the interstitial quartz and in slide 2906, and also in the enlargements of the old quartz grains. This section nicely illustrates the micaceous alteration of feldspar, by the decomposition of which, accompanying the micas, saturating quartz has been formed. Many of the pebbles in the conglomerate are large, interlocking, complex fragments of quartz. (Pl. XXXII, Fig. 1.)

*Section in the north part of T. 45 N., R. 1 E., Wisconsin.*

52. Chloritic graywacke, from a lower middle horizon. Specimen 9123 (slide 2794), 300 N., 0 W., Sec. 8, T. 45 N., R. 1 E., Wisconsin.

The rock is dark gray, fine grained, massive, and breaks with conchoidal fracture.

In thin section small particles of quartz, generally enlarged and sometimes finely complex, with fragments of feldspar, both of greatly varying magnitudes, compose from one-half to two-thirds of the rock. The feldspar includes orthoclase, microcline, and plagioclase. Many of the feldspars are much altered, while some of them are almost or quite decomposed, the resulting products being mainly chlorite and quartz, although with these minerals are found sericite, or kaolin and ferrite. The matrix consists chiefly of finely crystalline quartz, with some amorphous silica, mingled with which are a considerable quantity of chlorite and a little kaolin or sericite and ferrite. In the matrix are also numerous irregular patches of opaque material, which is in part gray and in part black. These patches are probably mixtures of ferrite and partly altered pyrite. The section is that of a fine grained typical graywacke.

53. Chloritic graywacke, from a middle horizon. Specimen 9124 (slide 2908), 1200 N., 0 W., Sec. 8, T. 45 N., R. 1 E., Wisconsin.

The rock is like 52.

The thin section is like that of 52.

54. Chloritic graywacke, from an upper horizon. Specimen 9126 (slide 2909), 1000 N., 55 W., Sec. 5, T. 45 N., R. 1 E., Wisconsin.

The rock is coarser grained than 52 and 53 and contains crystals of pyrite, but otherwise is like them.

The thin section differs from those of 52 and 53 only in being coarser grained.

*Section near east range line of R. 1 E., Wisconsin.*

55. Magnetitic clay-slate, from base of formation. Specimen 9148 (slide 2924), 1100 N., 40 W., Sec. 1, T. 45 N., R. 1 E., Wisconsin.

The rock is gray, fine grained, finely laminated, and easily cleavable along the lamination. Composition: Silica, 52·58; alumina, 20·76; iron sesquioxide, 12·17; iron protoxide, 4·08; manganous oxide, ·21; calcium oxide, ·30; magnesium oxide, 1·33; potassa, 4·87; soda, .37; lithia, trace; water, 3·43:=100·10.

In thin section the groundmass is very finely divided. It appears to consist of quartz, feldspar, kaolin, with perhaps chlorite and biotite. In this groundmass is contained very numerous small crystals of magnetite. The analysis well bears out the appearance of the section.

56. Magnetitic clay-slate, from near base of formation. Specimen 9139 (slide 2911), 1200 N., 1975 W., Sec. 6, T. 45 N., R. 2 E., Wisconsin.

The specimen differs from 55 only in being of a darker color. Composition: Silica, 53·44; alumina, 19·62; iron sesquioxide, 11·38; iron protoxide, 5·35; manganous oxide, trace; calcium oxide, ·42; magnesium oxide, 1·58; potassa, 1·73; soda, 2·61; lithia, trace; water, 4·07; phosphoric acid, trace: = 100·20.

The thin section differs from that of 55 only in that its matrix and the contained crystals of magnetite are both somewhat coarser.

57. Chloritic graywacke, from a lower middle horizon. Specimens 9078 (slide 2778); 9079 (slide 2779), 0 N. to 100 N., 0 W., Sec. 36, T. 46 N., R. 1 E., Wisconsin.

The rocks are like 52 and 53.

As in 52, 53, and 54, in thin section, fragmental particles of quartz and feldspar compose a large portion of the rocks. The quartz grains are usually enlarged. The feldspars comprise both orthoclase and plagioclase and are frequently quite fresh. The abundant matrices consist of finely crystalline quartz, of chlorite, of sericite or kaolin, and of opaque brown or black ferrite. In a few places small flakes of biotite are seen. In fragmental material and siliceous paste, as in other particulars, these rocks are typical graywackes.

58. Chloritic graywacke, from a middle horizon. Specimen 9077 (slides 3296 and 3377), 700 N., 0 W., Sec. 36, T. 46 N., R. 1 E., Wisconsin.

The rock is like 57.

The thin section is like those of 57.

*Section between the east range line of R. 1 E., Wisconsin, and the west branch of the Montreal.*

59. Chloritic graywackes, from a middle horizon. Specimens 9068 (slide 2922), 1115 N., 1560 W., Sec. 28; 9066 (slide 2889), 1040 N., 160 W., Sec. 29, T. 46 N., R. 2 E., Wisconsin.

The specimens are almost exactly like 54.

The thin sections in no essential points differ from that of 54.

60. Chloritic graywackes, from an upper middle horizon. Specimens 9071 (slide 3295), 1380 N., 180 W.; 9072 (slide 2890), 1400 N., 605 W., Sec. 29, T. 46 N., R. 2 E., Wisconsin.

The rocks resemble closely the previously described graywackes.

The thin sections are in essential particulars like the chloritic graywackes previously described. The fragmental grains of quartz are always distinctly enlarged. While many of the feldspar areas are quite fresh, others are badly kaolinized and chloritized. The abundant matrix is of the same composition as in the previous chloritic graywackes. It, however, contains a little biotite and muscovite. Here and there are black opaque areas which appear to be ferrite, but which may contain pyrite or carbonaceous material.

61. Chloritic graywacke, from an upper middle horizon. Specimen 9070 (slide 4415), 1950 N., 1540 W., Sec. 28, T. 46 N., R. 2 E., Wisconsin.

The rock is precisely like 60.

The thin section is rather finer grained than that of 60; otherwise it is like it.

*Section east of the west branch of the Montreal and in the vicinity of the Montreal river.*

62. Graywacke-slate, near base of formation. Specimen 9030 (slide 2917), 530 N., 1470 W., Sec. 24, T. 46 N., R. 2 E., Wisconsin.

The rock is dark brown, fine grained, finely banded, and cleaves readily along the plane of lamination.

In thin section fragmental quartz and feldspar in grains of small size compose perhaps one-half of the mass of the rock. The grains of feldspar are mostly much chloritized or kaolinized. The particles of quartz have frequently been enlarged. The abundant filling material is chlorite, finely crystalline quartz, dark brown oxide of iron, and black iron oxide, a portion of which appears to be magnetite. This rock resembles very closely the fragmental rocks found at the base of the Upper slate at Black river.

63. Graywacke-slate, from a lower horizon. Specimen 9166 (slide 2928), 715 N., 1700 W., Sec. 24, T. 46 N., R. 2 E., Wisconsin.

The rock differs from 62 only in being of a dark green color.

The thin section differs from that of 62 only in that some of the iron oxide is magnetite.

64. Chloritic graywacke-slate, from a lower middle horizon. Specimen 9026 (slide 2882), 1350 N., 1000 W., Sec. 22, T. 47 N., R. 47 W., Michigan.

The rock is dark greenish-gray, very fine grained, and finely laminated.

In thin section the rock differs from the graywackes just described chiefly in being much finer grained. There is much fragmental quartz, and feldspar appears, but it is very fine grained, while the matrix is extremely so.

65. Chloritic graywacke, from a lower middle horizon. Interstratified with 64. Specimen 9027 (slide 2883), 1350 N., 1000 W., Sec. 22, T. 47 N., R. 47 W., Michigan.

The rock is gray, medium grained, massive, and breaks with conchoidal fracture.

In thin section the rock is a typical graywacke. It differs from that of 54 only in being slightly finer grained and in containing calcite.

66. Chloritic graywacke, from an upper middle horizon. Specimen 9163 (slide 2925), 1150 N., 1100 W., Sec. 22, T. 46 N., R. 2 E., Wisconsin.

The rock is like 54.

In most points this section is like the previously described graywackes. Many of the fragmental feldspars, however, are large and fresh. They comprise both orthoclase and plagioclase, a portion of the latter being microcline. The alteration of feldspar to kaolin or muscovite is nicely illustrated, some of the feldspar areas containing very numerous flakes.

67. Chloritic graywacke, from an upper horizon. Specimen 9034 (slides 2884 and 2918), 555 N., 1445 W., Sec. 14, T. 46 N., R. 2 E., Wisconsin.

The rock is gray, medium grained, massive, and breaks with conchoidal fracture.

The thin sections closely resemble that of 54. Very plainly fragmental quartz and feldspar in grains of medium size compose two-thirds of the sections. The quartz grains are often slightly enlarged. The feldspars are frequently fresh and often also much altered, the alterations resulting in the formation of sericite or muscovite, chlorite, and perhaps a little biotite. The matrix is like those of the previously described chloritic graywackes, except that sericite or muscovite is here present.

68. Chloritic and sericitic graywacke, from near top of series. Specimen 9032 (slide 2770), 720 N., 1280 W., Sec. 14, T. 46 N., R. 2 E., Wisconsin.

The rock is like 67, except that it is finer grained.

The thin section is finer grained than that of 67. It also differs greatly from it in that it has a much more crystalline appearance, equaling in this respect many of the chlorite-schists west of the south end of Gogebic lake. The crystalline appearance is made still stronger by the fact that while the quartz particles are exceedingly angular, it is with the greatest difficulty that enlargements can be seen to cause this angularity—in most grains quite impossible. The mineral constituents are identical with those of 67, but sericite is much more plentiful than in it, and both the sericite and chlorite are mostly in rather small, well defined leaflets. That all of these two minerals are secondary to feldspar can not be shown, although a large portion of them certainly is of this nature. However, from the association with and likeness to 67, it can not be doubted that both are of like origin—that is, altered mechanical sediments. It is also certain that the crystalline appearance of 67 is due to the prevalence of the sericitic and chloritic alteration of feldspar, combined with the separation of quartz in the interstices and the enlargement of the quartz particles.

*Section at and west of Black river.*

69. Chloritic clay-slate, from a middle horizon. Specimen 9194 (slide 2932), 1200 N., 1140 W., Sec. 13, T. 47 N., R. 47 W., Michigan.

The rock is gray, aphanitic, and shows a slaty cleavage which cuts across the bedding plane.

The section is exceedingly fine grained. It appears to consist of a confused mixture of chlorite, kaolin, quartz, ferrite, mingled with which are here and there a few larger grains of quartz which appear to be clastic.

70. Pyritic clay-slate, from a lower horizon. Specimen 12530 (slide 5334), 1000 N., 1200 W., Sec. 17, T. 47 N., R. 46 W., Michigan.

The rock is light gray, very fine grained, and contains a large amount of pyrite, both disseminated through the rock and in large irregular masses.

The thin section consists of a confused mass of minute particles of quartz, feldspar, chlorite, kaolin, ferrite, and perhaps other clay-forming minerals. Contained in this material are abundant crystals and areas of pyrite.

71. Chloritic graywacke, from an upper horizon. Specimen 10417 (slide 4021), 800 N., 1340 W., Sec. 10, T. 47 N., R. 46 W., Michigan.

The rock is gray, of a rather fine uniform grain, and massive.

In the thin section, fragments of quartz and feldspar of varying sizes compose two-thirds or more of the rock. The feldspar fragments are often quite fresh and comprise orthoclase, microcline, and plagioclase. The filling material is finely crystalline silica, chlorite, kaolin, and ferrite.

72. Chloritic graywacke, from a lower middle horizon. Specimen 9517 (slide 2986), 325 N., 715 W., Sec. 10, T. 47 N., R. 46 W., Michigan.

The rock is gray, rather fine grained, massive, breaks with subconchoidal fracture, and contains large fragments of black cherty material.

In thin section, rather large fragmental particles of quartz and feldspar, the two minerals being in about equal abundance, compose the greater part of the rock. The grains of quartz are usually quite widely enlarged. A portion of the feldspar is relatively fresh, but the greater part of it is much chloritized and kaolinized. The interstitial material consists of quartz, chlorite, kaolin, ferrite, with some biotite and muscovite.

73. Micaceous graywacke-slate, from a lower middle horizon. Specimen 9518 (slide 3090), 325 N., 715 W., Sec. 10, T. 47 N., R. 46 W., Michigan.

The rock is dark gray, fine grained, finely laminated, and the cleavage surface shows numerous glittering flakes of mica.

In thin section, rather small clastic particles of quartz and feldspar compose about one-half the bulk of the rock. The grains of quartz are generally enlarged and the feldspars are usually much decomposed. The interstitial material consists of quartz, chlorite, biotite, muscovite, and ferrite. Folia of muscovite and biotite are arranged with their longer axes in a common direction, as though the rock had been subjected to squeezing.

74. Chloritic clay-slate, from a low horizon. Specimen 9515 (slide 2985), 250 N., 1750 W., Sec. 11, T. 47 N., R. 46 W., Michigan.

The rock differs from 69 only in that its cleavage and bedding correspond.

The thin section is like that of 69.

75. Clay-slate, from base of formation. Specimen 9493 (slide 4422), 700 N., 1015 W., Sec. 12, T. 47 N., R. 46 W., Michigan.

The rock is dark olive green to black, aphanitic, finely laminated, cleaves parallel to the bedding and also in another direction, cutting across the first at an obtuse angle. Included are particles and nests of pyrite.

The thin section is excessively fine grained. It appears to consist of finely crystallized quartz, partly amorphous silica, chlorite, feldspar, ferrite, and crystals of pyrite. Quite a proportion of the quartz and feldspar are, however, coarse enough to show that the rock is a fragmental one.

## SECTION II.—ORIGIN OF THE UPPER SLATE ROCKS.

From what has preceded, it is evident that the association of the mica-schists and mica-slates of the Upper-slate member with the graywackes and graywacke-slates is of a most intimate nature, both as to composition and occurrence. The same set of minerals occur in both classes of rock; they are closely interstratified with each other. There is an identical change in each class in mineral composition in passing from east to west, and in any one region the change occurs simultaneously in both classes. Finally, there is every gradation between them, and the placing of many specimens in one class rather than in the other is somewhat arbitrary. It becomes, then, probable that the original condition of the graywackes and graywacke-slates and the mica-schists and mica-slates must in the main have been the same. As some of the graywackes are completely fragmental, others somewhat crystalline, others still more crystalline, thus grading into the crystalline mica-schists and mica-slates, we will begin with those which are nearest their original condition and trace the processes step by step in which the original rock has been changed into a fully crystalline mica-schist.

A general notion of the graywackes and graywacke-slates has already been given. Before proceeding to trace these processes of alteration it will be necessary to describe in more detail the graywackes which are near their original condition.

Macroscopically the graywackes vary from tolerably coarse grained to aphanitic. Many of them are apparently completely massive in hand specimen, and such break with conchoidal fracture, although even these in exposure show more or less of a cleavage along the bedding planes. Specimens of the graywacke-slates show a decided tendency to cleave parallel to the bedding. In color these rocks vary from light gray or light green, through various shades of gray and green, to almost black. Under the microscope the only difference between the graywackes and graywacke-slates is one of fineness of grain. The least altered varieties of them may be divided into two classes, one being composed mostly of tolerably large well rounded particles of quartz and feldspar (Pl. XXXII), and the other having feldspar predominant, little or no quartz being present (Pl. XXXIII, Fig. 1). The feldspars commonly comprise orthoclase, microcline, and plagioclase. Usually some of the feldspars are altered to a greater or less extent to chlorite, sericite, muscovite, biotite, and kaolin. In the interstices there may be a small quantity of finely crystalline quartz. In many cases, however, the graywackes and graywacke-slates are not so simple in composition. Mingled with the larger particles of fragmental quartz and feldspar are finer particles of the same sort, with other minerals (Pl. XXXII, Fig. 4). When this finer silt is preponderant the graywackes and graywacke-slates grade into the clay-slates or phyllites. Naturally, in a belt in which the above described simple graywackes and clay-slates both occur there would be found gradations between them. Frequently in the same specimens we find mingled coarse and fine material. As the quantity of finer material increases it becomes increasingly difficult to trace the exact changes which have taken place in the minerals. Unless all of the material is excessively fine, i. e., unless the rock passes into a clay-slate of the finest possible sort, the processes of change subsequently described are seen to have taken place with the larger particles of quartz and feldspar in these fine grained slates. The graywackes, besides showing great variation in appearance, due to the mingling of coarser and finer material, occasionally contain so much ferrite—brown iron oxide—as to make this substance a chief constituent. Pyrite, some carbonate (calcite, dolomite, or siderite), and rarely carbonaceous material are also quite often present as more or less plentiful accessories.

(1) *Quartzose graywacke* (Pl. XXXII).—In the freshest of the quartzose graywackes many of the particles of feldspar are as unaltered as in ordinary granite, but generally they have decomposed to a greater or less extent. This decomposition has ordinarily taken place to a greater degree near the exteriors of the feldspar particles than in their centers. In the particles in which the decomposition has been somewhat extended the alteration has affected the regularity of the original fragmental oval outlines. Upon the other hand, even when alteration has progressed quite to the centers of the feldspars, the original outlines may at times be quite sharp. The minerals which have resulted from the partial alteration, and

which therefore are included by or closely encircle the feldspar, are chlorite, sericite or muscovite (or both), biotite, probably kaolin, and quartz. In the grains which have decomposed to the greatest extent, the original feldspar remaining and the mica and quartz most intricately interlock, so that an examination with a moderately high power which covers only one original individual of feldspar or a part of one gives the appearance of a completely crystalline rock in which the interlocking is of the most intricate sort; yet when the same grain is examined with a low power its rounded character is evident, and that the area is but an altered feldspar is manifest, while the completely fragmental character of the rock as a whole is plain at a glance (Pl. XXXII, Figs. 2 and 3).

The fragmental grains of quartz, although now unusually sharply angular, often show with perfect clearness well rounded cores, their present angularity being due to a renewed growth subsequent to their deposition in their present resting place. Commonly the majority of the grains of quartz are simple, but at times many of them are more or less finely complex, or even of a chalcedonic character. The quantity of this kind of quartz varies greatly, rarely becoming almost or quite as abundant as the simple quartz fragments. In the interstices of the rock is found usually a little finely crystalline quartz, which is of a secondary nature, as plainly so as are the enlargements of the fragmental quartz grains. In the simplest quartzose graywackes and graywacke-slates little else is present. In these specimens it is evident that the induration which has often occurred is caused almost wholly by the enlargement of quartz fragments and the separation of finely crystalline quartz in the interstices, thus completely filling the spaces which originally existed between the loosely piled fragments and making the rock as compact and strong as though it were a granite. The green and gray colors of the rock (in the absence of ferrite) are due to the secondary products of the feldspar, chlorite, biotite, etc.; green when chlorite, gray when muscovite and biotite are preponderant. The original conditions and secondary changes of the simplest of the graywackes are thus clear. They were quartz-feldspar sediments, mingled in places with a little clayey matter, perhaps also with a small quantity of fragmental mica and some ferrite. They reached their present condition by a secondary enlargement of quartz fragments; the deposition or formation in situ of interstitial finely crystalline quartz, accompanied with a micaceous or chloritic alteration of the feldspar—the first two being processes already fully described by us.[1]

Before following further the series of changes which explains the metamorphosis of fragmental sediments to mica-slates and mica-schists, it is important to recall the chemical changes[2] which occur in the alteration of orthoclase, microcline, and oligoclase to chlorite, muscovite, and biotite. The average content of silica of the following minerals is taken from Dana's System of Mineralogy: Orthoclase and microline, 65 per cent; oligoclase, 62 per cent; muscovite, 45 per cent; biotite, 40 per cent; chlorite, 25 to 30 per cent. Evidently where the alterations of orthoclase, microcline, and oligoclase to muscovite, biotite, and chlorite have taken place so extensively as in the rocks under discussion, it is not difficult to explain the presence of the silica which has enlarged the fragments of quartz, replaced those of feldspar, and separated as independent interstitial quartz. One of these alterations is stated by Tschermak[3] to occur as follows: "Wenn man die dreifache Formel des Feldspathes 3 ($K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$) mit jener des daraus entstandenen Glimmers $K_2O{\cdot}Al_2O_3.2SiO_2 + 2\,(H_2O{\cdot}Al_2O_3{\cdot}2SiO_2)$ vergleicht, so ergibt sich, dass von der ursprünglichen Menge $6SiO_2$ nur $2SiO_2$ in die neue Verbindung übergehen und $4SiO_2$ übrig bleiben." In further speaking of the alteration of orthoclase to muscovite, Tschermak also observes: "Der neue entstandene Muscovit ist öfters auch von Biotit (Magnesiaglimmer) begleitet."

For the iron of the biotite and chlorite in the rocks under consideration, it is not difficult to account. Pyrite, marcasite, and ferrite are quite widely present in these rocks as accessory constituents. Often the relations of the pyrite or marcasite and biotite (folia of the latter surrounding particles of the former) are such as to lead to the supposition that the former min-

[1] On Secondary Enlargements of Mineral Fragments in Certain Rocks. R. D. Irving and C. R. Van Hise. Bull. U. S. Geol. Survey, No. 8.

[2] I insert freely, without quotations, here and in the following pages, such parts of an article by me on this subject, already published—Am. Jour. Sci., 3d series, vol. XXXI, 1886, pp. 153–159—as can be used.

[3] Lehrbuch der Mineralogie, zweite Auflage, p. 462.

erals have furnished the iron necessary for the transformation from feldspar to biotite. At all events, they indicate a sufficient supply of iron.

For a part at least of the magnesium of the biotite and chlorite, it seems that we must look to some source extraneous to the feldspar fragments; i. e., we must regard it as having been supplied by some other mineral or by percolating waters. That calcium-bearing and magnesium-bearing waters have been present in these rocks is evident from the occasional presence of secondary calcite and dolomite. Partial analyses of three of the biotite-schists gave an average content of MgO of 2.22 per cent, which if entirely contained in the biotite would correspond to a probable proportion of that mineral of from 10 to 20 per cent.[1]

(2) *Muscovitic and biotitic graywacke* (Pl. XXXIII, Fig. 1).—Macroscopically, this rock is gray, medium grained, and massive. It breaks with a conchoidal fracture. Under the microscope large fragments of feldspar, with the alteration and replacement products of the latter, compose the rock. Most of the feldspar is orthoclase, although both microcline and plagioclase are present. Much of it is quite fresh, many individuals showing no alteration further than a slight kaolinization. Other feldspar fragments, however, include in each many grains of quartz, or a single large reticulating quartz individual and numerous flakes of muscovite and biotite. Here the quartz, muscovite and biotite are plainly replacements and alteration products of the feldspar. In rare cases this alteration has proceeded so far as to leave but irregular, partly replaced and altered cores of feldspar which are entirely surrounded with the secondary quartz, muscovite, and biotite.

The finer grained parts of the rock are composed of finely crystalline quartz, a portion of which may be clastic; of feldspar, the proportion being smaller than in the coarser parts, probably on account of the more extended alterations in the small particles; and of biotite and muscovite. The mica is here clearly also to a very large extent secondary to feldspar, while there is little doubt that the small remaining fraction of the mica is of the same origin. Scattered through the finer portions of the section are

[1] Lehmann, in his work on the "Entstehung der altkrystallinischen Schiefergesteine," demonstrates the formation of abundant secondary biotite and other minerals as accompanying metamorphoses by folding. His work does not state, however, from what the biotite developed.

numerous small particles of a black substance which is taken to be partly altered pyrite or marcasite, and perhaps partly carbonaceous material. The induration in the rock is due to the formation in situ of quartz, or infiltration of silica, from which finely crystalline quartz has formed, assisted by the partial transformation of the feldspars into interlocking complex areas of quartz, mica and feldspar, which also interlock with the material of the matrix.

(3) *Biotitic graywacke* (Pl. XXXIII, Fig. 2).—Macroscopically, this rock differs from (2) only in being of a darker gray color; and under the microscope also it is much the same, except that micaceous alteration of the feldspars has been carried farther. Fragments of feldspar, with its secondary products, compose most of the section. The alterations of feldspar to biotite and quartz are beautifully shown. The freshest of the feldspar grains are surrounded and more or less deeply penetrated by secondary biotite. These grains yet retain their well rounded forms. However, in many cases, the original outlines of the grains of feldspar are lost, although often the complex aggregate of resulting biotite folia and quartz, mingled with the remaining feldspar, retain very perfect general roundish or oval forms. Often the entire surfaces of the feldspars include very numerous particles of the biotite and quartz—the former usually much the more plentiful—there remaining through such areas here and there little spots of feldspar which act as a unit in each area. With a low power such areas appear to be roundish aggregates of biotite. It is only with a higher power that the remaining feldspar and its true relations to the biotite are discovered. In this rock all the stages of the process of alteration of the feldspars are nicely shown from those areas in which the secondary biotite forms but a film around the feldspars to those in which no feldspar remains, there being in the place of the fragmental feldspars interlocking aggregates of biotite and quartz. Even these areas often so perfectly retain their general oval or roundish character that, taken by themselves, they would be regarded in the sections as peculiar complex fragments, which in this condition had become worn and deposited. Taken in connection with these other grains present, there can be no doubt of their formation by the alteration of feldspar. As from a single large particle of feldspar many individuals of quartz and mica are

formed, the result of the alteration is to make the rock a finer grained one.

The rather sparse matrix of the rock does not differ materially from that of (2), except that it contains more mica. The induration is caused by the same processes as in (2).

(4) *Muscovitic biotite-slate* (Pl. XXXIII, Figs. 3 and 4).—Macroscopically, this phase of rock is mottled dark gray and black, quite massive. The mottling is due to more or less distinct roundish areas, which show in a greater or less degree cleavage. In some of the specimens the roundish areas are distinctly outlined, and in these cases the cleavage is eminent. In others, these areas are indistinctly outlined; and in such the cleavage is less plain. Under the microscope the grains showing cleavage macroscopically are found to be well rounded, partly altered feldspars, mostly of the species orthoclase. These feldspars are set in a groundmass which consists of intimately mingled minute grains of quartz and brown folia of biotite with a considerable quantity of ferrite. In some specimens the quantity of matrix is considerable, even equal or greater than the known feldspar fragments and the material coming from them. In other cases, however, the feldspar areas were set very close together with room for little other material. The partial decomposition of the fragmental feldspar has resulted in the formation of very numerous small folia of biotite, fewer larger ones of muscovite, and also quartz. In the fresher feldspar areas the secondary mica is found most plentifully at or near the exteriors of the grains, although in almost every case the alteration has proceeded to a greater or less degree quite to the centers. In some specimens most of the original feldspar grains are yet chiefly unaltered, and in these the mottling and cleavage, seen macroscopically, is most distinct. In other specimens nearly every feldspar grain has almost wholly altered to mica and quartz, and in such specimens, those which are most completely altered and now therefore consist of a complex interlocking aggregate of quartz and mica, with little or no remaining feldspar, are with great difficulty separated from interstitial material. Many also are doubtless so completely changed as to be indistinguishable from the matrix. In the matrix of the rock it is usually quite impossible to determine if any of the quartz is fragmental. In some specimens some grains are certainly so, as

evidenced by rounded cores and secondary enlargements. The biotite of the matrix is in part plainly secondary to feldspar and is precisely like that found in the larger feldspars The folia are deep brown and very strongly dichroic, and therefore probably bear a large percentage of iron. Doubtless much of this matrix is due to the decomposition of fragmental feldspars, which were smaller than those which yet remain partly unaltered, and which have therefore completely altered to mica and quartz.

The feldspar plainly shows this rock to have been fragmental, and the alteration of feldspar to both biotite and muscovite upon a large scale is most beautifully shown. The large quantity of dark brown and black ferrite has doubtless furnished the iron required for the formation of the biotite. The peculiar spotted appearance of the sections, the distinctness of the spots varying with the freshness of the feldspar, viewed without the microscope, gives a clear idea, when taken in connection with their appearance under the microscope, of the processes by which the rock reached its present condition.

This rock must as deposited have been a tolerably coarse grained one, many of the larger, fresher feldspars averaging about 1 mm. in diameter, but the alteration of each of these most changed feldspars in the specimens to a vast number of mica folia and quartz grains has caused the rock to become exceedingly fine grained, there remaining, however, perfect proof even in these specimens of the original rounded fragmental character of some of the feldspar.

(5) *Nearly crystalline muscovitic biotite-schist* (Pl. XXXIV, Fig. 1).—Macroscopically, this rock is fine grained, grayish, and quartzose, with small mica flakes visible. Under the microscope the thin section shows a fine grained groundmass of quartz and feldspar in which are abundant muscovite and biotite. Many of the quartz grains include numerous folia of mica. The feldspar areas include quartz and both muscovite and biotite. This section by itself if not examined closely would be taken to be of a completely crystalline mica-schist in which the interlocking and mutual inclusions of the different minerals are of the most intricate kind, but, like the other mica-schists of the Penokee series, it is an ordinary clastic rock in which the metasomatic changes have gone very far. The large areas of quartz,

including folia of mica, are in the places of feldspar fragments. As the feldspar has altered to mica the excess of silica has separated as quartz. Frequently the alteration of a single feldspar has resulted in the formation of a single ramifying individual of quartz with several or many included folia of mica, mingled with which are detached remnants of the feldspar. In this rock in such cases the mutual interlocking of these four minerals, muscovite, biotite, quartz, and feldspar, could not possibly be more intricate in any schist, gneiss, or granite. In other cases the decomposition of a feldspar has resulted in the formation of many grains of quartz as well as numerous folia of mica. In yet other cases the feldspar areas have not altered to such an extent as described above. In almost every case the rounded exteriors of the clastic grains are lost, but irregular areas of considerable size often remain which include but few folia of biotite or little replacing quartz, or both. The folia of mica in this rock are the largest anywhere found in the mica-schists, many of them being 1 mm. in length. The biotite has a remarkably strong dichroism, and both biotite and muscovite have well defined cleavages.

(6) *Crystalline muscovitic biotite-schist* (Pl. XXXIV, Fig. 2).—Macroscopically, this rock is rather fine grained. It has a finely laminated structure, along which the rock most readily breaks, although it is massive enough to break quite easily across the direction of lamination. The individuals of quartz and feldspar are too small to be seen with the naked eye, but are distinguishable with a lens. The very abundant black, glittering flakes of mica are large enough to be readily seen. A lens shows the rock to contain a considerable quantity of pyrite.

Under the microscope with a medium power the sections show a rather fine grained, apparently completely crystalline, typical mica-schist. The groundmass consists chiefly of quartz, mingled with which is considerable feldspar, both orthoclase and plagioclase. The grains of quartz vary considerably in size, but none are minute and none large, the largest being not more than ½ mm. in diameter. Some few of the largest, which are now very irregular in outline, contain rounded cores, proving them to be fragmental, and these cores do not include folia of mica. Much of the feldspar present is quite fresh, many of the plagioclases exhibiting sharply defined twinning bands and these may be secondary developments. Biotite in well defined folia of varying size, the larger being about ½ mm. in length, is very abundant. Muscovite is much less abundant. The folia of mica often cut through the smaller quartz-grains and into those of the feldspars, just as in a typical crystalline schist. That much of the mica is a secondary product can not be proved from the sections from the locality of English lake, taken by themselves. A portion of it is, however, certainly of this nature. Many grains of feldspar are so cut by folia of mica as to make it probable that the latter is a secondary product, while some of the larger particles of feldspar contain throughout their areas folia of mica and grains of quartz which, with the remaining feldspar, give an appearance of most intricate interlocking, as in no case do the grains of feldspar now show the rounded outlines which they once doubtless had. This mica included in the feldspar is precisely like that of the remainder of the rock—the word matrix for remainder can hardly be used, for in coarseness of grain the parts of the rock which show no trace of fragmental origin are about the same as the quartz and mica included in the feldspars, and which, taken in connection with the rocks previously described, are regarded as proving that this rock, like them, was once altered sediments. Quite numerous crystals of pyrite are seen.

The rocks (2) to (6), above described, thus constitute a graded series from the fresh feldspathic graywackes to the crystalline mica-schists. The gaps here left in these typical descriptions may be filled in by following the detailed descriptions of the graywackes and graywacke-slates and mica-slates and mica-schists (pages 309–326). Here the wide interval between the most plainly fragmental graywackes and the most crystalline mica-schists is completely filled by almost imperceptible stages, and the processes which caused the alterations are clearly indicated; *the result being the production from a completely fragmental arkose rock, by metasomatic changes only, of a rock which presents every appearance of complete original crystallization, and which would be ordinarily classed as a genuine crystalline schist.*

*Black mica-slates* (Pl. XXXIV, Figs. 3 and 4).—The series of alterations above described has also been very important in the production of various black mica-slates of the Penokee series. Macroscopically, these slates are all exceedingly fine grained and finely laminated, cleaving readily along the planes of lamination. In color they vary from dark gray to black. A lens shows many of them to contain numerous small particles of pyrite. Very numerous roundish black areas are contained in the fine grained, gray material in many of the specimens. These areas in some cases show distinct cleavage surfaces and are taken to be large fragmental particles. In other cases they are dull and break without giving cleavage surfaces, while in yet other specimens these darker spots are not found at all.

Under the microscope the rocks which have the mottled appearance described above consist of two parts, a finely crystalline matrix and coarse, well rounded fragmental feldspars, which are always altered to a greater or lesser extent. This alteration is to biotite and quartz, many small folia of biotite and grains of quartz always being found in a single feldspar individual. Every gradation of this change is seen, from grains of feldspar which contain but little biotite and quartz to those in which the remaining feldspar is just sufficient in quantity to enable one to perceive that the detached particles are parts of a common individual. Doubtless also the alteration to biotite and quartz has often been carried out completely. Accompanying the biotite, thus secondary to the feldspar, is much black, opaque, partly altered pyrite in minute particles. The black, roundish spots seen macroscopically are evidently the partly altered feldspar fragments. The degree of this alteration as determined by microscopical study corresponds exactly with the appearance of the rock as seen in the various hand specimens. In the specimens in which the feldspar areas are well outlined and show clearly marked cleavage surfaces, the biotitic and quartzose alteration has taken place to but a small extent. In the specimens in which the feldspars are obscurely outlined and which lack cleavage the alteration has extended very far. The matrices of these rocks and the sections of those not containing large grains of feldspar are composed of intimately mingled quartz, feldspar, biotite, and pyrite, with perhaps a little organic matter.[1] A portion of the quartz is certainly frag-

[1] Geol. Wis., vol. III, p. 136.

mental, as is evidenced by secondary enlargement. The biotite is all believed to be due to the alteration of feldspar, much of it certainly being of this nature. The matrices of the different sections vary in coarseness and in the relative proportions of the various mineral constituents, but are alike in all essential points.

We have here plainly a series of rocks which are parallel to (4), the chief differences between the two sets of rocks being that the black mica-slates are much finer grained, that they contain more pyrite, and also contain carbonaceous material. As the unaltered or partly unaltered feldspars are as large as in (4), it is probable that the greater fineness of grain in the black mica-slates at present is simply due to the fact that the feldspars altered to smaller individuals of mica and quartz in them than in (4).

*Source of material.*—It will be later shown that between the Penokee series and the Southern Complex there is a great structural break, the clastic series having been laid down by water action upon the older crystalline formations. From the description of the Upper slate, it is evident that the most of its material has been derived from a set of acid rocks, its two predominating constituents being quartz and acid feldspar in various degrees of comminution. There is no reason to believe that the Southern Complex, which stretches a great distance southward, was ever covered throughout the whole of its extent by this newer series; and as the material of which this upper belt is composed is of precisely the character which would be expected if derived from its granite, gneiss, and schist, it may be considered as probable that this is the source of the material of the Upper slate. This hypothesis receives reenforcement when the distribution of the granitic and schistose areas is considered, and the material which they are able to supply is compared with that of the material of the Upper slate member at adjacent points. With the exception of a few miles the newer series of rocks is directly in contact with areas of green schists as far west as Penokee gap. Without doubt the contiguous granite in the western part of Michigan and south of the schist areas has also furnished its quota of material; so that it has come, not from the schist alone, or the granite or gneiss alone, but from both of them. In passing westward toward Bad river, as has been seen, there is a gradual change in the nature of the original material of the Upper slate, it becoming more and more strongly feldspathic; west of Bad river practically all of it was feldspar of an acid character. By reference to chapter I it will be seen that the Western granite, which reaches the newer series in the vicinity of Penokee gap, extends west and south for a long distance. The granite contains an unusually small quantity of quartz, being either a true syenite or a granite in which the quartz is usually not abundant. There is clearly a connection between the character of this part of the Upper slate and the underlying rock. The degradation of the latter, accompanied by natural sorting, has furnished the nearly pure feldspar material which originally constituted the Upper-slate member and made it of such a composition that it was possible by metasomatic processes to produce from it a fine grained crystalline mica-schist.

*Summary.*—1. The rocks of the Upper-slate member are mechanical sediments, which have been everywhere altered to a greater or less extent by metasomatic changes, and at times the alterations have extended so far as to produce crystalline schists.

2. In general, the eastern part of the formation is less altered than the western part. Here the prevailing rocks are clay-slates, graywackes, and graywacke-slates. In passing to the westward the rocks become more crystalline in character, and at the extreme west end only mica-slates and mica-schists are found.

3. While this is true in a general way, in the same vertical section there may be found all phases of the transformation from completely fragmental rocks to crystalline schists. As far east as Sec. 14, T. 46 N., R. 2 E., Wisconsin, a rock which is very close to a crystalline schist is found. At the Penokee gap section the most completely fragmental graywacke of the whole member occurs, and in this section there are all gradations to that but one degree removed from the most crystalline phases found in the formation. Even in a single exposure in this section are found plainly fragmental graywackes and mica-slates, and micaceous graywackes which approach very close to a mica-schist.

4. The parts of the Upper slate which have received large fragmental particles of quartz are those in which the clastic character is easiest to rec-

ognize, for the grains of quartz always remain in their entirety. It may be, and indeed usually is, the case that they have undergone a second growth and have thus become angular; but generally the original cores are easily discovered. In the nearly pure feldspar sediments, upon the other hand, when the feldspar has changed to other minerals, it is more difficult, and, taking a specimen of the most crystalline mica-schist by itself, impossible to make out the original fragmental character of the rock.

5. The more crystalline mica-schists are derived from nearly pure arkoses and in all cases the resultant schists are much finer grained than were the original sediments, for from each fragment of feldspar there has been produced several or many individuals of mica and quartz.

6. The material for the Upper slate has been derived from the Southern Complex, and there is a direct connection between the character of the rocks to the south and those of the slate belt adjacent. The greater part of the belt has received its material in part from the granitic and in part from the schistose areas; while the part of the belt west of Penokee gap has received nearly all of its material from the syenitic granite to the south and west.

# CHAPTER VII.

By C. R. Van Hise.

## THE ERUPTIVES.

Structural relations. General character of the rock. Comparison of Penokee greenstones with greenstones of the Southern Complex and Keweenaw series. Microscopical character of the diabases. Eruptives in the Iron-bearing member. Summary.

*Structural relations.*—The eruptives of the Penokee series are structurally of two classes. Some are sheets, while others are dikes. The field relations of many ledges, however, are not well enough exposed to show to which class they belong. The exposures in T. 44 N., R. 5 W., Wisconsin, are large, and there seems to be every indication short of demonstration that these rocks are really interleaved with the sediments of the Iron-bearing member. In the east part of T. 47 N., R. 46 W., Michigan, and the west part of T. 47 N., R. 45 W., Michigan, the iron-bearing belt has an unusual width. Here the eruptives are particularly abundant, as shown by natural exposure and by test pitting, and the relations of the greenstones and the iron-bearing rocks are such as to indicate that to some extent the greenstones are interleaved, but there is not sufficient evidence of this to enable one to make the assertion without qualifications. There is no absolute proof whether these interleaved greenstones are contemporaneous volcanic outflows which interrupted the deposition of the iron belt, or subsequent intrusions. All the evidence at hand is of a lithological character, and it points to subsequent intrusions rather than to contemporaneous flows. The rocks are medium grained, holocrystalline, nonamygdaloidal, and do not contain minerals in two generations; properties which are ordinarily taken as indicating that the rocks possessing them have solidified at depth.

The presence of very numerous dike-rocks in the iron-bearing belt has become apparent through exploring and mining operations. These dikes are much altered and soft, and therefore they do not outcrop, so that their existence would never have been otherwise suspected. In almost every mine in the whole district, and in many test pits, dike-rocks have been encountered. These vary greatly in thickness, running from but a few inches to 90 feet. The positions of these dike-rocks are given in detail in the discussion of the origin of the ores; and here it is only necessary to say that in general they cut across the iron formation nearly at right angles, and therefore were probably formed before the uplifting of the Penokee-Gogebic series. In quite a number of cases they have been traced into the underlying quartzite. Frequently the places of passage of the dike-rocks from the iron formation into the quartzite show faulting to a greater or less degree. This faulting along the line of dikes is illustrated by Pl. XXXI, Fig. 6.

In the Upper slate member the greenstones outcrop with sufficient frequency to show that they are quite plentiful, but it has not been possible to determine whether they are interleaved or are in the nature of dikes. It is not at all unlikely that both dike-rocks and sheets occur. Indeed it would almost certainly be the case that some material from the numerous dikes which pass through the iron belt would succeed in intruding itself between the layers. A large exposure on the Wisconsin Central Railroad, in the NE. ¼ of the NE. ¼ of Sec. 8, T. 44 N., R. 2 W., Wisconsin, gives indications that a certain amount of interleaving has taken place, the greenstones and slates being mingled, however, in a confused manner. The outcrop occurs just north of the railroad, and in passing eastward mixed greenstone and slate appear. There are several belts of almost pure slate contained in the greenstone, but after a time the slate is continuous. If the eruptive is a great dike, it may be that slate fragments have been caught by it; but it appears more probable that it has squeezed itself between the layers of the slate adjacent to the contact. The line between the Upper slate member and the overlying Keweenaw series is very irregular, and along this contact line at a number of places the slates and greenstones are mixed in the same confused manner as in the outcrop just mentioned. On the ground it is difficult at these places to say at what point the Penokee series ends and the overlying eruptives of the Keweenaw series begin. The slates are cut by masses of greenstone which seem to be at times interbedded and at other times in the nature of dikes. These relations are what would be expected along the line of contact of a fragmental series and an overlying eruptive one.

*General character of the rock.*—The igneous material of the Penokee series has all unmistakably been at the time of its intrusion one species of rock, diabase. Occasionally the diabases vary toward or into a gabbro, but this is exceptional, and all plainly belong together. The degree of alteration is very great at times, large masses of rock being totally decomposed; but even the most altered phases so frequently retain their diabasic structure and can be traced into a comparatively fresh rock that the conclusion is reached that they all are altered diabases. The eruptives in the central part of the Iron-bearing member (the ore-producing part) are those which are most altered. The greenstones in the Upper-slate member are much fresher upon the whole than those contained in the iron belt; while occasionally there is here found a fresh olivine diabase in which even the olivine is mostly unaltered. As there is every reason to believe that the rocks here found are contemporaneous with the dikes contained in the iron belt (are in fact, in all probability, in many cases but continuations of them), it would seem to follow that the great difference in degree of alteration in the two cases is due to the difference of characters of the rocks in which the dikes are contained. This difference in alteration is interesting in connection with what has previously been said in reference to the origin of the ores. It was noted that the iron-bearing belt (particularly in the part which bears ores) is much more readily penetrable by percolating waters than the slate belt. The lower horizon iron rocks have been subject, at least near the present surface, to a long series of changes which have been shown to be due to percolating waters. The ready penetrability of the Iron-bearing member by percolating water has also been favorable to the alteration of the inclosed greenstones. On the other hand, the Upper slate, composed of a series of clayey rocks, penetrable with great difficulty if at all by percolating water, contains greenstones which are relatively little altered.

*Comparison of Penokee greenstones with greenstones of the Southern Complex and Keweenaw series.*—The rocks underlying the Penokee series—the Southern Complex—contain here and there exposures which in all essential respects are like the diabases of that series. However, parts of the basic eruptives of the older succession are massive, profoundly altered greenstones and schistose rocks which are believed to have been greenstones, but if so they have undergone extreme metamorphism. That there should be eruptives here which do not differ in degree of alteration from those contained in the Penokee series is what would be expected, for through these underlying rocks must have passed the dikes which traversed the Penokee series itself, and doubtless the fresher greenstones represent parts of the same dikes which are found in the higher series.

The Keweenawan eruptives differ from those contained in the Penokee series in their great variety and also in their manner of alteration. The immediately overlying rock is in turn a coarse grained gabbro, a diabase, a diorite which at times is schistose or quartzose, a melaphyre, an augite-porphyrite, a porphyrite, and an amygdaloid. Not only do all phases of these basic rocks here occur, but in the same locality several may be found closely associated. In short, nearly all of the phases of the basic eruptives of the Keweenaw series occur, and in the sudden alterations from one phase to another and their intricate mingling they are typical of the series to which they belong.[1]

The Keweenawan eruptives above the Penokee series are the volcanic equivalents of the Penokee dikes and sheets. Along the contact line of the two series the eruptives are sometimes intricately related. These facts strongly suggest that the Penokee dikes are the pipes through which the volcanics passed. The identical lithological character of the dikes and sheets suggests that the former fed the latter. We are thus led to the hypothesis that all of these eruptives belong to a single period, the Keweenawan.

[1] Roland D. Irving: Monograph U. S. Geol. Survey, vol. v, Copper-bearing Rocks of Lake Superior.

*Microscopical character of the diabases.*—The diabases usually have a well developed ophitic structure, the augites being of large size and including many somewhat idiomorphic lath-shaped plagioclases. In the diabases in which this structure reaches the extreme the feldspars have a tendency toward two generations, there being, aside from the smaller lath-shaped plagioclases, larger, somewhat porphyritic appearing ones. The rocks vary from ophitic diabases to a true gabbro, all grades of variation being observed. In the passage from diabase to gabbro the feldspars become broader; the pyroxene includes less of feldspar, until in the coarsest grained rocks the structure is granitic (granular) and the contained pyroxene takes on the diallage cleavage. The gabbro occurs in only a few localities and is of little importance as compared with the diabases.

The original minerals are apatite, magnetite, olivine, plagioclase, and monoclinic and orthorhombic pyroxene. The latter occurs only in one exposure, and in the most widespread phase of rock the only important original minerals are magnetite, plagioclase, and augite. The order given is that of crystallization. In some of the rocks this succession can be made out with a good deal of sharpness, each mineral present having nearly completed its crystallization before the succeeding one began to separate. This is particularly true of the ophitic diabases and becomes less and less true in passing toward the gabbros.

In the minerals present and their relations there is nothing particularly different from other occurrences of diabase in the Northwest with the exception that an orthorhombic pyroxene is found. The points of most interest are found in connection with the alteration which the rocks have undergone. As has before been said, they vary from an almost perfectly fresh condition to one in which none of the original minerals remain. The rock in which the alteration has gone farthest is contained in the Iron-bearing member, and as this peculiarly altered rock is different from the ordinary altered rocks of the series it will be separately considered.

The apatite is but sparsely present in most of the rocks, but is occasionally found in quite plentiful large, well formed crystals. It is always the first mineral to crystallize and has the usual well developed crystal outlines.

Magnetite or menaccanite is always quite abundant. It occurs in small crystals or rod-like areas in the finer grained diabase to grate-like forms in the ophitic diabases, and in large solid grains in the gabbro. Usually it has to a greater or less degree crystal outlines. Very frequently it is altered to gray leucoxene, proving that it was originally menaccanite or titaniferous magnetite. Some of the grate-like mingled magnetite and leucoxene areas are very regular. More ordinarily the magnetite or menaccanite is but little altered. It is very often associated with secondary biotite.

The olivine, as usual, is found in roundish granules. It is present in comparatively few of the rocks, and these the fresher ones, but in one case is very abundant. It may have been a constituent of the much altered phases, but if so it has left no evidence of its presence. It is always altered to a certain extent, the most usual resultant product being pale green material, which is taken to be serpentine, but which in some cases may be chlorite.

Plagioclase is one of the two most abundant minerals of the rock. Only in a single exposure, that containing the orthorhombic pyroxene, is it subordinate in quantity. It is always striated and is found in small lath-shaped to large, broad individuals.

The feldspars of three of the freshest diabases were separated from the other constituents and analyses made. In only one of these cases was there two feldspars present. No. 1 (specimen 12880) is from a diabase from the southeast corner of Sec. 13, T. 47 N., R. 46 W., Michigan; No. 2 (specimen 9656) is from a gabbro from the center of the south half of Sec. 14, T. 44 N., R. 4 W., Wisconsin; No. 3 A and B (specimen 9108) are different feldspars from an olivine diabase from the NE. ¼ of Sec. 13, T. 45 N., R. 1 W., Wisconsin. The analyses are by Mr. Thomas M. Chatard of the chemical laboratory of the United States Geological Survey.

*Analyses of feldspars.*

| | 1 | 2 | 3A | 3B |
|---|---|---|---|---|
| $H_2O$ at 105° | .......... | ·03 | ·13 | .......... |
| $H_2O$ at red heat | 1·19 | ·54 | ·64 | ·95 |
| $SiO_2$ | 51·18 | 51·99 | 56 15 | 61 65 |
| $Al_2O_3$ | 27·00 | 29·32 | 26·05 | 19·91 |
| $Fe_2O_3$ | 3·19 | 1·23 | 1·98 | 2·28 |
| $FeO$ | (*) | (*) | (*) | (*) |
| $MnO$ | ·17 | trace. | ·13 | trace. |
| $CaO$ | 11·70 | 12·60 | 8·70 | 4·12 |
| $MgO$ | 1·92 | ·63 | ·54 | ·61 |
| $K_2O$ | ·41 | ·28 | 1·56 | 5·72 |
| $Na_2O$ | 3·48 | 2·91 | 4·79 | 4·74 |
| | 100·24 | 99.53 | 100·67 | 99·98 |

* Undetermined.

According to Zirkel's Mineralogie, p. 682, $Al_1An_2$ has the following composition: $SiO_2$, 51·34; $Al_2O_3$, 31·20; CaO, 13·67; $Na_2O$, 3·79. In No. 1, it will be seen that, if the alumina and ferric oxide are put together, the calcium and magnesium counted as the protoxide base equivalent to calcium, and the sodium and potassium be put together, this analysis corresponds almost exactly to the above theoretical calculation. Therefore it may be considered as very close to $Al_1An_2$, which, under the present accepted nomenclature, makes the feldspar labradorite.

According to the same authority $Al_2An_3$ has the following composition: $SiO_2$, 53·01; $Al_2O_3$, 30·06; CaO, 12·36; $Na_2O$, 4·57. The composition of $Al_1An_2$ has just been given. Combining percentages in the same way as before, it will be seen that No. 2 is intermediate in composition between $Al_2An_3$ and $Al_1An_2$, which again makes the feldspar labradorite.

From the same authority $Al_4An_3$ has $SiO_2$, 57·37; $Al_2O_3$, 27·12; CaO, 8·92; $Na_2O$, 6·59. Making allowance for the water contained in 3A, and combining as in the previous case, it is seen that this analysis corresponds very closely to this theoretical composition, which would place this feldspar at the acid end of the andesine series. The analysis of 3B, and particularly the large amount of potassium which it contains, would seem to indicate that we have here probably one of the anorthoclase series, and it is possible that the percentage of 1·56 per cent of potassium in 3A is accounted for by a mingling of anorthoclase and andesine. It is to be noticed that it is in the olivine diabase—that is, the rock which has an abundance of a basic mineral—that the most acid feldspar is found. These determinations are from the fresher rocks. Usually the feldspar is considerably decomposed, while not infrequently some unaltered plagioclase remains. The most usual alteration of the feldspars has resulted in giving it a gray turbid appearance, which is taken to be a kaolinitic decomposition. Frequently the inclosed flakes are large enough to give brilliant polarization colors. Next to this kaolinitic decomposition in frequency is a change to green pleochroic needles, which are amphibole, probable variety smaragdite. Independent needles of this kind not only occur in great abundance throughout the feldspar, but others have penetrated it, coming from the enlargement of augite and paramorphic hornblende. In some cases the feldspar is penetrated in every direction by these needles, so that but little of the original material remains. At times a green chloritic substance is contained within the feldspars, within which is developed epidote. Not infrequently, also, small blades of secondary biotite are found included.

The pyroxene is generally of the augitic variety, although in the rocks which approach gabbros it takes on a diallage parting. It has a slight pleochroism, varying from colorless to very pale reddish brown. In no section is the pyroxene entirely unaltered, while in many sections there only remain here and there detached cores of the original mineral, and not infrequently it has entirely decomposed. The most common alteration is to ordinary hornblende. The angle $c : \mathfrak{c}$ of the secondary hornblende is rather high, being in some cases more than 20°. Its pleochroism is normal. Ordinarily $\mathfrak{c}$ is greenish blue, $\mathfrak{b}$ bluish green, and $\mathfrak{a}$ pale bluish green to almost colorless. Less frequently $\mathfrak{c}$ is yellowish green, $\mathfrak{b}$ greenish yellow, and $\mathfrak{a}$ a light yellow. Rarely the alteration is to typical basaltic hornblende. Here $\mathfrak{c}$ is dark brown, $\mathfrak{b}$ brown, and $\mathfrak{a}$ a light yellow. The absorption is $\mathfrak{c} \geqq \mathfrak{b} > \mathfrak{a}$. The hornblende is usually paramorphic, a single large individual of hornblende resulting from one of pyroxene. The rare diallagic variety of pyroxene has generally altered to a green fibrous amphibole, which is taken to be smaragdite. But the most interesting fact in connection with the change of augite to amphibole is that the areas now found are at times larger than were the original augites; that is, a growth subsequent to the consolidation of the rock has occurred. This growth is much better illustrated by the diabases of the eastern area and its description is deferred to chapter VIII.

The series of alterations has not ended in the change from pyroxene to amphibole. The secondary amphibole has to quite an extent altered to biotite. The biotite is as clearly secondary to amphibole as the amphibole is to augite. In certain rocks in the Northwest, the alteration of hornblende to biotite occurs, definite crystallographic relations obtaining between the two; but in the Penokee rocks the alteration of each of the amphibole individuals has resulted in the formation, not of a single biotite, but in many small folia. All of the biotite is, however, not derived from the amphibole, for a considerable quantity of that mineral is found surrounding the magnetite areas, and, when the latter occurs in grate-like forms, filling the spaces between the bars. This biotite is also plainly secondary and is in the nature of a reaction mineral, the magnetite furnishing the oxide of iron necessary for its formation, while the surrounding minerals have furnished the remaining constituents. Magnetite areas inclosed wholly within feldspar are in some cases surrounded by such secondary biotite, and it would then seem that the plagioclase has largely furnished the material for the formation of the biotite.

All the minerals of the diabases have now been considered, except the rare rhombic pyroxene. This has its usual fine fibrous rectangular cleavage, and characteristically includes very numerous minute black particles along its parting. It is somewhat feebly pleochroic and is probably bronzite or hypersthene. It has a tendency to occur in idiomorphic six-sided forms, showing apparently two macropinacoids and the four planes of the domes. It is quite frequently surrounded by reactionary or intergrowth rings, which consist in part of minute, brilliantly polarizing particles. The rhombic pyroxene is in strong contrast with the more abundant colorless or pale brown augite. The augite has no black inclusions, does not ordinarily show rectangular extinction, and has a coarsely prismatic, nearly rectangular cleavage, instead of a finely fibrous rectangular one.

*Eruptives in the Iron-bearing member.*—The eruptives contained in the iron formation are mostly in the form of dikes. This is particularly true of its central part, but in T. 47 N., R. 45 W., Michigan, there are eruptives which are apparently interleaved. The great abundance of these dikes in the parts of the iron formation which have been cut by mining, and their relation to each other as well as to the containing formation, are shown by Pls. XXX and XXXI.

Macroscopically, the dikes vary in extent from a coarse diabase to a very fine grained rock. The fact that the greenstones included in the iron formation are as a whole altered to a much greater extent than the eruptives elsewhere in the Penokee-Gogebic series has been noted in a previous chapter. Even those which are very much altered retain the characteristic structure of a greenstone, although in some cases the decomposition has gone so far, or else the rocks were originally so fine grained, that they are now aphanitic. The greenstone structure is usually so pronounced that the writer in the field had little doubt as to the real nature of these rocks, even before they were traced into the less altered phases, and of course before a microscopical study of them was made. In several mines the same dike in different places is a comparatively little altered rock, which is properly a diorite, and a completely altered one, which is a typical soapstone. The great Colby dike presents a good instance of this, its major portion being, however, extremely altered. The color varies, depending upon the degree of alteration, from the dark greenish gray of the ordinary diabase of the Penokee-Gogebic series, through various shades of dark green and light green, to almost snow white. The more common phases of the rock are dirty greenish white. All are colored various shades of brown and red upon their surface and along the cracks by iron oxides, and oftentimes these stains have penetrated the solid dikes to a considerable distance. As a result of the decomposition the diabases have become very soft, so that they can readily be scratched by the finger nail, and a specimen may be broken to pieces in the hands. This softness has not resulted, however, in making them porous or less compact than when unaltered. Their non-penetrability by water is clearly shown by the fact that the interiors of the dikes are in the main unstained by iron oxide, which has colored red everything else adjacent. The rocks have a strong soapy feel, and because of this, and the fact that they are somewhat like rocks in other districts associated with iron ore, the miners have given them the name of soapstones. These soapstones in this district never have the schistose structure and sericitic appearance presented by the soapstones of the Marquette, Vermilion lake, and Menominee districts. This difference may be and, indeed, probably is, due to the fact that in the latter the rocks have been subject to powerful dynamic forces.

A microscopical study shows that in the less decomposed phases of rock the character of the alteration is not materially different from that already described as occurring in the diabases of other parts of the series; that is, the augite is merely altered to amphibole and the feldspar has been to some degree affected by gray decomposition. In other cases the alteration has resulted in the formation of green chlorite in the place of the augite, the feldspar being affected the same as in the previous case. When the decomposition has proceeded farther there appears quite often, in considerable quantity, a brilliantly polarizing material which is taken to be a zeolite.

When the decomposition has gone very far even the magnetite is mostly or wholly peroxidized. The place of the augite and feldspar is largely taken by a colorless or pale yellow material. Between crossed nicols this substance is often wholly dark or dull gray and does not change its appearance by rotation. At other times it polarizes as an obscure aggregate whose color and appearance are somewhat like those of serpentine, although analyses indicate that that mineral is not present. In all but the most altered phases some chlorite and apparently a little secondary quartz are present. Abundantly scattered through most of the sections are particles of limonnite, hematite, and sometimes magnetite. When the rock is so altered that none of the original minerals remain, the diabasic structure frequently is imprinted upon the homogeneous almost amorphous material. In the somewhat rare extreme degree of alteration, however, all definite structure has been obliterated, and such material, if examined by itself, gives no indication whatever of its origin. That these soapstones are altered diabases is shown by the facts: that in certain cases the same dikes exhibit little altered and extremely altered phases; that the great majority of the soapstones retain a distinct diabasic structure; and that the alterations of the minerals from their fresh condition to complete decomposition are traceable in all its stages. With the decay of the rock there has come about, as would be expected, a very considerable change in composition.

The analyses below are by Mr. Thomas M. Chatard of the chemical laboratory of the United States Geological Survey. No. 1 (specimen 12880) is a fresh diabase, from Sec. 13, T. 47 N., R. 46 W., Michigan. The feldspar of this diabase is labradorite, No. 1 of page 352 being from this rock. No. 2 (specimen 12878) is from the same dike, where the alteration has extended to a middle stage; and No. 3 (specimen 12966) is typical soap rock from the Aurora mine, in the NE. ¼ of the SW. ¼ Sec. 23, T. 47 N., R. 47 W., Michigan.

*Analyses of diabases and soapstone.*

| | 1 | 2 | 3 |
|---|---|---|---|
| $H_2O$ at 105° | ·15 | 3·12 | ·29 |
| $H_2O$ at red heat | 2·34 | 8·25 | 13·54 |
| $CO_2$ | ·38 | 1·89 | ·38 |
| $SO_3$* | ·03 | ·06 | ........ |
| $P_2O_5$ | ·13 | ·16 | ·14 |
| $SiO_2$ | 47·90 | 46·85 | 41·60 |
| $TiO_2$ | ·82 | 1·12 | 3·79 |
| $Al_2O_3$ | 15·60 | 22·62 | †37·20 |
| $Fe_2O_3$ | 3·69 | 5·12 | 3·21 |
| $Cr_2O_3$ | trace. | ........ | ........ |
| FeO | 8·41 | 1·58 | ·30 |
| NiO (CoO) | ·10 | ·08 | ........ |
| MnO | ·17 | 2·54 | ·08 |
| BaO | 05 | ·10 | trace. |
| CaO | 9·99 | 1·25 | ·23 |
| MgO | 8·11 | 2·01 | ·02 |
| $K_2O$ | ·23 | 2·66 | ........ |
| $Na_2O$ | 2·05 | ·80 | ·07 |
| | 100·15 | 100·21 | 100·85 |

* $SO_3$ calculated from BaO found, as this latter probably exists as $BaSo_4$.

† $Al_2O_3$ is probably a little high owing to alkali retained by titanic acid.

The analyses indicate that in the decomposition of these rocks the minerals become hydrated; that the silica lessens in quantity; that the relative proportion of alumina is largely increased; that the calcium, magnesium, and iron protoxide are almost wholly removed; and that the relative proportion of titanic oxide is increased, this probably being due to the fact that all of the titanium which was originally present in the magnetite remains in the decomposed rock. The percentage of silica which is taken away is really larger than is indicated by the difference between 1 and 3, since in the latter so large a proporton of water is present. Pure kaolinite, $H_4Al_2Si_2O_9$ contains $SiO_2$, 46·50; $Al_2O_3$, 39·56; $H_2O$, 13·94. Disregarding the small amount of impurities in No. 3, its composition corresponds very closely with this mineral. It seems plain that, as a result of the leaching action to which the lower part of the iron formation is subjected, the dikes—that is, augite-plagioclase-magnetite rocks—are so changed that their composition is very close to that of the mineral kaolinite; although it is possible that this average composition is due to several important minerals rather than to a single one.

That the diabase dikes high up in the Penokee series are really continuations of the dikes which cut nearly at right angles the underlying iron formation there can hardly be a doubt. The contrast between the two is a striking instance of the influence of environment upon the decomposition of a rock. The diabases inclosed by the impervious Upper slate have been kept in a well preserved condition through the ages which have elapsed since their intrusion, and some of them are remarkably fresh. Other parts of the same dikes in a formation which contains evidences of having been long subject to the action of percolating waters have been completely decomposed. It thus appears that in this case environment has been a far more important element than age in the preservation of the rock.

*Summary.*—The Penokee eruptives are of two classes. Dikes cutting the formations, and interbedded sheets, which are probably intrusions of the same age as the dikes.

The eruptives are diabases, which occasionally pass over into gabbros.

Diabases in every respect like those of the Penokee series are found both in the Southern complex and in the Keweenaw series. These are all presumably of the same age; that is, Keweenawan.

The Penokee diabases are in all respects typical rocks of their class.

In one case a rhombic pyroxene of some interest is present.

While the diabases of the Upper slate member are often quite fresh, these rocks have generally undergone an extensive series of alterations;

the feldspars having altered to or been replaced by kaolin, chlorite or smaragdite; and the pyroxene having passed over into hornblende, biotite or chlorite.

The alterations have extended farthest in that part of the Iron-bearing member containing the great bodies of ore; that is, in those parts of the formation which have been subject to the action of percolating waters. This alteration has gone so far that often none of the original minerals remain. All traces of the original structure of the rock may even be lost, although frequently the diabasic structure remains imprinted upon the homogeneous almost amorphous material which results from the complete alteration of the rock.

The strong contrast in the characters of the diabases in the Upper slate and Iron-bearing members shows that environment may be a more important element than age in the preservation of a rock.

# CHAPTER VIII.

By C. R. Van Hise.

## THE EASTERN AREA.



### INTRODUCTION.

The area east of the center of T. 47 N., R. 44 W., Michigan, or roughly east of the Little Presque Isle river, differs from the simple successions described in the previous chapters in many important points. As will be seen later, the differences are due to the fact that this area was the center of great contemporaneous volcanic activity. Consequently the succession includes large thicknesses of volcanic tuffs and lava flows. These beds are not paralleled by any that are found in the western area. Further, this volcanic material has greatly disturbed the normal succession of belts in the district, so that it is difficult to certainly correlate the formations east of the Presque Isle with those west of it. Another point in which this area differs from the western area is that in one place the relations of the horizontal Eastern sandstone to the Penokee series can be made out. The subject is divided into the following sections: The Iron-bearing member; the fragmental rock south of the greenstone-conglomerates; the greenstone-conglomerates; the fragmental and ferruginous rocks north and east of the greenstone-conglomerates; the greenstones; stratigraphy.

### SECTION I.—THE IRON-BEARING MEMBER.

*Distribution.*—The rocks naturally and artificially exposed east of the Little Presque Isle river which can certainly be referred to the Iron-bearing member, although quite numerous, do not form as continuous a belt as do similar rocks to the westward. Through the east part of T. 47 N., R 44 W., Michigan, and the west mile of T. 47 N., R. 43 W., Michigan, the gaps between the exposures are in each case about a mile, while in one instance a gap of 2 miles occurs. East of this latter point prospecting has shown rocks of the Iron-bearing member to be practically continuous for about 4 miles; i. e., from the southwest part of Sec. 20 to the northwest part of Sec. 23, T. 47 N., R. 43 W., Michigan. East of the latter point no rocks are found which certainly can be referred to the Iron-bearing member.

In the easternmost section of the western area of the Iron-bearing belt the exposures spread over a horizontal distance greater than at any other locality in the whole Penokee series, extending as they do from the northeast part of Sec. 21 to the northwest part of Sec. 15, T. 47 N., R. 44 W., Michigan, a distance of nearly a mile. The most of the exposures of this section are south of a huge ridge of basic eruptives, some of them being in contact with this rock. North of this eruptive, and about a half mile north of the nearest exposure of iron-bearing rocks to the southward, are exposed by a test pit rocks which undoubtedly belong to the Iron-bearing member. The only other locality where the thickness of the belt approaches that here attained is west of Sunday lake, and here again the apparent thickness is in part and perhaps largely due to eruptives. For the distance between these two points the Keweenaw series directly overlies the Iron-bearing member. In the eastern area the rocks belonging to the Iron-bearing member constitute, as far as at present known, a narrow belt, narrower than anywhere to the west. The causes of this change from extreme width to extreme narrowness will be discussed later.

*Petrographical character.*—The locations of the exposures belonging to the iron formation are found upon Pl. XIII and indicated in the tabulations to follow. The kinds there found include nearly every phase of rock characteristic of the Iron-bearing member west of the Presque Isle. This likeness of the rocks east and west of this stream is such that no question can be entertained as to their identity of character and origin. A general discussion of the original nature and subsequent modifications of the rocks of the Iron-bearing member has been given in another place and need not be here repeated. It is, however, worthy of note that in some of the ferruginous cherts in T. 47 N., R. 43 W., Michigan, are found very numerous small geodic cavities which are lined with quartz crystals. That this quartz is of a secondary nature, or at least has been rearranged since the rock was originally formed, can hardly be doubted. The close association of siderite, magnetite, hematite, actinolite, and quartz is finely shown by one exposure. The relations here are such as to indicate that the magnetite has formed directly from siderite, as has hematite so extensively in the iron-bearing belt to the west. Further, the actinolite appears wherever quartz is found, while the quartz present in the section is in irregular veinlike forms cutting across the lamination. The conclusion is that this quartz is secondary, and that at the time it formed a portion of the silica in solution united with the bases present—calcium, magnesium, and iron—to form the actinolite. We have here, then, another reenforcement of the argument given for the derivation of the actinolitic slates from an original cherty carbonate.

*Mingled fragmental and nonfragmental sedimentation.*—The one important point in which the iron-bearing rocks east of the Little Presque Isle differ from those to the westward is that they are interstratified with a greater or less quantity of mechanical sediments. This mingling of fragmental and nonfragmental sediments has occurred so extensively in the eastern area that a new color is used upon Pls. II and XIII to designate this additional phase of rock. This color is intermediate between the yellow of the Quartz-slate member and the brown of the Iron-bearing member. It is thus chosen because the ledges so marked contain a large amount of both fragmental and nonfragmental material, and are therefore intermediate between the two members. This new characteristic of the rocks of the series is noted as far west as in the west part of Sec. 17, T. 47 N., R. 44 W. Here are cherts and jaspers which contain a varying and even a large amount of fragmental quartz and feldspar (Pl. XXXV, Fig. 1). Apparently interstratified with these rocks are clay-slates which are largely mechanical sediments, although it is difficult or impossible to determine exactly what proportion of the very fine material in these slates is fragmental and what nonfragmental.

In Secs. 19, 20, 21, 22, and 23, T. 47 N., R. 43 W., Michigan, the iron-bearing rocks have been located in many places by explorations, but the numerous test pits there sunk have as often struck the soft chloritic slate as the iron-bearing rocks proper. The cross-cuts from these test pits clearly show that in the distance north and south through which the iron-bearing rocks occur there are also several or many intermediate layers of clay-slates or other partially fragmental rocks, and in some cases there is interstratified with the iron-bearing rocks a vitreous quartzite. The succession of rocks in Sec. 21 is as follows: At the south are well developed exposures which belong to the feldspathic quartz-slates, the exposures containing both the characteristic variegated slates, and above these next to the iron formation a vitreous quartzite. To the north follow a series of interlaminated cherty ore formation rocks and chloritic slates of some thickness. Farther, to the north in a test pit is shown vitreous quartzite, the particles of which are chiefly large grains of quartz which have had a second growth. Still farther to the north is again found lean cherty ores, and again north of these, after passing an interval of some distance which is unexplored, is found a wide belt of ferruginous fragmental slates. Where the slates belong in the succession will be discussed later; but disregarding the last mentioned rock, there is here found several interlaminated belts of fragmental and nonfragmental sediments at a horizon which, from its relations to the Quartz-slate member and the character of a portion of the rocks contained, must be considered as belonging to the iron-bearing formation.

In the southern part of Sec. 20, T. 47 N., R. 43 W., Michigan, iron-belt rocks occur over a distance of about one quarter of a mile north and south. The first explorations were carried on in the extreme southern part of the section. Here, resting upon a basic eruptive flow, is a conglomerate the matrix of which is largely nonfragmental. This peculiar conglomerate is considered fully in another connection and need not at present be noted further. Above this conglomerate there is within a few paces of one another ankerite, chloritic and quartzose siderite, and actinolitic quartz rock. This occurrence well illustrates the mingling of fragmental and nonfragmental sediments, the quartz of the quartzose siderite being fragmental. Also here, in striking juxtaposition, are unaltered carbonate and completely altered actinolitic slates. Other rows of test pits, running north and south, extend for some distance east and west from the east line of the section to three-quarters of a mile west of that line. Each of these rows shows interlaminated layers of purely nonfragmental sediments, which are typical ferruginous cherts and mixed ores, and layers of chloritic slates, which, while very fine grained, are in some cases certainly partly fragmental, and are believed to be mainly a finely divided mechanical sediment. A westward extension of this belt, as judged by its course to the east (Pl. XIII), would carry it through the extreme south part of Sec. 19 and the north part of Sec. 30, T. 47 N., R. 43 W. This expectation of a westward extension of the belt is further indicated by exposures of a westward continuation of the basic eruptive flow found in Secs. 18 and 29. The only outcrops of rock, however, which are here known to occur cannot be referred to the Iron-bearing member, but must be placed in the intermediate phase of rock referred to above, being about one-half a fragmental and one-half a nonfragmental sediment. At the exposures in the north part of Sec. 30 the mechanical sediment is preponderant, while in the exposures in Sec. 19 the rock is a conglomerate which contains fragments of jasper, quartz, and feldspar interlaminated with narrow seams of jasper which appear to be nonfragmental. It is of course possible that the iron-bearing rocks proper occur in Secs. 19 and 30, but explorations have not yet developed the fact. So far as we are able to judge by present knowledge the belt which in Secs. 20 and 29 is largely a nonfragmental sediment becomes to the west in the next sections largely a mechanical sediment.

*Probability of ore deposits in the eastern area.*—We are now in a position to judge as to the probability of finding iron ore in paying quantities in the eastern area. The position of the ore deposits in the main area to the west and the conditions which favor their concentration have been discussed. It will be remembered that they in general rest upon a fragmental foot-wall quartzite, and that the concentration has been possible because of the penetrability of the layers of the formation by percolating waters combined with the impervious character of the belts of rock north and south of the Iron-bearing member, as well as the presence in a peculiarly favorable condition of numerous impervious dikes. In the eastern area it is evident that none of these conditions are found. In the first place the original iron carbonate, instead of being deposited in a single homogeneous belt 800 feet in thickness, is scattered through a much greater thickness of rock, part of which is more largely a fragmental than nonfragmental sediment. Second, the different layers of the iron-bearing rock which are purely nonfragmental are separated from one another by almost impervious layers of chloritic and clay-slates or eruptive outflows; so that it is not possible for the concentration to have gone on as a unit, as in the western area. Instead of having a single impervious basement for the nonfragmental rocks we have several or many such basements. In each one of these narrow belts there could have been but a scant supply of iron carbonate from which iron ore deposits could have formed. It would thus follow that if concentration has taken place in these belts the deposits there formed would be of small size. Again, many of the rocks of the iron-bearing belt in the eastern area belong to the actinolitic slate type. It has been already noted that in the main area, where the ore formation is mainly of this type of rock, no ore deposits have been discovered. Finally, at the base of the belt itself we have no proof that there is a continuous layer of feldspathic quartz-slates, as is the case to the west.

It is, then, improbable that the eastern area will in the future be found to contain large ore deposits although small ore-bodies may be found. This improbability, arrived at inductively, is still further reenforced by the fact that extensive explorations throughout its whole extent have failed to find a single workable ore deposit.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.[1]

1. Magnetitic, sideritic, and actinolitic slate. Specimens 12696 (slide 5416), 12697, (slide 5417), 1000 N., 1850 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

The rocks are dark gray to black, mostly fine grained, laminated, the lighter colored belts being coarser grained than the others.

In thin sections a background of finely crystalline interlocking quartz contains abundant magnetite, siderite, actinolite, and some hematite. Both the magnetite and siderite, in certain belts, exclude the other minerals. The light gray belts seen macroscopically are very largely siderite. These sections illustrate the simultaneous occurrence of quartz, magnetite, hematite, actinolite, and siderite, as well as any thin sections from the Penokee district. The magnetite and actinolite are closely associated, as is usual in the actinolitic slates; also in the almost solid masses of siderite; wherever quartz occurs, actinolite is abundantly present. The quartz is mostly in vein-like forms as though it were a secondary mineral. This association of actinolite with the quartz suggests that the entrance of silica was necessary in order that the actinolite might form. The quartz in slide 5417 differs from that found in any other section of the series in that the individuals are several times longer than broad. The elongation of the grains corresponds to the banding of the rock. This arrangement and interlocking of the quartz grains are those of a much squeezed crystalline schist.

2. Magnetitic actinolite rock. Specimen 10403 (slide 4494), 1164 N., 1779 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

In thin section, an interlocking felted mass of actinolite, stained red by hematite, contains numerous crystals and areas of magnetite, the projecting edges of which show crystal outlines. A little finely crystalline quartz is also included.

3. Ferruginous actinolite-schist. Specimens 9354 (slide 3308), 9355 (slide 3119), 9356 (slide 3268), 300 N., 1500 W., Sec. 25, T. 47 N., R. 44 W., Michigan.

The rocks are dark green, fine grained, banded, and magnetitic.

[1] The numbers of specimens and slides are those of the collection of the Lake Superior division. Locations are given from the southeast corner of the sections in steps of 2,000 per mile.

Actinolite, chlorite, quartz, magnetite, hematite, and brown iron oxide are all found in the thin sections, but iron stained actinolite is predominant. The alteration of actinolite has formed the chlorite. The sections resemble closely those of 73 in the iron member west of the Presque Isle, p. 244.

4. Hematitic and magnetitic actinolite-schist. Specimens 9291 (slide 3011), 9292 (slide 3107), 1270 N., 1775 W., Sec. 30, T. 47 N., R. 43 W., Michigan.

These rocks are finer grained than those of 3, but are otherwise like them.

The minerals present and their relations are the same as in the previous number. The predominant actinolite, which is largely arranged in sheaf-like forms, is everywhere heavily stained with brilliant red hematite. Magnetite in crystals is abundant.

5. Hematitic cherts. Specimens 12581 (slide 5341), 500 N., 1000 W.; 12582 (slide 5342), 533 N., 810 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rocks are composed of alternate belts of white or gray chert and of red or brown iron oxide.

In thin sections a groundmass of finely crystalline, with perhaps some amorphous silica, contains both hematite and limonite, which are largely concentrated in roughly parallel belts.

6. Ankerite. Specimen 9264 (slide 4487), 75 N., 600 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rock is light gray, fine grained, massive, and breaks with conchoidal fracture. It sparingly contains pyrite in small crystals and thin layers of almost pure magnetite. The weathered surface is brown, from the presence of peroxide of iron. The following is an analysis made by Mr. W. F. Hillebrand: $SiO_2$, 3·16, $TiO_2$, none; $Al_2O_3$, 0·08; $Fe_2O_3$, 0·93, FeO, 15·18; MnO, 1·15; CaO, 26·65; MgO, 11·01; $H_2O$, 0·54; $CO_2$, 41·10; $P_2O_5$ 0·06, Cl, trace; $FeS_2$ 0·34. Total, 100·20.

The thin section consists almost wholly of an interlocking mass of finely but perfectly crystalline ankerite. Contained as accessories in this are small crystals of pyrite, magnetite, and small clusters of radiating needles of much altered actinolite.

7. Actinolitic chert. Specimen 9265 (slide 4488), 75 N., 600 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rock is light olive green, fine grained, and massive.

The thin section consists chiefly of the two minerals, quartz and actinolite. The quartz makes a finely crystalline interlocking groundmass, in which the actinolite is contained in clusters of small radiating blades. A little brown ferrite and a few crystals of magnetite are seen. The section is cut by a vein which is composed mostly of comparatively coarsely crystalline quartz, including almost indefinitely numerous minute long needles of actinolite, which are arranged parallel to one another.

8. Quartzose siderite. Specimens 9266 (slide 4489), 9267 (slide 4490), 100 N., 600 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rocks are dark green, rather fine grained and finely laminar.

The thin sections contain a matrix of siderite, with some quantity of finely crystalline quartz, in which are buried plentifully rather small fragmental grains of quartz and numerous areas of pale green fibrous chlorite. A little brown iron oxide and magnetite are found. These sections are intermediate between the nonfragmental rocks of the iron-bearing belt and the fragmental slates, and might with almost equal propriety be classed with one division as with the other.

9. Hematitic chert. Specimen 7402 (slide 1865), 1320 N., 615 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rock is red, aphanitic, and breaks with a conchoidal fracture.

The thin section is composed mostly of finely crystalline quartz. This includes hematite in finely disseminated particles and in areas of considerable size. The iron oxide and chert are arranged to quite an extent in more or less perfect concretions.

10. Siliceous hematites. Specimens 7384 (slide 1850), 1000 N., 75 W., 9250 (slide 4483), 1210 N., 450 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rock is a cherry red and black, banded, nearly pure hematite.

In thin section, a continuous ramifying mass of hematite contains numerous complex cherty areas.

## SECTION II.—FRAGMENTAL ROCKS SOUTH OF THE GREENSTONE-CONGLOMERATES.

*Geographical distribution.*—South of the Iron-bearing member, throughout all the main area and constituting one of the most characteristic features of the Penokee series, is the Quartz-slate member. The easternmost exposure of these slates in this area is in the north part of Sec. 21, T. 47 N., R. 44 W., Michigan. East of this point there is a break of about 4 miles, which, so far as at present known, is not bridged by a single exposure of a plainly fragmental rock referable to this belt. In the southwest part of Sec. 19, T. 47 N., R. 43 W., the first exposure east of the Little Presque Isle is found which can be regarded as the equivalent of the Quartz-slate member. From this point, running somewhat north of east to the northwest part of Sec. 23, T. 47 N., R. 43 W., are quite numerous exposures south of and mingled with the iron-bearing belt which have in places great likeness to or even lithological identity with the Quartz-slate formation to the westward. In Sec. 21, T. 47 N., R. 43 W., just east of the Presque Isle river and in the east part of the section, occur large exposures of slates and quartzites which in every way are lithologically like the feldspathic quartz-slates of the main area. Not only are these rocks similar, but their arrangement with reference to each other is the same as those to the west. The southernmost layers are green and brown variegated slates interleaved with layers of fine grained vitreous feldspathic quartzite, just as shown by the lower layers of the quartz-slates at the typical localities of Tylers fork, Potato river, and the west branch of the Montreal. Above these variegated slates are thick beds of coarse vitreous quartzite which outcrop in bold exposure. A very short distance north of the quartzites test pits have shown that the iron-belt rocks occur. Thus far at this point we have the typical Penokee succession, but test-pitting shows, as heretofore explained, that the iron-bearing rocks are mingled to a greater or less extent with fragmental material. East and west of Sec. 21, T. 47 N., R. 43 W., Michigan, are fragmental rocks, which are, however, not a separate belt below the iron formation, but are intercalated with its nonfragmental sediments.

*Petrographical character.*—It is not practicable to separate these fragmental rocks into sharply defined divisions, as the different phases grade into each other by insensible degrees. They can be somewhat arbitrarily divided into quartz-slates including quartzite, and ferruginous feldspathic quartz-slates. As to this first division nothing more need be said, as they are precisely like rocks of the same name in the Quartz-slate member to the west. The second division comprises the following varieties: Ferruginous and feldspathic quartzite, sometimes conglomeratic, jasper-conglomerate, and ferruginous chlorite-slates.

The ferruginous feldspathic quartzites differ from the quartzites found in the main quartz-slate area to the west in that they contain a very large amount of iron oxide, which is mostly hematite, but mingled with limonite and some magnetite. In some specimens the hematite is so abundant as to form a continuous ramifying sheet in which is buried the worn fragments of quartz and feldspar. These fragments at several exposures are so large as to class the rock as a conglomerate.

The exposures shown by the test pits in the south part of Sec. 20, T. 47 N., R. 43 W., Michigan, are of peculiar interest because of their relations to the underlying eruptive, and the great likeness under the microscope of some of them to a large part of the greenstone-conglomerate, to be later described. Just south of the place of their occurrence is a high east and west ridge of diorite-porphyrite, which is a part of a flow outcropping at various places for a distance of two miles east and west. At the northern foot of this hill, dipping to the north, is the jasper-conglomerate, having a slaty matrix. The specimens from the test pits a few paces to the north are the nonfragmental sediments of the iron belt. In the matrix of this jasper-conglomerate are very numerous irregular compact fragments, which contain tabular plagioclases and which appear to be fragments of the fine grained basic eruptive just to the south. These fragments are often vaguely defined; they are extraordinarily irregular in form; they are very much altered. Besides these complex fragments there are found quite numerous angular particles of feldspar of moderate size. These may have been furnished by the porphyritic plagioclases of the underlying porphyrite. These two varieties of fragments are cemented by a groundmass which consists largely of cherty silica. This silica is around and between the fragments in narrow belts, just as it is found in a widespread phase of the greenstone-conglomerate. Contained in the above matrix are very numerous angular blood-red jasper pebbles of varying sizes, some of them being large enough to be classed as bowlders. These bright red jasper pebbles give the rock a very striking appearance. The only essential difference between this conglomerate and certain phases of the greenstone-conglomerates is in the presence of these jasper pebbles, and whether it ought to be classed here or with the greenstone-conglomerates is a somewhat doubtful question It is placed here because it is certainly a water-deposited fragmental rock, and is also certainly below the rocks of the iron-bearing belt.

The third phase of rock is the chloritic and clay-slates, which are plentifully interstratified with the nonfragmental iron-bearing sediments in Secs. 20, 21, 22, and 23, T. 47 N., R. 43 W., Michigan. Macroscopically, these rocks are soft, green or brown, aphanitic, finely laminated ones. Their constituents are difficult to make out with certainty. Some of the chief ones are quartz, chlorite, sericite, brown iron oxide, pyrite, and perhaps kaolin. How far these rocks are fragmental and how far nonfragmental sediments it is difficult to determine, so fine grained are they. In a portion of them some of the quartz is in small roundish areas which have an unmistakable fragmental character. Further, all of the characteristics of the rocks, both in hand specimen and thin section, are those of compact clayey sediments, which in all probability they are.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.[1]

1. Ferruginous and feldspathic conglomerate. Specimen 9295 (slide 3012), 150 N., 1750 W., Sec. 19, T. 47 N., R. 43 W., Michigan.

The rock is dark gray and massive, and the matrix is medium grained. The contained pebbles are jasper, white quartz, and green schist. They are mostly small, although occasionally one 10 inches in diameter is found.

A thin section from the matrix shows fragmental particles of quartz and feldspar of quite uniform size, the former composing perhaps four-fifths of the section. The grains of quartz are often enlarged, and some of them are finely complex. The feldspar is orthoclase, microcline, and plagioclase. Its grains are in part fresh, and in part also much kaolinized or partly altered to chlorite. In the interstices are finely crystalline quartz, dark brown iron oxide, and green chlorite.

2. Ferruginous and feldspathic quartzites. Specimens 7436 (slide 1891), 7437 (slide 1892), 1950 N., 1420 W.; 9285 (slide 2962), 9286 (slide 2963), 1975 N., 1350 W.; 9287 (slide 3008), 1940 N., 1390 W., Sec. 30, T. 47 N., R. 43 W., Michigan.

The rocks are dark gray to black, medium grained, and vary from massive to schistose, the darker colored specimens containing much oxide of iron.

In each of the thin sections the mineral constituents are the same as in the previous number, the only difference between the various sections being relative proportions of the minerals contained. Slides 1891 and 2962 have dark brown ferrite in a continuous ramifying sheet in which the other minerals are buried. In slides 2963 and 3008 the oxide of iron is much less in quantity, while the fragments of feldspar and quartz in them are abundant. The grains of fragmental quartz are frequently enlarged.

3. Sericitic graywacke. Specimen 9284, (slide 2961), 300 N., 500 W., Sec. 19, T. 47 N., R. 43 W., Michigan.

The rock is dark gray, fine grained, schistose, and cleaves readily along the plane of schistosity.

Rather small clastic particles of quartz and feldspar, the former preponderant, compose three-fourths of the thin section. The interstices are filled with finely crystalline quartz, kaolin or sericite, chlorite, dark brown ferrite, and plentiful grains of black lustrous galenite.

[1] The numbers of specimens and slides are those of the collection of the Lake Superior division. Locations are given from the southeast corner of the sections in steps of 2,000 per mile.

4. Jasper-conglomerate. Specimens 9261 (slide 3005), 9263 (slide 4486), 7418 (slide 1877), 60 N., 600 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The matrix of the rock is dark green, fine grained, finely laminated, has a greasy feel, and contains numerous medium sized grains of a cleavable mineral. This matrix is quite thickly studded with fragments of red jasper, some of which are from 6 to 8 inches in diameter.

The thin sections are composed of finely crystalline and coarsely fragmental parts. The fragmental portions comprise large, somewhat rounded areas of a finely crystalline basic eruptive and medium grains of feldspar, the former variety of fragments being more abundant. These complex basic areas contain chlorite, biotite, tabular feldspars, ferrite, and epidote, and are almost precisely like the basic eruptive which is developed upon a large scale just to the southward. The feldspar fragments are in part orthoclase and in part plagioclase. The abundant fine grained cementing material consists of cherty silica, small flakes of chlorite, and few of biotite. The pebbles of the conglomerate are typical red-banded jaspers. The rocks are apparently intermediate between fragmental ones and those of the nonfragmental iron-bearing belt. Nonfragmental sedimentation has begun, but it is yet accompanied with mechanical sedimentation.

5. Clay-slate. Specimen 12580 (slide 5340), 460 N., 1010 W, Sec. 20, T. 47 N., R. 43 W., Michigan.

The rock is a light green, aphanitic, finely laminated, soft slate.

The thin section consists of intimately mingled finely crystalline quartz, chlorite, sericite, and iron oxide. Much of this quartz is fragmental. The sericite is a light greenish-yellow, somewhat brilliantly polarizing, and is arranged in parallel rows of flakes which extinguish rectangularly. If other constituents are present, they are too obscure to be recognizable.

6. Feldspathic quartzites. Specimens 7383 (slide 1849), 900 N., 460 W.; 9244 (slide 4479), 9245 (slide 4480), 1100 N., 460 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rock varies from flesh color through greenish-gray to dark brown; is rather fine grained, almost massive, and breaks with a subconchoidal fracture.

The thin section is composed largely of clastic particles of quartz and feldspar, the former much the more abundant and often enlarged. The feldspars are orthoclase, microcline, and plagioclase. The rather abundant interstitial material is finely crystalline quartz, chlorite, kaolin, and iron oxide.

7. Quartzite. Specimen 7385 (slide 1851), 900 N., 750 W., Sec. 21, T. 47 N., R 43 W., Michigan.

The rock is a greenish-gray, medium grained, compact vitreous quartzite.

The thin section is mainly composed of enlarged fragmental grains of quartz. The induration is, however, mostly due to finely crystalline interlocking interstitial quartz, mingled with which is chlorite and brown oxide of iron.

8. Ferruginous and chloritic slate. Specimens 7400 (slide 1863), 1140 N., 530 W.; 9248 (slide 4481), 1170 N., 510 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rock is of a peculiar lustrous brownish green color, mottled with irregular patches of a dull brick-red color, is finely laminated and very soft.

In thin section, a quartz background contains abundant pale green chlorite, brown iron oxide, red hematite, and numerous scales of a brilliantly polarizing mineral which is taken to be sericite.

9. Chloritic and biotitic slate. Specimen 7386 (slide 2045), 950 N., 800 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

In thin section, a finely crystalline quartzose groundmass contains a felted mass of fibrous somewhat iron stained chlorite and biotite, the fibers of which are arranged in a common direction, and give the rock a strong schistose character. Scattered through this fine material are a few small grains of plainly fragmental quartz.

10. Ferruginous and chloritic slates. Specimens 7399 (slide 1862), 1130 N., 520 W.; 7401 (slide 1864), 1200 N., 480 W.; 9249 (slide 4482), 1210 N., 450 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rocks are dark green, thinly foliated, and have a soft greasy feel.

In thin section the rocks differ from 8 chiefly in that they have no hydromica, and contain quite plentifully small grains of plainly fragmental quartz, which stand out sharply from the groundmass. Both hematite and limonite are plentiful.

11. Ferruginous quartzite. Specimens 9252 (slide 4484), 9253 (slide 4485), 1315 N., 570 W., Sec. 21, T. 47 N., R. 43 W., Michigan.

The rocks are greenish to reddish gray, massive, and vitreous.

The thin sections are almost wholly composed of interlocking large grains of quartz. Films of iron oxide are found in the interstices and between the cores and enlargements of the quartz grains.

12. Feldspathic quartzite. Specimen 12588 (slide 5343), 1312 N., 1790 W., Sec. 22, T. 47 N., R. 43 W., Michigan.

The rock is gray to pink, fine grained, vitreous.

The thin section is chiefly composed of rather small originally well rounded particles of quartz and feldspar of remarkably uniform size. The quartz is several times as abundant as the feldspar. The grains are sometimes finely complex and often plainly enlarged. The feldspar comprises orthoclase, microcline, and plagioclase, all quite fresh, although a few of the grains have been affected by decomposition. Between the clastic particles are found finely crystalline silica, numerous small well defined brilliantly polarizing flakes of kaolin or sericite, and a few particles of ferrite. The section also contains a few grains of each of the minerals zircon and tourmaline, the former at times showing its characteristic zonal structure. These minerals are rounded, and must be classed as fragmental constituents rather than as indigenous in this rock.

## SECTION III.—THE GREENSTONE-CONGLOMERATES.

*Distribution.*—The greenstone-conglomerates are restricted to the area represented in Pl. XIII, occurring nowhere except in T. 47 N., R. 43 W., and R. 44 W., Michigan. It will be seen that their westernmost appearance is in the extreme northeast part of Sec. 16, T. 47 N., R. 44 W., Michigan. In the northwest part of Sec. 14, T. 47 N., R. 44 W., Michigan, are areas which are mapped as detached from the main mass of conglomerate because they are not known to be connected with it. From the exposure in the south part of Sec. 15, T. 47 N., R. 44 W., a belt of the conglomerate continues eastward, rapidly widening, and in Secs. 24 and 25, T. 47 N., R. 43 W., reaches its maxium width, 1¾ miles. Continuing eastward, the belt quite rapidly narrows, and its last appearance is in the northwest part of Sec. 23, T. 47 N., R. 43 W., Michigan. The exposures of eruptive rocks in Secs. 13 and 14, in the west part of Sec. 23 and in the northeast part of Sec. 24, T. 47 N., R. 44 W., Michigan, have all the characteristics of surface flows; that is, they contain minerals of two generations, are often amygdaloidal, and have a groundmass which is frequently partly amorphous and is always finely crystalline. These exposures are believed to be more closely allied to the greenstone-comglomerates than to the diabases of the Penokee series.

*General characteristics.*—The term "greenstone-conglomerate" is applied to the rock of this area because it is a fragmental one, in which nearly all the fragments are from basic eruptives, as is also the major portion of the matrix in which these fragments are set. The term "agglomerate" would convey a false impression. The rocks covered by the term greenstone-conglomerate include agglomerates and water-deposited clastics, the detritus of which is chiefly from greenstones,[1] as well as gradations between these two extremes. Macroscopically, the rocks vary from an aphanitic slate[2] to a coarse conglomerate. At times the fine grained clay-slates and the conglomerates are intimately mingled, but in general the slate exposures are

[1] The word greenstone is used here in its old sense, to cover all the basic eruptives of the district.

[2] A rock remarkably similar to many of these conglomerates is described by Gümbel under the term Schalstein. (Grundzüge der Geologie, pp. 196, 197.) The matrices and finer fragments of some of the rocks in question present a schistose structure very similar to that figured by him. The minerals now present are identical with those contained in his schalstein, and his description could be applied almost exactly to them.

apart from the conglomerate ones. These slates are more frequently found in the southern than in the northern part of the belt. The color of the rocks, whether fine grained or conglomeratic, is some shade of green or grayish-green. Sometimes the rocks show a schistose structure, although in general they are quite massive. The conglomeratic phases are the predominant ones, and here the fragments are very abundant, so as to leave but little room for a matrix. Nearly all of the pebbles and bowlders are of a single variety, pale greenish-gray, aphanitic, and massive. In some localities aphanitic, dark reddish-brown, felsitic-looking pebbles are quite numerous, although they never become the predominant variety. Very rarely worn white quartz pebbles are found. The pebbles are usually more resistant then the matrix, and consequently protrude upon the weathered surface in nodular or mammillary forms. In the greater number of the exposures fracture takes place through matrix and pebble with about equal ease. In those exposures in which the matrices are much altered, and therefore schistose, fracture occurs around the pebbles to a greater or less extent, depending upon the degree of alteration. The lines of separation between the pebbles and matrices in the fresher rocks are quite sharp, but in those which are more altered they are vague; and as there is often but a slight difference in the color and texture of the pebbles and matrices, when the rocks are much altered it is difficult to separate one from the other on a fractured surface, although the difference is clearly seen upon the weathered surface.

A study of some fifty thin sections shows that the matrices are of many phases, which vary into each other by imperceptible gradations. At times the matrix appears to be a fine grained eruptive, which contains fragments of essentially the same material. This phase of matrix is described under the greenstones of the eastern area and the description will not be here repeated. An important fragmental kind is composed of the fine debris from material like the contained pebbles, combined with finely crystalline quartz; that is, it is a recomposed greenstone, and is often schistose. The minerals most frequently found in this phase of matrix are quartz, tabular plagioclases, chlorite, epidote, titanite and leucoxene, actinolite, and, as accessories, oxide of iron, a carbonate, and occasionally remnants of augite.

The proportions of these minerals vary widely in the different sections. In one variety a quartzose background subordinate in quantity contains fine debris from the basic eruptives; that is, tabular plagioclases, actinolite, and chlorite, all of the minerals being mingled in the most confused manner, but generally showing a laminated structure. In another variety of fragmental matrix of about equal importance to the last the background is composed almost wholly of quite pure finely crystalline and chalcedonic quartz, in which are well outlined sharp areas of intermingled chlorite and epidote. Between these two main varieties there are various gradations. In some of the sections the matrix and fine fragmental material have a pretty well defined stratiform arrangement; in others, they vary from this regular stratiform character to a most extraordinary irregular arrangement, the fragments being extremely angular, and the matrix between running around and through them in the most lawless fashion. Words fail to give any proper conception of this strange appearance, but some idea of it will be obtained by reference to Pl. xxxv, Figs. 2, 3, and 4. Of less importance than the foregoing are the black chlorite-slates and black calcareous slates. These phases are usually nonconglomeratic, and are precisely like the slates of the fragmental belt north and east of the greenstone-conglomerates. Some of them contain unmistakable fragmental quartz mingled with fine grained clayey material. Others contain a good deal of some carbonate, oxides of iron, and finely crystalline quartz; in other words, are like the mingled nonfragmental and fragmental water-deposited sediments of the eastern area.

The fragments of the conglomerates vary from large bowlders to single individuals of one mineral. The pebbles are usually numerous, and often so thickly set as to give little room for a matrix, although they vary in abundance and are sometimes absent. It has already been stated that the great majority of the pebbles are of two well defined types. The common light green or grayish-green pebbles are ordinarily fine grained to aphanitic porphyrites, which are quite often amygdaloidal. Their background varies from glassy to holocrystalline. When glassy, they have been almost wholly devitrified, being changed into a pale green or light gray nonpolarizing or very feebly polarizing aggregate. The common recognizable minerals contained in the glassy varieties are tabular plagioclases, leucoxene, and titanite, chlorite, and epidote. The holocrystalline variety of pebble is sometimes fresh enough to be distinctly recognized as a diabase-porphyrite; the more altered ones would be classed as porphyrites. These have as chief constituents the minerals above mentioned with the addition of actinolite or hornblende, and occasionally augite and menaccanite, with almost always more or less of secondary quartz. The chlorite and epidote are in large measure the result of the alteration of an original pyroxene mineral, although in part they are derived from the decomposition of feldspar, and apparently the actinolite comes from the same sources. The quartz is believed to be always secondary. When the pebbles are of an amygdaloidal character, the amygdules are usually of quartz or calcite or epidote, or two or all three of these combined. These augite-porphyrites and porphyrites resemble closely the rocks described by Irving as diabase-porphyrite and ash-bed diabase in the Keweenaw series.[1]

The second variety of pebbles, the red felsitic-looking kind, differs only from those just described in that the constituents are deeply stained with oxide of iron. They are then simply ferruginous porphyrites. It thus appears that almost all of the larger fragments of the greenstone-conglomerates are in their character basic eruptives. Besides the fragments thus derived from basic eruptives there are rarely found well rounded pebbles of white quartz. These pebbles, although so infrequent, are important as bearing upon the probable origin of the rocks. In one case there is in a section a rounded quartz area which is complex, and which is composed of simple quartz grains now interlocking by enlargement. This pebble was then derived from a sandstone, which was changed to a quartzite either prior to or since its deposition in its present place. Aside from the classes of fragments mentioned there is not infrequently present in the matrix large simple well rounded grains of quartz and feldspar. These quartz grains are often enlarged. They, like the quartz-pebbles just referred to would seem to indicate that the rock is water-deposited.

*Origin of the Greenstone-conglomerates.*—The one feature in common which nearly all exposures of the area classed under this term have is the

[1] R. D. Irving: Copper-bearing rocks of lake Superior; Monograph U. S. Geol. Survey, vol. V, 1883, pp. 77-87.

presence of fragments of a basic eruptive, although a few exposures of a schistose nonconglomeratic material are found. These fragments, as has been seen, vary from those which are well rounded to those which have the extreme of angularity. Basic eruptive fragments of this sort may have been derived from various possible sources, those which are well rounded having been probably, although not certainly, subjected to water action, but this does not necessarily tell their source. It has been seen that south of the iron-bearing belt of the formation is a layer of amygdaloidal porphyrite; also, very closely associated with the conglomerates themselves in the northern portion of the area are other large exposures of a similar rock. These massive rocks are remarkably like many of the pebbles contained in the greenstone-conglomerates. It is, then, possible that the fragments of the greenstone-conglomerates have been derived by the degradation of older or contemporaneous eruptive outflows, or it is possible that they are the direct ejecta from a volcanic vent, or (and this is most likely the case) the pebbles have in part come from both of these sources.

The greenstone-conglomerates and breccias, which have a matrix essentially like an altered greenstone and most irregular fragments of basic eruptives with difficulty separated from the matrix, have a remarkable likeness to the schistose fine grained porphyrites with which they are closely associated in the field. This material certainly can not have resulted from the breaking down of a solidified rock by water action. The fragments are precisely like in their shape and character to the ejecta of a volcanic vent. How these fragments and the matrix in which they are contained became mingled it is impossible to say with certainty. The brecciation may be merely that of an onflowing bed of lava which continues its forward movement after it has reached so viscous a condition that it becomes fractured in every direction by its motion, caused by a force in the rear, or this mixture may be the ejecta from a cone falling upon a lava stream flowing down its side. The first explanation is regarded as the more probable. Whichever hypothesis is true, that this material is essentially the same in composition as the surrounding surface lava flows is certain, for take away the fragments and it would be impossible to distinguish the matrix from the more schistose and altered of the flows. In those phases of the greenstone-conglomerate in which there is almost no matrix at all and those in which the matrix appears but to be fine debris of the same kind as the pebbles and bowlders—that is, composed of angular fragments of very greatly varying sizes which have been closely packed together and subsequently cemented by alterations of the materials contained with the addition of interstitial quartz—it seems probable that the rock is merely a heap of volcanic tuff. The volcanic material may have fallen upon the sides of the cone or farther away have been deposited in water; in which latter case the debris would have been subjected to water action. In those cases in which the matrices exhibit the extraordinary irregular and concretion-like areas, varying into roughly stratiform deposits, it would seem that the ashes had accumulated under or at least had been subject to the leaching action of water.

In the phase of conglomerates in which finely crystalline quartz becomes an important constituent it would seem that the rocks had originated by the mingling of volcanic material with nonfragmental sediments under water. Whether the contained fragments fell directly upon the water from a volcanic vent or the water was the agent which broke down this material from recently formed lava can not positively be determined, but the rounded forms of a portion of the pebbles and the irregular forms of others would seem to indicate that both processes may have furnished a share of the pebbles. That this class of conglomerate was deposited under the surface of water is further indicated by the fact that in this nonfragmental quartzose background there is not infrequently contained well rounded particles of quartz and feldspar, the former of which have been enlarged, and in a few cases these rounded quartzose fragments attain the magnitude of pebbles. That this peculiar mingled fragmental and nonfragmental material is of the origin indicated is further evidenced by the jasper-conglomerates in the extreme southern part of the SE. $\frac{1}{4}$ of Sec. 20, T. 47 N., R. 43 W., Michigan. The associations of this rock are explained in chapter VIII. It was there seen that the conglomerate gradually passes upward into the nonfragmental sediments—chert and cherty iron carbonate—of the iron belt. There is little doubt that it is a mingled nonclastic and clastic sediment. If this is the origin of this jasper-conglomerate it is a strong indication that the greenstone-conglomerates, which differ from it only in the absence of jasper fragments, are of a like character. It follows from the above that the class of conglomerates which contain a preponderating amount of nonfragmental material are closely allied to the rocks of the Iron-bearing member of the Penokee series. The contained fragments of basic eruptives is the chief point in which they are unlike this iron-bearing belt. This phase of the greenstone-conglomerates is still more nearly like in essential character the ferruginous and fragmental rocks north and south of the greenstone-conglomerates, the chief difference between the two classes of rocks being that the complex basic eruptive fragments take the place of the simple quartz, feldspar, and clayey fragments of these belts. It has been noted that closely mingled with the greenstone-schists and greenstone-conglomerates are a few rocks which are essentially like the ferruginous and fragmental rocks to the north and east. It would appear that in these cases for a short time mingled fragmental and nonfragmental sedimentation has occurred without having received basic eruptive debris. In these interlaminated rare varieties of rock we have still another link between the greenstone-conglomerates and the ordinary ferruginous and fragmental belt to the north and east.

From the foregoing it would appear that in the greenstone-conglomerate area and vicinity we have gradations from a rock which is a purely basic eruptive amygdaloidal flow to those which are simply mingled clastic and nonclastic sediments. Intervening between these widely separated phases are the brecciated rocks, which appear to have had a lava base and contain fragments of essentially the same material; rocks which appear to be tuffs alone; rocks in which tuff has fallen upon water and has become mingled with water-formed detritus and, varying from this by a gradual lessening of the tuff, rocks which are simply mingled fragmental and nonfragmental water-deposited sediments.

Whether all of the above conclusions as to the origin of the different phases of this rock are true or not, it is certain that this area has been the center of great volcanic activity. This is evidenced by the great masses of greenstone in Secs. 26 and 27, T. 47 N., R. 44 W., Michigan, by the surface porphyritic flow in Secs. 29 and 30, T. 47 N., R. 43 W., Michigan, and by the large eruptive exposures in Secs. 14, 15, and 16, T. 47 N., R. 44 W., Michigan, as well as by the great mass of greenstone-conglomerate itself. This volcanic activity is an exceptional thing in the Penokee succession, and in it is believed to lie the key which explains the very exceptional characters of the series in T. 47 N., R. 43 and 44 W., Michigan.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.[1]

1. Chloritic slate. Specimen 12689 (slide 5410), from 1655 N., 60 W., Sec. 16, T. 47 N., R. 44 W., Michigan.

The rock is a dark green, fine grained, schistose one, containing large vaguely outlined areas which seem to be of a conglomeratic character.

The thin section seems to be that of a fine grained porphyrite which has once had a glassy background. The background has almost wholly devitrified. At one side of the section it consists of a turbid gray amorphous aggregate. This gradually changes into green nonpolarizing chlorite in passing towards the other side of the section. The background contains many minute tabular plagioclases, gray areas of leucoxene (which here and there include particles of unaltered menaccanite), and some finely crystalline quartz. The section contains also a few porphyritic crystals of plagioclase and intersecting veins of quartz.

2. Greenstone-conglomerates. Specimens 9366 (slide 3032), 425 N., 1250 W.; 9369 (slide 3035), 365 N., 1325 W., Sec. 15, T. 47 N., R. 44 W., Michigan.

The matrix of the conglomerate is a mottled green color, fine grained, and quite massive, although traces of a schistose structure are shown. The larger part of the contained pebbles are of a pale green color, aphanitic, massive, and often with illy defined outlines. A few pebbles are of a dark brown color, well rounded and clearly defined.

In thin section the fragments are seen to be from basic eruptives. A few of them are well rounded, but they are mostly extraordinarily irregular and sharply angular in form. In places they are so closely packed together that their outlines are with difficulty determined. As a result of these peculiarities the sections present a striking appearance, as if made up of a pile of various kinds of particles having the greatest possible irregularities of outline. The majority of the fragments have a gray partially devitrified glassy background, in which are set small tabular crystals of plagioclase; in others there seems to have been an amorphous background, but it is now wholly devitrified, being composed of chlorite, gray feebly polarizing material and somewhat brilliantly polarizing minute needles. The basic fragments are chiefly

[1] The numbers of specimens and slides are those of the collection of the Lake Superior division. Locations are given from the southeast corners of the sections, in steps of 2,000 per mile.

cemented by interlocking quartz and feldspar, the latter comprising both orthoclase and plagioclase. The feldspar in this cementing material, unlike that contained in the fragments, is usually fresh. This difference may be due to a more acid character. Contained in one of the sections are quite numerous areas of a colorless mineral which shows cleavage in two directions, gives somewhat brilliant interference colors, and is taken to be pyroxene. Quite frequently roundish cores of this mineral have a border of fibrous material which terminates by a gradual fraying out. A few large fragments of an undetermined mineral, which has very feeble double refraction, are seen. (Pl. XXXV, Figs. 3 and 4.)

*Section in and near west half of Secs. 14 and 23, T. 47 N., R. 44 W., Michigan.*

3. Actinolite-chlorite-schists. Specimens 9377 (slide 3037), 1330 N., 25 W.; 9378 (slide 3038), 1425 N., 15 W., Sec. 22, T. 47 N., R. 44 W., Michigan.

The rocks are dark lustrous green, fine grained, and finely laminated.

The sections are mostly composed of pale green nonpolarizing chlorite, needles of actinolite and biotite, finely crystalline and chalcedonic quartz, and roundish granules and clusters of granules of yellowish-gray titanite. In places the silica is so abundant as to constitute a matrix for the remaining minerals, while in other parts of the sections the chlorite, biotite, and actinolite almost entirely exclude the quartz. The actinolite is in needles, which intersect and often occur in radiating clusters. Those included in the quartz are usually quite fresh, but those embedded in the chlorite have altered to a large extent to biotite, all of which mineral is secondary to and most often pseudomorphous after the actinolite.

4. Ferruginous chlorite-slate, north of 3. Specimen 9341 (slide 3023), 1500 N., 1550 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

The rock is dark greenish-gray, aphanitic, and has a well developed slaty cleavage.

The section is exceedingly fine grained. It consists of pale green, fibrous, nonpolarizing chlorite, finely crystalline and amorphous silica, and of minute opaque or nearly opaque particles of ferrite, with a little biotite.

5. Calcitic and chloritic slate interstratified with 4. Specimens 9342 (slide 2979), 9343 (slide 3116), 1500 N., 1550 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

The rocks are light grayish-green, fine grained and vary from slaty to schistose.

The thin sections consist of pale green nonpolarizing chlorite and calcite or other carbonate, and a finely crystalline chalcedonic and amorphous silica, with also apparently some kaolin or sericite. The carbonate is particularly abundant, and gives the sections an appearance closely allied to some of the sideritic cherts of the iron-bearing belt.

6. Greenstone-conglomerates, interstratified with 4 and 5. Specimens 9338 (slide 3114), 9339 (slide 3115), 1500 N., 1550 W.; 7452 (slide 1906), 1500 N., 1710

W.; 7453 (slides 2048 and 2049), 1500 N., 1550 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

The rocks are like 2. Upon the weathered surface the more resistant pebbles protrude with oval outlines. When the rock is freshly fractured the pale grayish-green, rounded pebbles are well defined in their darker colored matrix.

In thin section the smaller fragments and their relations to the background are precisely as in 2. This background is finer grained, and appears to consist of very finely crystalline quartz, mingled with the finest sort of debris from material like that composing the fragments. This background and the smaller fragments are arranged in a roughly stratiform way, which must indicate stratification or a flowage structure. The sections contain abundant larger fragments, which vary in character from those having an almost wholly devitrified glassy background containing much altered tabular plagioclases to those which have a holocrystalline base in which is found many comparatively fresh augites and porphyritic crystals of plagioclase. The plagioclase has often wholly altered to white mica or has been replaced by calcite. Since the above pebbles contain augite, they are properly augite-porphyrites.

7. Greenstone-conglomerates north of 6, near middle of belt. Specimens 9337 (slide 3022), 75 N., 1500 W.; 7465 (slide 1916), 7466 (slide 1917), 7467 (slide 1918), 140 N., 1500 W.; 9336 (slide 3021), 270 N., 1500 W.; 7468 (slide 1919), 290 N., 1500 W., Sec. 14, T. 47 N., R. 44 W., Michigan.

In places the conglomerate is free from pebbles, and is then dark grayish-green, fine grained, and schistose. The pebbles, when present, are all of the green massive variety described in 2. They vary in size from those so small as to be lost in the matrix to those several inches in diameter. The conglomerate is thickly studded with the pebbles, which are best seen upon the weathered surface.

The matrices of the sections are of two varieties; in one, finely crystalline quartz is the predominant constituent, in the other it is subordinate in quantity. In this latter phase with the quartz there is mingled very abundant chlorite, much amorphous gray material, and many partly altered tabular plagioclases. The phase of the matrix rich in quartz also carries these minerals, although in less quantity. Contained in both varieties of matrix are, scattered somewhat sparsely, large well rounded fragmental grains of feldspar and quartz, the latter being sometimes bunched into areas of some size, the constituent grains of which are usually enlarged. The pebbles, as in the previously described conglomerates, are fragments of altered basic eruptives. Commonly this alteration has extended very far, so that they are now composed of chlorite, epidote, and partly decomposed tabular plagioclases as chief constituents, and with these rather abundant titanite and some secondary quartz. The pebbles vary from quite well rounded to those as irregular in form as in 2. Many of them are cut into or even apparently dissevered by the ramifying quartzose matrix. The well rounded character of the quartz grains in a matrix of nonfragmental quartz would seem to be evidence that these rocks were formed under water.

8. Greenstone-conglomerate north, of 7. Specimen 9331 (slide 2977), 1040 N., 1500 W., Sec. 14, T. 47 N., R. 44 W., Michigan.

The matrix of the conglomerate is dark mottled green, fine grained, and schistose. It is studded with pebbles and bowlders, some of the latter being of large size.

The thin section is cut from the matrix. A continuous ramifying mass of nonpolarizing green chlorite and cherty and chalcedonic quartz contains numerous roundish complex areas of epidote, many small areas of titanite, few much altered crystals of feldspar, and occasionally large areas of calcite, these latter apparently replacing feldspars. There is nowhere any evidence of fragmental material. Parts of the section are quite like an altered eruptive, and it thus appears probable that the matrix, as well as the fragments of this rock, is almost wholly or wholly a volcanic product.

*Section along and near the east line of Secs. 14, 23, and 26, T. 47 N., R. 44 W., Michigan.*

9. Greenstone-conglomerates. Specimens 9358 (slide 3029), 400 N., 1525 W.; 9357 (slide 4932), 450 N., 1700 W., Sec. 25, T. 47 N., R. 44 W., Michigan.

The rocks are in nowise different from 6, except that they show a more decided schistose structure.

The thin sections show no difference between matrix and pebbles. The background appears to consist of amorphous gray material, in which are included exceedingly finely crystalline chlorite, quartz, epidote, perhaps a little actinolite, and here and there much altered porphyritic crystals of feldspar. A few large roundish areas of quartz or calcite, or both, of an amygdaloidal character are seen. So far as the sections go, one would call this rock a schistose greenstone, and yet the conglomeratic appearance of the exposure is marked.

10. Chlorite-slate, north of 9. Specimen 10413 (slide 4018), 800 N., 1625 W., Sec. 25, T. 47 N., R. 44 W., Michigan.

The rock is dark green to black, aphanitic, very finely laminated, and readily cleavable.

In thin section an exceedingly finely crystalline quartzose background contains abundant chlorite and small particles of black and dark brown ferrite. The arrangement of the chlorite and iron oxide corresponds with the laminæ of the rock. Contained in the fine grained material are some larger grains of quartz which are plainly fragmental.

11. Greenstone-conglomerate, north of 10. Specimen 7459 (slides 2050 and 2051), 345 N., 0 W., Sec. 23, T. 47 N., R. 44 W., Michigan.

The thin sections of this rock do not differ essentially from those of 6.

12. Greenstone-conglomerate; north of 11. Specimen 9312 (slides 2970 and 2971), 9313 (slide 4929), 190 N., 20 W., Sec. 14, T. 47 N., R. 44 W., Michigan.

The matrix of the rock is dark mottled green, fine grained, and schistose. The prevailing pebbles are the same as those in 7. Occasionally a white quartz pebble is seen.

The thin sections are in essential respects like those of 7, having a quartzose matrix. Large fragments of extraordinary irregularity are contained in a reticulating groundmass consisting mostly of finely crystalline quartz. The quartz runs around and through the fragments in such a manner as to suggest that it is, in large part at least, secondary and has dissevered the contained fragments. This is rendered probable by the fact that the irregular outline of one fragment is often the reverse of the outline of the adjoining one. The fragments are composed of green nonpolarizing chlorite, much altered tabular plagioclases, roundish granules of titanite, and abundant epidote, the latter being sometimes concentrated into large irregular complex areas. (Pl. xxxv, Fig. 2.)

*Section east and west of the line between Sec. 19, T. 47 N., R. 43 W., and Sec. 24, T. 47. N., R. 44 W., Michigan.*

13. Greenstone-conglomerate. Specimen 9350 (slide 4931), 20 N., 475 W., Sec 24, T. 47 N., R. 44 W., Michigan.

The specimen does not differ from those of 2.

The thin section combines the characteristics of those of 2 and 12. The pebbles vary in size and are closely packed together, so that the matrix is very sparse. It consists of the fine debris of the pebbles mingled with finely crystalline quartz. A portion of the pebbles have the gray amorphous background so common in 2, contained in which are many somewhat altered crystals of plagioclase. Pebbles of another class are similar to those in 12, in that they contain a large amount of epidote and chlorite.

14. Greenstone-conglomerate. Specimen 9349 (slide 3027), 425 N., 500 W., Sec. 24, T. 47 N., R. 44 W., Michigan.

The specimen is not different from the previously described greenstone-conglomerates.

The thin section is cut from a schistose portion which was taken to be the matrix, and is plainly a much altered, very fine grained, amygdaloidal porphyrite. The background now consists of gray amorphous material, much altered plagioclases, and, as secondary materials, chlorite, epidote, and small, brilliantly polarizing flakes. The amygdules are chiefly chalcedonic quartz, but frequently associated with it are chlorite and calcite.

15. Greenstone-conglomerate. Specimen 9300 (slide 3013), 850 N., 1750 W., Sec. 19, T. 47 N., R. 43 W., Michigan.

The matrix of the conglomerate is dark green, rather coarse grained, and schistose. The pebbles do not differ from those of the previously described conglomerates.

The thin section is like those of 12, except that the quartzose background is finer grained.

16. Greenstone-conglomerate. Specimen 7451 (slides 1905 and 2153), 900 N., 850 W., Sec. 24, T. 47 N., R. 44 W., Michigan.

The rock varies from dark grayish green to dark green, is schistose, and weathers to a dirty yellowish brown color.

In thin section the matrix of the conglomerate is very fine grained and schistose. It consists of finely crystalline quartz and the debris of basic eruptives, including chlorite, epidote, and brilliantly polarizing needles arranged in parallel lines. The fragments vary from those of large size, which are very plainly altered porphyrites, to minute altered particles which are lost in the contained matrix. Epidote is plentiful in all parts of the section.

17. Greenstone-conglomerates. Specimens 7447 (slide 1900), 1925 N., 1000 W.; 9311 (slide 4928), 1950 N., 1350 W., Sec. 24, T. 47 N., R. 44 W., Michigan.

The rock is dark mottled green, roughly schistose, and contains numerous small, vaguely outlined pebble-like areas.

These sections do not differ materially from those of 12.

With the naked eye the well rounded outlines of the pebbles are clearly distinguished from the matrix in which they are contained. The background microscopically consists of quartz (much of which is chalcedonic), chlorite, epidote, and gray amorphous material. The large pebbles have a background consisting in about equal proportion of gray material and pale green nonpolarizing viridite, which contains greatly altered plagioclases and finely crystalline secondary quartz.

*Exposures in the east part of Sec. 20, T. 47 N., R. 43 W., Michigan.*

18. Greenstone-conglomerates. Specimens 9242 (slide 2949), 950 N., 625 W.; 9239 (slide 4925); 9241 (slide 2948), 920 N., 920 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rocks are like 2, except that the matrix is distinctly schistose.

The thin sections are like those of 2 so far as the fragments are concerned, but the matrix consists, aside from finely crystalline quartz, of the fine debris derived from the basic fragments.

19. Greenstone-conglomerate. Specimen 7415 (slide 1874), 1075 N., 35 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The specimen is like 2.

The section is from a pebble of the conglomerate. It is a fine grained, amygdaloidal porphyrite, having a gray, nearly amorphous background, which contains greatly altered plagioclases, epidote, kaolin, and some calcite. Frequently the epidote is contained in the plagioclase and clearly is secondary to it. A large amygdule contains a core of epidote, which is surrounded by an aggregate of pale green chlorite.

*Exposures near corner of Secs. 14, 15, 22, 23, T. 47 N., R. 43 W., Michigan.*

20. Greenstone-conglomerates. Specimen 9227 (slide 2944), 1985 N., 170 W.; 7377 (slide 2013), 1990 N., 180 W., Sec. 22, T. 47 N., R. 43 W., Michigan.

The matrix of the rock is dull gray, in places heavily iron stained, aphanitic, and sometimes slaty. The apparent pebbles resemble very closely the matrix in which they are contained.

The thin sections are very fine grained and obscure. They appear, however, to contain large illy defined fragments, derived from a fine grained porphyrite, which are mostly composed of gray material containing minute tabular plagioclases. These fragments are set in a matrix, the chief constituent of which is quartz, but which also contains abundant material like that composing the fragments.

21. Greenstone-conglomerate. Specimens 9222 (slide 2942), 9223 (slide 3002), 9225 (slide 2943), 7375 (slide 1843), 1970 N., 1640 W., Sec. 23, T. 47 N., R. 43 W., Michigan.

The matrix of the rocks is dark green and thinly foliated. The pebbles are in part of the pale green sort found in the previously described conglomerates, while some of them are coarser grained than usual and have the characteristic appearance of massive basic eruptives.

The matrix consists, as in several cases before, of finely crystalline quartz, mingled with the debris derived from the basic fragments. The fragments vary in size from this fine material to large bowlders. Some of the smaller fragmental areas are almost completely altered to chlorite and gray material, but the roundish forms which they still retain probably represent original fragments. The larger pebbles are plainly from basic eruptives. The coarser ones consist of greatly altered plagioclase, gray leucoxene, chlorite, and blades of actinolite or hornblende, the latter being plainly of secondary origin. At times these hornblende blades are so large as to include many particles of the other minerals of the pebbles, even containing so much foreign material at times as to make a single individual of hornblende appear in section as detached areas.

### SECTION IV.—FRAGMENTAL AND FERRUGINOUS ROCKS NORTH AND EAST OF THE GREENSTONE-CONGLOMERATES.

*Geographical distribution.*—North and east of the greenstone-conglomerates occurs a continuous wide belt of fragmental rocks, which extend from near the north quarter post of Sec. 14, T. 47 N., R. 44 W., Michigan, to the center of Sec. 28, T. 47 N., R. 42 W., Michigan, a distance of about 11 miles. Through T. 47 N., R. 43 W., Michigan, this belt runs in a nearly east and west direction, and probably has a surface width through this township of about 1½ miles. West of T. 47 N., R. 43 W., Michigan, the few exposures found indicate a northern trend to the belt. In the other direction —that is, east of T. 47 N., R. 43 W., Michigan, the belt bends southward, entering T. 47 N., R. 42 W., Michigan, in Secs. 18 and 19, and from this place describes approximately the arc of a circle, the easternmost point of which is in the center of Sec. 28.

*Surrounding rocks.*—The rocks south of the belt vary in their character. In Sec. 14, T. 47 N., R. 44 W., Michigan, this rock is a porphyrite, of such a nature as to indicate that it is a surface flow. Through the greater part of the distance, from the west line of Sec. 13, T. 47 N., R. 44 W., Michigan, to the northwest part of Sec. 23, T. 47 N., R. 43 W., Michigan, the greenstone-conglomerate is the nearest known rock. It is to be observed that here is a strip of country, in some places as much as half a mile wide, in which no exposures are known between the fragmental rocks and the greenstone conglomerates; therefore there may be between these two formations another belt. From the north quarter post of Sec. 23, T. 47 N., R. 43 W., Michigan, to the eastern end of the belt, its southern boundary is the underlying complex of hornblende-schists and mica-schists, gneisses and granites. Here there is little doubt that these rocks are the immediately underlying ones; for in several places in the fragmental series are basal conglomerates and recomposed granites, which are chiefly composed of debris derived from the crystalline rocks immediately to the south, while in one section the actual contacts between the fragmental and nonfragmental rocks are seen.

The rocks north of the fragmental belt, from its western end to near the center of Sec. 18, T. 47 N., R. 42 W., Michigan, are the greenstones of the overlying Keweenaw series. In two places the fragmental rocks are found very close to the greenstones, and it is therefore probable that these rocks lie immediately to the north of the fragmental belt. East of the center of Sec. 18, T. 47 N., R. 42 W., Michigan, no exposures are found northeast of the belt except in Sec. 28, where the Eastern sandstone is found in horizontal position, unconformably overlying the fragmental belt of rocks under discussion.

*Continuation of the belt east and west.*—Whether this belt continues east and west of the area outlined for it upon Pl. XIII is an open question. West of the westernmost exposure of the belt, in the north part of Sec. 14, T. 47 N., R. 44 W., Michigan, is the valley of the Little Presque Isle, in which there are no exposures. About a mile west of the Presque Isle, and 1½ miles west of the exposure referred to, is developed, by a test pit, rocks which are almost purely nonfragmental sediments, but which have mingled with them some fragmental sedimentation. It is doubtful whether the belt under discussion ought not to be carried west to this pit, and from here be continued westward until it merges into the iron-bearing belt of the main area. The eastern end of the belt, in Sec. 28, T. 47 N., R. 42 W., Michigan, is very narrow. Between the gneisses and granites and the horizontal Eastern sandstone are but a few score of feet, or at most one or two hundred feet. There is, then, but little room at surface for the belt under consideration. Whether southeast of the center of section 28 it is entirely covered by the Eastern sandstone or not we have no means of knowing. In case the Eastern sandstone does thus overlap, we have here the eastern end of the Penokee series.

*Structure of the belt.*—The exposures in T. 47 N., R. 44 W., Michigan, and most of those in Sec. 28, T. 47 N., R. 42 W., Michigan, are without structure; but the most of the exposures in T. 47 N., R. 43 W. and 42 W., Michigan, are clay-slates or graywacke-slates, which have well defined strikes and dips. In the few outcrops in T. 47 N., R. 42 W., Michigan, in which this dip is known, it is northeast. These dips are not indicated upon the map because they are not so accurately known as could be desired. However, at one exposure in the southeast part of Sec. 20, the dip is clearly northeast, while the statement of the explorers who have done the test pitting generally agree with the above statement as to a northeasterly dip. In T. 47 N., R. 43 W., Michigan, however, where the exposures are the most numerous of anywhere in the belt, a portion of them dip north and a portion south, the greater number of exposures having the latter inclination. These apparent southern dips are of great importance, because these are the only known ledges with a southern dip which unquestionably belong to the Penokee series.

The more ferruginous of these rocks—that is, the few exposures which approach a jasper—have a northern dip. The rocks which show a southern inclination are rather hard, green and black slates. All ledges in which a southern dip was found were closely examined, in order to ascertain whether this apparent southern dip is true bedding, or is due to slaty cleavage. It was found impossible to determine this point in most cases. In one or two ledges there is a decided banding with northern dips transverse to the southern cleavage. In these cases, at least, it seems probable that the southern dips are cleavage and not bedding. Taking all the facts into consideration, it is probable that all of these apparent southern inclinations are due to cleavage and the true dip of the whole belt is northward, as a part of it certainly is, and as are all of the remaining rocks of the whole area belonging to the Penokee series. This probability is rendered greater by the fact that all rocks which do not readily take on a slaty cleavage, like the jaspers, have a northern dip; while the clayey rocks, kinds which are known to most readily take a slaty cleavage, are the only ones which exhibit a southern inclination.

*General petrographical character.*—The rocks of the belt, as before stated, are essentially fragmental, although the amount of nonfragmental sediments is not inconsiderable. Many of the exposures are simple fragmental rocks, but in numerous places, mingled with the fragmental, is a greater or less quantity of nonfragmental material; either a carbonate and the products of its alteration, or chert, or both. Generally this nonfragmental material is subordinate in quantity to the fragmental, but in a number of places, in narrow belts, nonfragmental sedimentation has built up the larger part of the rock, while a considerable thickness in several places is formed by nonfragmental and fragmental sediments in about equal proportions. The pure fragmental kinds, those which are both fragmental and nonfragmental, and those which are purely nonfragmental, can not be separated from one another in any stratigraphical order. In some parts of the belt its whole section, so far as known, is partly nonfragmental; while in others fragmental sediments exclude altogether nonfragmental sediments; and in yet other sections both classes of rocks are found. The only possible classification of the rocks of the belt is then a lithological one, and as their phases are exceedingly numerous, and the various phases merge into one another, any classification would be to a large extent arbitrary.

Below is given a list of kinds, but even this does not give a full idea of the many phases of rock which are almost as numerous as the ledges found, and which if the whole truth were known, would doubtless comprise all possible gradations between the varities mentioned:

| | |
|---|---|
| Fragmental | Quartzites.<br>Feldspathic quartzites.<br>Recomposed granite—often conglomeratic.<br>Graywacke.<br>Graywacke-slate.<br>Clay-slate.<br>Sericite-slate.<br>Chlorite-slate. |
| Mingled fragmental and nonfragmental | Hematitic and magnetitic quartzite.<br>Hematitic and magnetitic graywacke.<br>Hematite-schist.<br>Hematitic and magnetitic graywacke-slate.<br>Ferro-dolomitic slate and graywacke.<br>Chert-breccia.<br>Cherty quartzite. |
| Nonfragmental sediments | Chert.<br>Cherty ferro-dolomite<br>Ferro-dolomitic chert. |

The rocks above included among the fragmental sediments are given names which have been before used in the descriptions of the Quartz-slate and Upper slate members in the main Penokee area. These names are here used with the same significance as before and no characterization need be given of them as a whole. In the tabulations following the rocks are described in detail. The points of general interest shown by the belt are the mingled fragmental and nonfragmental sediments; the change in the nature of the nonfragmental sediments in following the belt from west to east; and the presence of chert-conglomerates and basal conglomerates at the east end of the belt.

*Mingled fragmental and nonfragmental sediments.*—The westernmost exposure of the belt is a hematitic schist and quartzite in the north part of Sec. 14, T. 47 N., R. 44 W., Michigan. The proportion of iron oxide is so great as to constitute a continuous ramifying background in which the fragmental quartz and feldspar is stuccoed. In no other ledges of as large size in the belt is the proportion of iron oxide so great. Rocks almost identical in character with these are found in the fragmental belt south of the greenstone-conglomerate, in the southwest part of Sec. 19, and the northwest part of Sec. 29, T. 47 N., R. 43 W., Michigan. So like are the exposures from these different localities that one is inclined to explain their similarity by supposing the area to have a structure which makes them contemporaneous in formation. It can as well be explained, however, by considering one of these belts as older than the other, the similarity being due to the recurrence of like, or nearly like conditions at two different times. In passing to the eastward, all the exposures in Sec. 13, T. 47 N., R. 44 W., Michigan, and in Secs. 18 and 19, T. 47 N., R. 43 W., Michigan, are ferruginous—most of them heavily. The larger part of the iron contained in the rocks is in the form of hematite, although in some places magnetite is found. In the northeast part of Sec. 19, T. 47 N., R. 43 W., Michigan, layers from mere films to several feet thick are so largely composed of hematite as to resemble somewhat an iron ore. This amount of iron oxide is so great as to have encouraged explorers to follow these beds to some depth in the hope of obtaining merchantable iron ore. In Secs. 17 and 20, and 16 and 21, T 47 N., R. 43 W., Michigan, the exposures are much less heavily ferruginous than farther to the westward. The amount of hematite and limonite remains considerable, and this is particularly true in the south half of the belt. The most of the iron is in the form of oxide as before, but with this iron oxide a considerable quantity of ferriferous carbonate is associated. The ferro-dolomite or siderite is seen in all stages of alteration to iron oxide, the areas of the latter at times being beautiful pseudomorps. This carbonate is also accompanied by a good deal of finely crystalline or cherty quartz. In the cases of some exposures in Secs. 16 and 20, T. 47 N., R. 43 W., Michigan, the amount of nonfragmental material is fully as great as the fragmental quartz and feldspar mingled with it. From the east side of Sec. 15 to the east end of the area in Sec. 28, T. 47 N., R. 42 W., Michigan, the quantity of iron oxide contained in the belt is small. Upon the other hand, the amount of ferriferous carbonate and of cherty silica is far greater than to the westward. The exposure in the eastern part of Sec. 15, T. 47 N., R. 43 W., Michigan, is in almost equal quantity fragmental and nonfragmental material. In places, in narrow bands, cherty silica and carbonate are almost free from any fragmental material, but the rock composing most of the exposure has a background of chert and carbonate which contains abundant fragmental material. Almost in contact with the crystalline rocks to the south, in the north part of Sec. 23, is a band a few feet thick of nearly pure cherty ferro-dolomite, and the fragmental rocks to the north contain quite a quantity of chert and carbonate. In the exposures along the east side of Sec. 14, T. 47 N., R. 43 W., Michigan, ferro-dolomite is a chief constituent. From the west side of Sec. 13, T. 47 N., R. 43 W., Michigan, to the center of Sec. 28, T. 47 N., R. 42 W., Michigan, chert and ferro-dolomite (chiefly the former, except locally) constitute the background in which the abundant fragmental material is contained; while in some of the quartzites and conglomerates the nonfragmental material sinks to an insignificant quantity.

It will thus be seen that there is a marked change in the nonfragmental sediments in passing from west to east. Throughout its eastern portion this material is cherty silica and a ferriferous carbonate; in its central part it is cherty carbonate and iron oxides, and here in most of the sections the iron oxides are seen in actual process of formation from the carbonate; in the western part of the belt the iron present is almost wholly in the form of oxides. Considering these facts by themselves, it seems a natural conclusion that it is probable that all of the iron was originally present as a carbonate, and that the iron oxides now found have been formed from the alteration of such material. This probability is made almost a certainty when the facts are taken in connection with what has gone before in reference to the iron oxides of the Iron-bearing member in the main area to the westward. We, then, have here another belt in which the widespread occurrence of iron oxide is due to the presence of an original ferriferous carbonate.

From the foregoing it is evident that this belt of rocks is different from any considerable area found in the main western area. The series there consists of four great formations, which are alternately nonfragmental and fragmental sediments, and which are separated from each other with surprising sharpness. In only a few localities are found transition belts between the two classes of sediments, and these are mostly narrow; but the belt under discussion—probably as much as 2,000 feet thick—is in part a fragmental and in part a nonfragmental sediment. Such deposits are rather unusual in the Iron-bearing series in the Northwestern states. Layers of mingled fragmental and nonfragmental material are present in certain localities in the Animikie and other series. According to the ideas generally accepted among geologists nonfragmental sediments originate under water of considerable depth which is comparatively quiet. How, then, does it occur that a thick belt of sediment contains both fragmental and nonfragmental material? This singular occurrence can be explained by supposing unusual conditions to have prevailed at the time of the formation of the belt. In the present place it will only be remarked that it is deemed probable that the exceptional conditions were due to eruptive activity in the immediate neighborhood. This probable connection between the mingled fragmental and nonfragmental sediments of the belt under consideration and the eruptives of the greenstone and greenstone-conglomerate areas will be more fully considered in another place.

*Coarsely fragmental rocks.*—In the north part of Sec. 23 and the northeast part of Sec. 24, T. 47 N., R. 43 W., Michigan, and in Sec. 28, T. 47 N., R. 42 W., Michigan, occur exceptional phases of rock, recomposed granites, conglomerates, and chert-breccias, mingled with which are cherty and ferro-dolomitic quartzites. Recomposed granites occur at each of the places mentioned. In the field these rocks so closely resemble the original granite that they are with difficulty separated from it. Only in thin section is the fundamental difference appreciated. The granites to the south have a structure characteristic of a thoroughly crystalline rock. Thin sections of the recomposed granite, upon the other hand, show it to consist of fragments of various sizes, which are packed very closely together. Most of these fragments are complex, and if a section chances to be cut from a single one of them it is, of course, precisely like a section from an ordinary granite. A set of sections, however, is sure to disclose the fact that these rocks are clastic, there being always discoverable thin films and small areas of finer material filling the spaces between the larger fragments and cementing them together. This cementing material is generally finely crystalline silica and a carbonate which is usually ferriferous. These peculiar rocks are of great interest because they show how closely a completely crystalline and a fragmental rock may resemble each other. The resemblance in the ledge is at times so close as to make it impossible to determine where the massive granite ends and the fragmental rock begins.

The conglomerates differ from the recomposed granites in that among the fragments of which they are contained are other materials with the granite debris. They are generally closely associated with the recomposed granites, both often occurring within a short distance of each other and practically in the same exposure. As would naturally be expected, simple and complex granite fragments are very abundant in the associated conglomerates, but mingled with these granite fragments are white quartz, green schist, and less frequently other varieties of pebbles. The matrix of the conglomerates is essentially like that of the recomposed granites. In general the matrix is more abundant, the simple grains of quartz buried in the matrices are often enlarged, and in a few cases the feldspar fragments also appear to have undergone a second growth.

Closely associated with the recomposed granites and the conglomerates are cherty quartzites and chert-breccias. The chert-breccias are a variety of rock in which a background of almost pure chert detritus contains rounded and angular fragments of the same material. In its purest phase finely crystalline and amorphous silica only is present. In the cherty quartzites a background of chert and ferriferous carbonate contains much fragmental material. By short steps the chert-breccias and cherty quartzites grade into each other.

The close association of the recomposed granites, the conglomerates, and the chert-breccias and quartzites corresponds to their lithological character, their matrices being essentially the same in each case. In the carbonated cherts nonfragmental sedimentation has prevailed almost to the exclusion of mechanical sedimentation. In the ferro-dolomitic and cherty quartzites, while nonfragmental sedimentation was going on, a large amount of fragmental material was brought in and intermingled. In the conglomerates and recomposed granites mechanical sedimentation was preponderant, but a sufficient amount of a nonfragmental sedimentation occurred simultaneously to firmly cement the clastic material.

In the ordinary quartzites which have been indurated by the enlargement of quartz-grains it is always taken for granted that the induration is subsequent to the deposition of the fragmental quartz. Doubtless when the grains of quartz lie close to one another and the enlargements have continued until they completely interlock this is true, but in the cases of the above quartzites, in which a considerable quantity of cherty silica is present, it is possible that the silica which now forms the matrix, and to which the induration is due, was deposited at least in part simultaneously with the fragmental material, perhaps by organic agencies. If so, it has subsequently been rearranged.

### TABULATION OF PETROGRAPHICAL OBSERVATIONS.[1]

*Sections from the east part of T. 47 N., R. 44 W., and the W. 2 miles of T. 47 N., R. 43 W., Michigan.*

1. Ferruginous quartzite. Specimens 9318 (slide 3018), 9319 (slide 2972), 9320 (slide 2973), 1825 N., 975 W., Sec. 14, T. 47 N., R. 44 W., Michigan.

The rocks are gray, dark brown or black, medium grained, and vary from massive to schistose.

In thin sections a continuous ramifying mixture of hematite and brown opaque oxide of iron contains numerous rather small grains of quartz and feldspar. The simple particles of quartz are often enlarged. The feldspar, which is much less abundant than the quartz, is mostly fresh, although a few grains are kaolinized. The sections are almost exactly like 2962 and 1891 (No. 2 of fragmental rocks south of greenstone conglomerates, p. 371).

2. Ferruginous and chloritic quartzites. Specimens 7445 (slide 1898), 900 N., 0 W.; 9308 (slide 3111), 925 N., 40 W., Sec. 13, T. 47 N., R. 44 W., Michigan.

The rocks are alternately light and dark greenish gray, fine grained, and compact.

The thin sections are mostly composed of small well rounded grains of quartz, with also some of feldspar. The induration of the rocks is due to the enlargement of the quartz grains, and to a rather plentiful interstitial carbonate, which is probably ferriferous. Chlorite and iron oxide are also plentiful.

3. Magnetitic graywacke. Specimens 7433 (slide 1888), 9309 (slide 2969), 9310 (slide 3016), 450 N., 1350 W., Sec. 18, T. 47 N., R. 43 W., Michigan.

The rocks are dark green, fine grained, schistose. The bedding is almost perpendicular to the plane of readiest cleavage.

[1] The numbers of specimens and slides are those of the collection of the Lake Superior Division. Locations are given from the southeast corners of the sections, in steps of 2,000 per mile.

The thin sections show that the rocks in their original condition were mostly composed of rather small fragmental particles of quartz and feldspar. The grains of quartz have received secondary enlargement. Those of feldspar have largely altered to aggregates of green chlorite, this mineral now being one of the most plentiful in the section. Uniformly distributed are numerous crystals of magnetite.

4. Hematitic graywackes and hematitic schists. Specimens 9302A (slide 3015), 140 N., 1000 W.; 7438 (slide 1893), 150 N., 1000 W.; 9303 (slide 4220); 9304 (slide 4221); 9305 (slide 3109), 175 N., 975 W.; 7439 (slide 1894), 180 N., 1000 W.; 7440 (slide 1895), 190 N., 1000 W., Sec. 18, T. 47 N., R. 43 W., Michigan.

The rocks vary from rather fine grained, banded, dark greenish gray graywackes to a dark brown hematitic schist. The belts of heavily ferruginous material vary in thickness from mere films to layers several feet across.

In thin sections, the least ferruginous phases are mostly composed of small fragmental particles of quartz and feldspar. The enlargements of the quartz are often relatively wide. The feldspar is altered to a considerable extent to kaolin and chlorite. In the interstices are found, in varying proportions, finely crystalline quartz, chlorite, hematite, crystals of magnetite and flakes of white mica. In the more ferruginous phases, the hematite, with some magnetite, constitutes a continuous ramifying sheet which contains fragmental material.

5. Ferruginous graywacke. Specimen 9302 (slide 3014), 1850 N., 325 W., Sec. 19, T. 47 N., R. 43 W., Michigan.

The rock is dark green, fine grained, massive, and includes a few crystals of pyrite.

The thin section differs from the least ferruginous phases of 4 only in that in the interstices a considerable quantity of ferro-dolomite is present.

6. Chloritic graywacke-slate. Specimen 9238 (slide 4478), 1750 N., 1250 W., Sec. 20, T. 47 N., 43 W., Michigan.

The rock is greenish gray, of a medium uniform grain and feebly schistose.

Fragmental quartz and feldspar in about equal quantity, the latter being a mixture of orthoclase, microcline, and plagioclase, compose nine-tenths of the thin section. The grains of quartz are enlarged and the interstices are filled with finely crystalline quartz and chlorite. Iron oxide is an accessory. The rock is a typical graywacke-slate.

7. Chloritic and magnetitic graywacke-slates, from south part of belt. Specimens 9237 (slide 4477), 1625 N., 750 W.; 9236 (slide 4476), 1750 N., 750 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rocks are like 6.

The thin sections differ from that of 6 in that the feldspars have altered more extensively to chlorite and kaolin; in that there was originally present a considerable amount of clayey material, and in that they contain some quantity of magnetite which is mostly in crystals. Sericite is an accessory.

8. Chloritic graywacke-slate, north of 7. Specimen 9235A (slide 4475), 200 N., 375 W., Sec. 17, T. 47 N., R. 43 W., Michigan.

The rock is dark green and fine grained, but contains numerous small grains of quartz and altered fragments of feldspar of sufficient size to be perceptible to the naked eye.

The thin section shows a rather abundant groundmass, consisting of finely crystalline quartz, chlorite, kaolin, and iron oxide. Contained in this matrix are abundant grains of both quartz and feldspar of widely varying sizes, the former often being slightly enlarged, and in such cases merging gradually into the clayey matrix.

9. Clay-slate, north of 8, at top of belt. Specimen 9235 (slide 3003), 400 N., 800 W., Sec. 17, T. 47 N., R. 43 W., Michigan.

The rock is dark gray to black, aphanitic, and has a well developed slaty cleavage.

The thin section is exceedingly fine grained, but appears to consist of an intermingled mass of chlorite, quartz, kaolin, and ferrite, with a little ferro-dolomite.

*Section mostly in the west half of Secs. 16 and 21, T. 47 N., R. 43 W., Michigan.*

10. Chloritic graywacke-slate, from south part of belt. Specimen 7416 (slide 1875), 1830 N., 100 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rock closely resembles 7.

The thin section differs from those of 7 only in containing in the interstices much more chlorite and apparently a little magnetite.

11. Ferro-dolomitic graywackes, north of 10, at south part of belt. Specimens 7397 (slide 1860), 9234 (slide 2947), 1900 N., 210 W., Sec. 20, T. 47 N., R. 43 W., Michigan.

The rocks are dark gray, rather fine grained, and contain very numerous dark brown areas of mingled ferro-dolomite and iron oxide, and white areas of ferro-dolomite.

The sections have an exceedingly fine grained matrix, consisting of crystalline and amorphous silica, of chlorite, and of black opaque iron oxide, a little of which is magnetite. Scattered plentifully through this matrix are fragmental particles of quartz and feldspar. The areas which give the rocks their mottled appearance are the ferro-dolomite or limonite or the two combined. All of these areas were plainly once ferro-dolomite, and the alteration of this mineral has produced limonite. All stages of the change may be seen, from those areas which are pure ferro-dolomite to those which are wholly limonite.

12. Chloritic graywacke-slate, from lower middle part of the belt. Specimen 7387 (slide 1852), 230 N., 1850 W., Sec. 16, T. 47 N., R. 43 W., Michigan.

The rock is dark gray, fine grained, schistose, but weathers to a dull pale yellow.

The thin section differs in no important respect from that of 8.

13. Clay-slate, from middle of belt. Specimen 7388 (slide 1853), 380 N., 1980 W., Sec. 16, T. 47 N., R. 43 W., Michigan.

The rock is grayish green, aphanitic, and finely schistose.

The thin section has a finely crystalline matrix consisting of quartz, chlorite, kaolin, and iron oxide, and contains many small fragmental particles of quartz and feldspar.

14. Clay-slate, from upper part of belt. Specimen 7389 (slide 1854), 650 N., 50 W., Sec. 17, T. 47 N., R. 43 W., Michigan.

The rock is black, aphanitic, and easily cleavable.

The thin section is like that of 9.

15. Ferro-dolomitic slate, from lower middle part of belt. Specimen 9233 (slide 2946), 175 N., 1610 W., Sec. 16, T. 47 N., R. 43 W., Michigan.

The rock is dark greenish gray, fine grained, schistose. Weathering gives a thick outer layer of dark brown material.

The thin section shows a groundmass consisting of ferro-dolomite, cherty silica, and chlorite, the first being predominant. Contained in this groundmass, and composing perhaps one-fourth of the rock, are plentiful fragments of quartz and few of feldspar. Here and there minute blades of sericite or muscovite are seen.

16. Chloritic graywacke-slate, from middle part of belt. Specimen 7398 (slides 1861 and 2044), 500 N., 1000 W., Sec. 16, T. 47 N., R. 43 W., Michigan.

The rock is like 12.

The thin section is like that of 12.

*Section in and near the east half of Sec. 15, T. 47 N., R. 43 W., Michigan.*

17. Quartzose ferro-dolomites. Specimens 7368 (slide 1836), 7369 (slide 1837), 9213 (slide 3000), 9214 (slide 2937), and 9215 (slide 2938), 40 N., 1986 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rocks vary in color from gray to bright brick red, are of a medium uniform grain, massive, and break with conchoidal fracture.

A matrix of ferro-dolomite composes as much as one-half of the mass of the thin sections. In this are set well rounded particles of quartz and feldspar, which, on account of the abundance of the ferro-dolomite, come rarely in contact with one another. The grains of quartz are as often finely complex as simple. As accessories occur chlorite, sericite, and iron oxide, the latter being so abundant in slide 2938 as to heavily stain the section.

18. Chert, interstratified with 17. Specimens 7370 (slide 1838), 7371 (slide 1839), 9216 (slide 2939), 9217 (slide 2940), from 58 N., 1984 W., to 98 N., 1940 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rocks are light to dark gray, aphanitic, have a conchoidal fracture, and some of them contain galena and chalcopyrite.

The sections are composed almost wholly of exceedingly finely crystalline interlocking quartz, with perhaps some amorphous silica. Ferro-dolomite, sericite, and ferrite are accessories. In places, the sections are cut by veins of coarser crystalline quartz.

19. Ferruginous clay-slate. Specimen 7373 (slide 1841), 400 N., 30 W., Sec. 15, T. 47 N., R. 43 W., Michigan.

The rock is dark greenish gray and has an aphanitic texture.

The thin section consists of an exceedingly fine mixture of quartz, cherty silica, kaolin, chlorite, and dark brown and black iron oxide. The section resembles 9 but is somewhat coarser.

20. Chloritic graywacke-slates, from middle part of belt, north of 16. Specimens 7396 (slide 1859), 500 N., 1090 W.; 9270 (slide 4927); 9271 (slide 4926), 575 N., 1145 W., Sec. 15, T. 47 N., R. 43 W., Michigan.

The rocks are grayish green, fine grained, and have a feebly developed cleavage

The thin sections show a clayey groundmass, consisting apparently of kaolin, quartz, chlorite, and ferrite, which contain many fragments of both quartz and feldspar. The sections differ from one another only in the relative abundance of these larger fragments. In slide 4926 the large fragments are nearly wanting and the rock approaches a clay-slate.

*Section in east half of Secs. 14 and 23, T. 47 N., R. 43 W., Michigan.*

21. Cherty ferro-dolomite, from base of belt. Specimen 9276 (slide 3006), 1840 N., 1000 W., Sec. 23, T. 47 N., R. 43 W., Michigan.

The rock is light gray, weathering to dark brown, fine grained, massive, and has a conchoidal fracture.

The section consists of intimately mingled particles of brilliantly polarizing ferro-dolomite and minutely crystalline interlocking quartz.

22. Quartzites, from near base of belt. Specimens 7362 (slide 1831), 1965 N., 580 W.; 9274 (slide 4493), 1950 N., 590 W., Sec. 23, T. 47 N., R. 43 W., Michigan.

The rocks are gray, fine grained, vitreous, and break with conchoidal fracture.

The thin sections have a fine grained interlocking groundmass composed of cherty silica, which contain numerous rounded grains of quartz, with fewer of orthoclase, microcline, and oligoclase. There occur quite plentiful areas of chlorite, which in most cases are heavily stained with oxide of iron.

23. Conglomerates interstratified with 22. Specimens 7364 (slide 1833), 1955 N., 590 W.; 9273 (slide 4492), 1965 N., 520 W., Sec. 23, T. 47 N., R. 43 W., Michigan.

The matrix of the rocks is mottled pink and gray, medium grained, and massive. In the matrix are very numerous granite pebbles, which vary from large size to those so minute as to be lost in the matrix.

In the thin sections, upon a close examination, one plainly sees that the rock is a recomposed one. But the granite fragments which make up the rock are so large and so closely packed together that one at first sight might mistake the rock for a massive granite. However, the rounded appearance of the complex quartz-feldspar-chlorite fragments, the presence of a few rounded grains of quartz and feldspar and of a sparse matrix, show the clastic origin of the rock. Many of the feldspar grains are broken or distorted, the latter phenomenon being beautifully shown. This is probably caused by pressure applied after the grains were deposited in the recomposed rock. The matrix consists of finely interlocking quartz, kaolin, ferrite, some carbonate and chlorite. Slide 1833 contains in the groundmass a larger portion of carbonate than does 4492.

24. Chloritic slate, from lower part of belt. Specimen 12590 (slide 5345), 155 N., 225 W , Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock is dark gray, fine grained, and finely laminated. The thin section consists of a continuous mass of chlorite, ferrite, feldspar, quartz, sericite, or kaolin, all of which are arranged in wavy lines, the general direction of which is parallel to the lamination of the rocks. Some of the larger particles of quartz and feldspar have a decided clastic appearance, so there is little doubt that the rock is a fragmental slate.

25. Chloritic graywacke-slate, from lower middle part of belt. Specimen 10397 (slide 4006), 207 N., 500 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock is light greenish gray, fine grained, almost aphanitic, and is readily cleavable.

The thin section has a schistose matrix, consisting mainly of chlorite and kaolin, or hydromica, with some chlorite and gray amorphous material, in which are set small fragmental particles of quartz and feldspar, the latter being more abundant.

26. Graywacke-slate, from a lower middle horizon. Specimen 12837 (slide 5496), 370 N., 0 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock is dark gray, medium grained, and laminated.

Fragmental quartz and feldspar, in grains varying from minute to those of medium size, compose about one-half of the section. These minerals are buried in a very fine grained clay background, which appears to consist of finely crystalline quartz, chlorite, sericite, and iron oxide. Many of the fragments of feldspar are more or less altered, the resultant products being two or more of the minerals which compose the background. Calcite or other carbonate occurs as an accessory.

27. Chloritic graywacke. Specimen 12589 (slide 5344), 500 N., 925 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock is greenish gray, fine grained, and massive.

Small angular particles of quartz and feldspar compose two-thirds of the section. The angularity of many of the particles appears to be original, and it is probably due to the fact that their small size has prevented rounding. A portion of them are somewhat rounded; these are enlarged. Apparently also a few of the orthoclase particles are enlarged. The rather abundant interstitial material is chlorite, finely crystalline quartz, flakes of kaolin or sericite, and particles of iron oxide. A few small particles occur which appear to be tourmaline.

28. Ferro-dolomitic slate, from top of belt. Specimen 12844 (slide 5499), 1000 N., 80 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock is light greenish gray, fine grained, finely laminated, and has the appearance of an impure clayey limestone.

Rather small particles of quartz, many of which are slightly enlarged, with feldspar, both of quite uniform size, compose about one-half of the thin section. This material is set in a groundmass which consists chiefly of ferro-dolomite. The ferro-dolomite is mostly in irregular reticulating areas, filling the interstices, but many detached particles have distinct rhombohedral outlines. Mingled with the ferro-dolomite are some finely crystalline quartz, chlorite, ferrite, sericite. A few small crystals of zircon are seen, one of which shows finely a zonal structure.

29. Ferro-dolomitic slate, interstratified with 28. Specimen 12843 (slide 5627), 1000 N., 80 W., Sec. 14, T. 47 N., R. 43 W., Michigan.

The rock differs from 28 in being composed of alternate layers of gray and green material.

The thin section is not essentially different from that of 28, except that it contains less fragmental material. Also a good many small crystals of pyrite, and numerous roundish areas of some mineral which has a radial polarization (perhaps chalcedony), are found.

*Section near the centers of Secs. 13 and 24, T. 47 N., R. 43 W., Michigan.*

30. Chloritic slate, from near base of belt. Specimen 12591 (slide 5346), 1986 N., 1077 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is like 24, except that it is coarser grained.

In thin section the minerals and their arrangement in wavy parallel lines are the same as in 24. The constituents are in coarser particles, and a portion of the quartz and feldspar are plainly fragmental.

31. Chloritic graywacke-slate, from a lower middle horizon. Specimen 10396 (slide 4005), 280 N., 1500 W., Sec. 13, T. 47 N., R. 43 W., Michigan.

The rock is like 25, except that it is coarser grained.

The thin section differs from that of 25, in being coarser grained, and in containing a little calcite or some other carbonate.

32. Graywacke-slate, from a middle horizon. Specimen 7358 (slide 1827), 370 N., 1000 W., Sec. 13, T. 47 N., R. 43 W., Michigan.

The rock is black, fine grained, almost massive, and has a subconchoidal fracture.

In thin section, a fine grained groundmass of quartz, chlorite, kaolin, pyrite, contains numerous fragments of quartz and feldspar, the latter being more plentiful.

*Section near range line between R. 42 W., and R. 43 W., Michigan.*

33. Recomposed granité, from a low horizon. Specimen 12592 (slide 5347), 1700 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is pink, white and black mottled, coarse grained, massive. In nearly all respects this rock is in appearance like a granite. It weathers to some depth to a dark brown color.

The section, if not examined closely, would be taken for a coarsely crystalline granite. The minerals abundantly present are quartz and feldspar, the latter being orthoclase, microcline, and plagioclase. In subordinate quantity are chlorite, pyrite, and ferro-dolomite. In the major portions of these sections the minerals are in large complex granite fragments, which are often crowded so close together as to make it difficult to follow their outlines. The interstitial material is chiefly finely crystalline quartz, but mingled with this is a little ferro-dolomite. In some places this interstitial material is in quite large areas and contains distinct fragments of quartz and feldspar. Many of the striated feldspars show finely the effects of bending and fracture; some grains are bent but not broken, while others are fractured, each of the fragments in such cases showing bending due to the strain before fracture occurred.

34. Ferro-dolomitic chert, interstratified with 33. Specimen 12593 (slide 5348), 1700 N., 232 W., Sec. 23, T. 47 N., R. 43 W., Michigan.

The rock is greenish gray, medium grained, and massive.

A large part of the section, constituting a background, is composed of finely crystalline cherty silica and somewhat coarsely crystalline ferro-dolomite. Where the silica is in excess, the carbonate occurs largely in well outlined rhombohedra. Contained in the background are angular fragments of a much altered, fine grained porphyrite.

35. Chert-breccia, from a low horizon, north of 34. Specimen 12594 (slide 5349), 1748 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is a gray and green chert-breccia, which contains between the chert fragments particles of coarsely crystalline quartz.

Rounded and angular fragments of chert of greatly varying sizes compose a large part of the section. Mingled with these chert fragments are many simple grains of quartz, which are widely enlarged and the enlargements of which merge into the matrix. Both classes of fragments are cemented with finely crystalline cherty silica, which is almost exactly like that in the chert fragments, and were it not for the iron stained outlines of the latter it would be impossible to separate them from the matrix in which they are contained.

36. Chloritic and graphitic schist, from a low horizon, north of 35. Specimen 12595 (slide 5350), 1770 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is strongly schistose, and shows alternate bands of gray quartzose and dark green to black material, the latter being the more plentiful. The cleaved surface shows a black lustrous appearance due to graphite.

The thin section has a finely crystalline background, consisting of quartz and ferro-dolomite in about equal quantity. This background contains much chlorite, sericite, and black graphitic material, arranged in parallel, wavy lines. A portion of the quartz is plain'y fragmental, and a part of the ferro-dolomite is in small perfect rhombohedra.

37. Sericitic slate, from a low horizon, north of 36. Specimen 12596 (slide 5351), 1824 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is dark green, of a uniform texture and finely foliated.

The section has a background consisting of finely crystalline quartz, chlorite, sericite, and pyrite. Set in this background, and making up about one-half of the section, are rather small fragments of quartz and feldspar. These fragments are with great uniformity scattered through the rock with their longer axes in a common direction. The appearance which has resulted from this arrangement of fine grained material is that of a net which has been drawn out diagonally, the groundmass representing the meshes, and the fragments of quartz and feldspar the open spaces.

38. Graywacke-slate, from a low horizon, north of 37. Specimen 12597 (slide 5352), 1852 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is dark green, foliated, of a uniform grain, coarse enough to show particles of quartz, feldspar, and pyrite. It closely resembles 30.

The section differs but little from that of 30, except that it is coarser grained.

39. Sericite-slate, from a low horizon, north of 38. Specimen 12598 (slide 5353), 1876 N., 232 W., Sec. 24, T. 47 N., R. 43 W., Michigan.

The rock is somewhat finer grained than, but otherwise precisely like 37.

The thin section differs from that of 37, in that the background is more abundant, and in that the sericite is very plentiful, while chlorite is subordinate in quantity. This supposed sericite is in minute particles, with the fibers in a common direction, and often so concentrated as to make up solid sheets, all of the constituent fibers of which extinguish simultaneously.

40. Quartzite, from a middle horizon. Specimen 12599 (slide 5354), 0 N., 1973 W., Sec. 18, T. 47 N., R. 42 W., Michigan.

The rock is a coarse grained, vitreous quartzite. The contained fragments of quartz have a somewhat different color from the matrix in which they are contained, so that their rounded outlines are distinctly seen. They vary greatly in magnitude, the largest ones being one-fourth of an inch in diameter, while from this they run to those so small that they can not be distinguished from the matrix in which they are contained. The matrix of the rock is so strong that when broken the fracture passes through the large particles of quartz instead of tearing them from their sockets.

The appearance in hand specimen is borne out in thin section. Nearly all of the rounded fragments are quartz, although mingled with them are a few small ones of feldspar. Most of these grains are simple, but some of them are very complex. But few of them are enlarged, and these but slightly. The plentiful matrix in which they are contained consists of finely crystalline quartz and sericite or muscovite, mingled with a little pyrite. In this rock the induration is as great as in any vitreous quartzite, yet it is not caused by interlocking enlargements so common in quartzites, but by the deposition of independent interstitial quartz.

41. Feldspathic quartzite, from a middle horizon, north of 40. Specimen 12600 (slide 5355), 62 N., 1973 W., Sec. 18, T. 47 N., R. 42 W., Michigan.

The rock is a gray, coarse grained, vitreous quartzite, which breaks with conchoidal fracture.

The thin section differs from that of 40 chiefly in that mingled with the large quartz fragments are many of orthoclase, microcline, and plagioclase.

*Exposure in the NE. ¼ of Sec. 19, T. 47 N., R. 42 W., Michigan.*

42. Chloritic and sideritic slate. Specimen 12841 (slide 5498), 1500 N., 250 W., Sec. 19, T. 47 N., R. 42 W., Michigan.

The rock is dark green, very fine grained, and finely foliated. The specimen is cut by veins of quartz.

The mass of the section consists of exceedingly fine material, which appears to be quartz, chlorite, kaolin or sericite (or both), and oxide of iron. Mingled with this matrix are small grains of quartz and feldspar, which have a strong fragmental appearance. The rock is taken to be a fine grained squeezed clayey one.

*Section in the east part of Sec. 20, T. 47 N., R. 42 W., Michigan.*

43. Clay-slate, from a low horizon. Specimens 9206 (slide 2935), 9207 (slide 3305), 9208 (slide 2998), 9209 (slide 2936), 7356 (slide 1826), 425 N., 50 W., Sec. 20, T. 47 N., R. 42 W., Michigan.

The rocks are from light grayish to very dark green, aphanitic, and have a ready cleavage.

The sections are all exceedingly fine grained. They consists of finely crystalline and cherty silica, abundant chlorite, kaolin, iron oxide, and perhaps other constituents. In one section many of the quartz grains are of sufficient size to make it plain that they are fragmental.

44. Chloritic sericite-slate, from a low horizon, north of 43. Specimen 12602 (slide 5356), 550 N., 300 W., Sec. 20, T. 47 N., R. 42 W., Michigan.

The rock is greenish gray, aphanitic, and finely foliated.

The thin section contains an almost solid mass of minute fibers of chlorite and a mineral which is taken to be sericite, mingled with which are finely crystalline quartz and ferrite. Contained in this background are numerous small particles of quartz and feldspar, which are plainly fragmental. The sericite is the most abundant mineral of the slide. It has strong absorptive power and gives brilliant polarization colors. The fibers lie with their longer axes in a common direction, and so extinguish simultaneously. The laminæ are in wavy lines, often broken asunder or sharply foliated as if they had been subject to intense pressure, and thus correspond in their appearance to the foliated character of the hand specimen.

45. Chloritic and sericitic slates, from a middle horizon, north of 44. Specimens 12603 (slide 5357), 427 N., 356 W.; 12605 (slide 5359), 1000 N., 340 W., Sec. 20, T. 47 N., R. 42 W., Michigan.

The rocks are dark green, fine grained, and finely laminated. 12605 is somewhat coarser grained than 12603.

The thin sections of these rocks are closely allied to that of 44, the chief difference being that they contain more numerous and larger fragments of feldspar.

*Exposures in NW. ¼ of Sec. 28, T. 47 N., R. 42 W., Michigan.*

46. Sericite-schist. Specimens 12816 (slide 5490), 12911 (slide 5515), 1472 N., 1499 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

The rocks are gray, aphanitic, finely foliated, are hard and felsitic appearing.

The thin sections have a finely crystalline background composing two-thirds or more of the sections, which contains roundish and angular grains of quartz of varying sizes. The background appears to be chiefly made up of quartz and sericite, mingled with which is some oxide of iron. The quartz grains, set in a matrix of finely crystalline quartz and sericite, at once suggests a coarse fragmental material in a nonfragmental sediment; but the excessive angularity of some of the quartz grains, and the lack of any enlargements, makes the fragmental character of the quartz somewhat doubtful, and thus it is difficult to determine whether this rock is a fragmental one or a felsitic schist.

47. Chert-breccia. Specimen 12625 (slide 5374), 1730 N., 1480 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

This rock consists of angular to rounded fragments of gray and black chert, which vary in size from minute particles to pebbles several inches in diameter. These cherty fragments are set in a matrix, which appears to consist mostly of the same material, in which occur large simple grains of vitreous quartz and cleavage areas of feldspar.

In general the section as seen under the microscope corresponds in appearance in hand specimen. The large fragments of the section are all finely crystalline cherty silica, the outlines of which are only discoverable by using a low power. Two of these fragments are somewhat peculiar. One contains besides the finely crystalline silica a large amount of brilliantly polarizing mineral in minute scales and many brown particles of hydrated iron oxide. Whether this fragment is impure opal or is from an altered felsite it is impossible to say. The other is an almost pure specimen of chert, except that it contains many small fragmental particles of quartz as though it were a nonfragmental sediment which had received a considerable quantity of mechanically deposited quartz. The interstitial material of the section consists of cherty silica, which contains large brilliantly polarizing flakes of sericite and also areas of brown hydrated iron oxide. This matrix includes many large, well rounded, simple grains of quartz and few of feldspar.

48. Recomposed granite. Specimen 12626 (slide 5375), 1730 N., 1480 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

The rock is chiefly composed of the coarse granite detritus, but contains some seams of fine quartzite-like material and few white quartz pebbles. The granite detritus is often in large complex fragments, but also there are present numerous large, apparently simple grains of quartz and feldspar.

The section is cut from the fine grained quartzite-like part. It consists of a matrix and contained fragments in about equal quantity. These fragments are almost wholly quartz, rather small, mostly well rounded, and often enlarged, the enlargements fading into the fine grained matrix. Flakes of muscovite of some size appear, which are taken to be fragmental. The matrix is mostly cherty quartz, but mingled with it is a good deal of sericite, hematite, and limonite.

49. Sericite-schist. Specimen 12629 (slide 5378), 1748 N., 1462 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

The rock varies from dirty yellow to brown, is finely foliated, and upon its cleavage surface has a micaceous sheen.

The thin section is essentially like that of 44, the only difference being that the fragmental particles are larger, the folia of the sericite is not in short wavy folds, and the section is heavily stained with iron oxide.

50. Recomposed granite. Specimen 12818 (slide 5492), 1507 N., 1464 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

In hand specimens this rock would be taken foran ordinary granite unless it were closely inspected. The eye recognizes coarse pink feldspar, translucent quartz, and a green material, all being arranged so as to show a somewhat banded appearance like a coarse gneiss. The only indications that it is different from an ordinary crystalline rock are its somewhat nodular weathering, as though composed in part of pebbles, and a roundish appearance of the larger white quartz areas.

A large part of the section consists of complex granite fragments, composed of quartz, microcline, orthoclase, chlorite, iron oxide, and other accessories. In the interstices are finely crystalline quartz, chlorite, and some ferrite, included in which are large simple particles of quartz and feldspar.

51. Cherty quartzites. Specimens 12620 (slide 5371); 12820 (slide 5493), 1600 N., 1360 W.; 12621 (slide 5372), 1600 N., 1300 W.; 12912 (slide 5516), 1615 N., 1360 W.; 12917 (slide 5519), 1628 N., 1360 W.; 12627 (slide 5376), 1730 N., 1480 W.; 12812 (slide 5488), 1712 N., 1462 W., Sec 28, T. 47 N., R. 42 W., Michigan.

These quartzites are tolerably coarse grained and massive. Some of them contain rather large pebbles of white and cherty quartz. They all have a rough fracture, due to the fact that when broken the large quartz fragments are torn from their sockets. In color they vary from greenish gray to grayish brown or red. Specimens 12620 and 12621, besides being reddened are somewhat honeycombed, as though some constituent, possibly a carbonate, had been leached out.

The sections of these rocks consist of two parts, a matrix and coarse material. The latter is chiefly quartz in large, simple, or coarsely complex grains, which are often well rounded, but also quite as often more or less angular, while part of them are very angular. There are a few fragments of very finely crystalline and perhaps partly amorphous cherty silica. Many of the simple quartz grains are slightly enlarged, the enlargements merging gradually into the matrix. Fragmental feldspar is quite plentiful in one of the sections, and sparse in the others. Also in one section are numerous large altered leaflets of biotite. The predominant constituent of the matrix is cherty silica, mingled with which is much sericite or kaolin, in small brilliantly polarizing flakes. In one or two sections this sericite is so plentiful as to be comparable with the silica in abundance. In such sections some of the complex sericite-quartz areas have a roundish appearance as though they were complex fragments. They perhaps represent altered feldspar detritus, as indicated by the fact that in one of the sections many undoubted feldspars have undergone alteration to quartz and sericite. The cavities seen in hand specimen are found in thin section to be mostly bordered by iron oxide. They are of very irregular form, resembling in this respect areas of iron oxides found in the matrix; and it seems probable that the cavities were either entirely filled with iron oxide, or more probably ferriferous carbonate, which largely went into solution, but from which the iron oxides now remaining were produced. This probability is further strengthened by the fact that in other rocks precisely similar to these and associated with them is found a good deal of carbonate. The sections differ from those of the slates and graywackes in one important particular. The fragmental particles are all large, none nearly approaching in minuteness the particles of the matrix, while in the graywackes there is every gradation from the coarsely fragmental material to the fine matrix. The minutely crystalline matrix in these rocks is taken to be a nonfragmental or recomposed sediment. The sericite in the matrix is largely arranged with its blades in a common direction.

52. Cherty and ferro-dolomitic quartzites. Specimens 12915 (slide 5517); 12916 (slide 5518), 1628 N., 1360 W.; 12628 (slide 5377), 1730 N., 1480 W.; 12922 (slide 5520), 1744 N., 1466 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

The rocks vary from greenish gray to mottled greenish gray or red, are medium grained, massive, and break with a somewhat rough fracture, resembling in this respect 51.

In most respects the thin sections are similar to those of 51, the essential difference between the two being that the matrices contain a large amount of ferro-dolomite. The relations of the hematite and limonite to the ferro-dolomite are often such as to clearly indicate that these oxides are the result of decomposition of that mineral.

53. Conglomerate. Specimens 12611 (slide 5364), 12612 (slide 5365), 12809 (slide 5481), 1050 N., 1000 W., Sec. 28, T. 47 N., R. 42 W., Michigan.

The conglomerate contains numerous white quartz, green schist, and worn granite pebbles. No unmistakable greenstone pebbles are seen, although some specimens of the conglomerate appear to contain small fragments of basic detritus. At times the conglomerate is so fine grained as to become a quartzite.

Thin section 5481 is from a red quartzite pebble. It is composed almost wholly of enlarged grains of quartz of nearly uniform size. Mingled with this quartz is a little feldspar. Between these grains are also films of limonite. In slide 5364 the pebbles are from green schist fragments. The green schist is very much altered, and consists mainly of confusedly mingled pale green chlorite, much altered feldspar, calcite, or other carbonate, sericite or muscovite, and leucoxene. Whether it is an altered eruptive it is impossible certainly to say. The matrix of the conglomerate is of the most complex nature, being composed of finely crystalline and coarse fragmental portions. The coarse grains are quartz and feldspar. They have been in part somewhat rounded, but are mostly angular. The quartz grains are often quite widely enlarged, and frequently the enlargements gradually merge into the matrix. The fragments of feldspar are as numerous as the quartz, and include orthoclase, microcline, and plagioclase. Some of the latter particles have excessively fine twinning. Many of the particles of feldspar are plainly enlarged. In some cases, particularly with orthoclase, the added portions extinguish simultaneously with the cores but in the striated feldspars the added portions, which entirely encircle the cores, extinguish wholly with one set of the bands. This may mean that the polysynthetic twinning of the original feldspar has been due to some cause which acted upon the kernels of feldspar before they were deposited in the present rocks. A few fragments of mica are also found. These large areas are contained in an excessively fine grained groundmass, the chief constituent or which is crystalline and half amorphous silica, mingled with chlorite, sericite, or kaolin, and many minute rectangula and hexagonal crystals of hematite. The groundmass contains also a few large areas of ferro-dolomite.

SECTION V.—THE GREENSTONES.

The eruptives belonging to the Eastern area may be considered in three divisions, based upon apparent geographic continuity or lithologic likeness, or both. The first division includes the very numerous exposures of greenstone which outcrop in Secs. 15, 16, 23, 25, 26, and 27 (except the northern exposure in Sec. 15), T. 47 N., R. 44 W., Michigan. The second area is in Secs. 20, 29, and 30, T. 47 N., R. 43 W., Michigan, and the third is in Secs. 13, 14, 15, and 24, T. 47 N., R. 44 W., Michigan.

*The main area.*—The exposures in Secs. 15 and 16, and those in Secs. 26 and 27, belonging to this area, are of large size. The greenstone in Secs. 15 and 16 forms a continuous high range, running east and west, and apparently joins the great greenstone ridge to the north and west belonging to the Copper-bearing series. In traversing the ridge in a north and south direction one has to ascend a height of some 500 feet above the valleys to the north and south. Also the large exposure near the center of Sec. 26 is another notable landmark, rising to about the same elevation above the level country surrounding.

Lithologically, the exposures in this area are essentially the same rock. The greater number of them are diabases, but they grade into gabbros. The gabbros have a granitic structure, and the pyroxene shows the diallagic cleavage. The contrast between the structure of these gabbros and the diabases with perfect ophitic structure, both belonging to the same area and probably to the same rock mass, is very great. One of the exposures in Sec. 25 has very large augites, each of which includes scores, if not hundreds, of small lath-shaped plagioclases. The gabbros are found in the central and western parts of the areas, while it is further notable that the rocks in the west part of Sec. 23 and near the center of Sec. 15, that is, those which are nearest to the greenstone-conglomerate area, are the ones which become fine grained, and the typical ophitic structure appears. And in the exposure near the center of Sec. 15 an amygdaloidal or pseudo-amygdaloidal appearance is presented. It does not, then, appear improbable that these greenstone masses are or were really connected with the greenstone-conglomerates, the latter perhaps being the surface material, while the diabases and gabbros were deep seated. As these diabases are in most respects precisely like the diabases in the main area to the westward, described on pp. 350–354, a description of them will not be given in detail, only points of difference being mentioned.

The augite of this area frequently shows twinning. The twinning is of the form most common, the twins each being in two parts and the composition plane the orthopinacoid.

The enlargement of augite and hornblende alluded to, pp. 353,354, as occurring in some of the diabases at the extreme west end of the western area, here most beautifully occurs. The cases of enlargement of both the augite and hornblende are finer than any known to the westward. Such a renewed growth of hornblende in a kersantite has been described by Friedrich Becke.[1]

The following quotation is from his description:

Die primären compacten Hornblende-Krystalle sind sehr häufig von einer Rinde umgeben, welche aus stängeliger grüner Hornblende besteht, die ganz mit der Hornblende des Uralit übereinstimmt. In Querschnitten beobachtet man die durch Kern und Hülle gleichmässig fortsetzenden Spaltrisse. Mitunter hat der so weitergewachsene Krystall andere Krystallflächen in der Prismenzone, als der Kern. In Längschnitten sieht man den compacten Kern mit Bündeln parallel angewachsener Hornblendenadeln versehen, welche sich weiterhin zu divergirenden Büscheln auflösen. * * * Die Art des Auftretens dieser Fortwachsungen lässt keinen Zweifel, dass während der Ausbildung dieser Fortwachsungen mechanische Bewegungen innerhalb dieses Gesteins nicht mehr stattgefunden haben. (P. 158.)

It thus appears that Becke discovered in 1883 the enlargement by secondary growth of individuals of hornblende in an eruptive rock, this change having taken place subsequent to its consolidation. I have described the enlargement of hornblende by second growth in certain fragmental rocks in northeastern Minnesota.[2] Here the change is of greater importance than in eruptive rocks, for it explains in part at least the induration of such clastic sediments. However, in the eruptives under consideration I have met with cases of new growths occurring upon augite and hornblende, which are corroborative of and add something to the observations

[1] Tschermak's Min. und Petr. Mitth., vol. V, part II, 1883, in a paper entitled "Eruptivgesteine aus der Gneissformation des niederösterreichischen Waldviertels."

[2] C. R. Van Hise: Enlargements of Hornblende Fragments. Am. Jour. Sci., 3d series, 1885, vol. XXX, pp. 231–235.

made by Becke. In many of the sections a new amphibole has attached itself to secondary hornblende.[1] There are here, then, two hornblendes, one of which is paramorphic, while the other has grown after the rocks reached a solid state. The added amphibole has found room for itself, as in the case described by Becke, by penetrating the surrounding feldspars. The new amphibole is also found, as has been noted, included in the partly decomposed feldspar in numerous small independent individuals. This new amphibole is fibrous, of a pale green color, is not strongly pleochroic, and often shows distinctly its intersecting prismatic cleavage. It has all the characteristics of the variety described as smaragdite. The crystallographic continuity of the paramorphic and new amphibole when the two are contiguous is as plain as in the case described and figured by Becke, where, however, the hornblende cores seem to have been original.

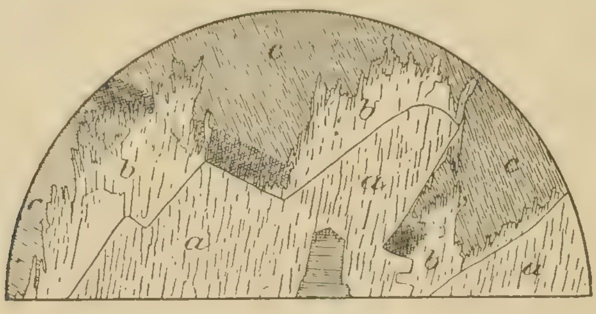


FIG. 10.—Hornblende enlargement of augite in diabase.

In other diabases from the same locality the greater part of the augite is unaltered. In these cases nearly every individual of this mineral is surrounded by a sheath of smaragdite. This smaragdite has clearly formed subsequently to the consolidation of the rock, as is shown by the following facts: It cuts into the surrounding feldspar in the most irregular manner. The augite cores have the forms common in many diabases, being bounded by well

[1] R. D. Irving and C. R. Van Hise: Geol. of Wis., 1882, vol. IV, p. 663. R. D. Irving: On the Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States; Am. Jour. Sci., 3d series, 1883, vol. XXVI, p. 27. R. D. Irving: Supplement to paper on the Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States; Am. Jour. Sci., 3d series, 1884, vol. XXVII, p. 130. M. E. Wadsworth: Notes upon the Geology of the Iron and Copper Districts of Lake Superior, 1880. G. H. Williams: On the Paramorphosis of Pyroxene to Hornblende in Rocks; Am. Jour. Sci., 3d series, 1884, vol. XXVIII, p. 259. G. H Williams: Bull. U. S. Geol. Survey, Nos. 28 and 62.

defined, broken right lines, or lines somewhat curved, as the spaces left by the feldspars allowed. Often the new growth has continued farther in places than in adjoining ones, and, as it went on, it has sometimes widened out, forming club-shaped protuberances of hornblende within the feldspar. In longitudinal sections (Fig. 10) the smaragdite is more plentiful at the extremities of the individuals than at the sides. The terminations of these enlargements are sharply serrate. The constituent fibers at times are slightly divergent and usually cut deeply into the feldspar. Ordinarily the fine fibrous cleavage of the smaragdite is coincident with the cleavage of the augite. However, the angles $\mathfrak{c} : \mathfrak{c}$ in the augite and in the enveloping smaragdite show their characteristic relations. In transverse sections (Fig. 11), where the intersecting prismatic cleavages of the augite and smaragdite are seen, their relations are such as to indicate that the ortho- and clino-pinacoids in the two minerals are parallel. The crystallographic relations of the two minerals are, then, in both longitudinal and transverse sections, precisely like those well known to occur between augite and amphibole paramorphic after it.[1]

FIG. 11.—Hornblende enlargement of augite in diabase.

Another difference betweenthe diabases of the Western and Eastern areas is the relative freshness of the pyroxene as compared with the plagioclase in the latter. Generally pyroxene decomposes more rapidly than plagioclase. The reverse has been the case here. In nearly every section the plagioclases have been found to be quite extensively altered. The double angles in the zone 001 : 100 do not exceed 62°, which would indicate that the most basic feldspar is labradorite. The most frequent alteration products of the feldspar are small brilliantly polarizing flakes, taken to be kaolinite, green smaragdite, chlorite, epidote, biotite, and quartz. In the

[1] Teall, J. J. H.: Quart. Jour. Geol. Soc., London, vol. 40, p. 353, Pl. 29. Fig. 3. Rohrbach, Carl E. M.: Ueber die Eruptivgesteine im Gebiete der schlesisch-mährischen Kreideformation; Min. u. petrog. Mitth., vol. VII, p. 21, Pl. 1, Figs. 1–7. Van Hise, C. R.: Note on the enlargement of hornblendes and augites in fragmental and eruptive rocks; Am. Jour. Sci., 3d series, vol. 33, 1887, p. 385. Hobbs, Wm. H.: On the petrographical characters of a dike of diabase in the Boston basin; Bull. Mus. Comp. Zool. Harvard Coll,. vol. 16, 1887, p. 10, Pl. 1, Fig. 2.

abundance of secondary kaolin and smaragdite these rocks are exactly like the diabases to the westward; but in the large development of chlorite and epidote there is a difference. In nearly every section minerals are found included in the feldspars. Frequently within the chlorite has developed the epidote, but at times the alteration seems to have been directly from feldspar to epidote, in which case the epidote is in small granules. Biotite and quartz are infrequently present as secondary products in the feldspar.

The minerals secondary to the augite are the same as those included by the feldspar, with the exception that quartz is absent; but as the augite is much fresher than the feldspar, the quantity of secondary material from this source is much less. Chlorite and amphibole are at times both abundant. Next in importance to these is biotite, which in one or two cases is largely found in both the augite and feldspar.

The iron oxide is always in the form of menaccanite, which in every case is altered to a large degree to leucoxene, some specimens showing beautiful alternating bars of menaccanite and leucoxene.

*The area in Secs. 20, 29, and 30, T. 47 N., R. 43 W., Michigan.*—Between Secs. 20 and 29, but mostly in Sec. 29, is a continuous range of greenstone which extends from the valley of the Presque isle for more than a mile westward. Here there is a break, and again in Sec. 30 this greenstone ridge appears. As examined on the ground it has the appearance of an interbedded flow. That it was really contemporaneous with the formation of the series is further indicated by the fact that at its northern base, in Sec. 20, a jasper-conglomerate is found which is largely composed of debris, like the material of the greenstone. (See pp. 369–370.) The iron-bearing formation in Sec. 30 is found upon the south side of the greenstone ridge, and upon the north side there is also a heavily ferruginous rock. In Secs. 20 and 29 the iron belt is on the north side, but whether a similar belt is on the south side has not been proved by exploration, but it probably exists there.

Petrographically, this rock also 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 in 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 the detached exposures are parts of a continuous belt.

The alterations have extended so far in places as to make the rock a porphyrite. If any of the rocks have had a glassy background, it has now wholly devitrified, and while it is at times very fine grained, the fresher parts are always holocrystalline. The structure of this background, in rocks fresh enough to determine this point, is hypidiomorphically granular. The original minerals were menaccanite, plagioclase, and augite, this being the order of crystallization. The secondary ones are kaolinite, chlorite, epidote, leucoxene, and smaragdite. The only mineral which appears in two generations is the plagioclase. It is always greatly altered and no separation of it was attempted, but as indicated by its double angle, according to Pumpelly's method, it is rather acidic, the angles determined being so low as to indicate a feldspar not more basic in any case than labradorite. The augite is occasionally found in unaltered, or little altered individuals, but in general it has very largely decomposed, while in several sections its decomposition is complete. The change in the feldspars and augite has resulted in the formation of the same set of minerals. One of the most abundant of these, if not the most abundant, is smaragdite. It is found in small particles and well defined blades, which penetrate the rock in every direction and thus cut the feldspar through and through. Chlorite is also an abundant secondary product, and in it has developed a large quantity of epidote. As a result of these changes in the augite and feldspar, the smaragdite, chlorite, and epidote are the three most plentiful minerals of the rock. The menaccanite is always altered to a greater or less degree to leucoxene, and frequently gives the characteristic grate-like appearance.

In original minerals contained and in secondary products, these 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. This likeness is still further reenforced by the correspondence of the double angles of the feldspars, as measured by Pumpelly's method.

*The area in Secs. 13, 24, 14, and 15, T. 47 N., R. 44 W., Michigan.*—The greenstones here included, unlike those of the two previous areas, are in several detached areas. They are all closely associated with greenstone-conglomerates. That in the northeast corner of Sec. 24 is apparently in the midst of a greenstone-conglomerate area; that in the north part of Sec. 15 is about half way between two known greenstone-conglomerate exposures; while the exposures in the west part of Sec. 13, and in Sec. 14, are bounded upon the south and west by greenstone-conglomerates. In fact, the exposures here included are so closely connected with the greenstone-conglomerates that the lines which separate them are to some extent arbitrary. Where the pebbles disappear from a conglomeratic area, and the rock at the same time has the character of a basic eruptive, it is mapped as a greenstone; but it is probable that the greenstone-conglomerates in the north part of Sec. 14 are parts of the same rock mass as the greenstones to the west and east. In macroscopic appearance these eruptives are very like the greenstone-conglomerates. The finer grained of them sometimes take on a schistose structure; they have a light green or grayish color, and, in short, so closely resemble the pebbles and some of the matrices of the greenstone-conglomerates as to be indistinguishable from them.

The close field association of the eruptives with the greenstone-conglomerates is still further emphasized by a study of the thin sections. They are all porphyrites, or augite-porphyrites—many of them being amygdaloidal. The background varies from not very fine grained holocrystalline, to a devitrified glass, the various phases being exact repetitions of the pebbles and matrices of the greenstone-conglomerates. Their macroscopic and microscopic characters are then those of surface flows, and they were doubtless contemporaneous with the greenstone-conglomerates which have been seen in large part, at least (pp. 377–381), to be volcanic products.

The exposures in the west part of Sec. 13 have a not very fine grained holocrystalline background. They are augite-porphyrites and, as their structure is a true diabasic one, they would be classed by Rosenbusch as the variety diabase-porphyrite. The menaccanite is often in small rod-like areas, but also has in many cases well defined crystal outlines. As in all the other rocks of the eastern area, it is altered to a greater or less extent to leucoxene. The plagioclase occurs to quite an extent in idiomorphic forms. While much altered, it is fresh enough, so that by Pumpelly's method it is determined to be probably not so basic as labradorite. Its alteration products are kaolin, smaragdite, chlorite, and epidote. Augite, the last mineral to crystallize, maintains relations with plagioclase and magnetite such as are usual in diabases. It has generally altered to a larger extent than the feldspar, the resultant products being usually biotite and chlorite, although smaragdite is found.

The exposures in the northeast part of Sec. 24 are not greatly different from the above, except that they contain no augite, and therefore must be classed as porphyrites rather than augite-porphyrites. In all probability they were originally nearly alike. These rocks are holocrystalline. In some cases the background is composed very largely of small, somewhat altered plagioclases, but in other cases the smaragdite is as plentiful as the feldspar. Aside from these two minerals secondary quartz, chlorite, epidote, and gray, nonpolarizing material are found. The minor minerals are somewhat confusedly mingled with the predominant ones. The constituents completely interlock, and there is no doubt that the rock is a crystalline eruptive. The exposures in the north part of Sec. 15 resemble closely the last described, except that they are more finely crystalline, the backgrounds of the finer grained ones being very minutely crystalline. The additional differences are, that the plagioclases lie with their longer axes in a common direction (which probably indicates a flowage structure), that menaccanite is abundant in small crystals and minute grains, and that its alteration has resulted in leucoxene, which appears to be of the nature of titanite. The secondary minerals are the same as in the previously described exposures.

The exposures in Sec. 14 contain rocks in which the groundmass is of agray a morphous or feebly polarizing material, which is taken to be devitrified glass, and also holocrystalline kinds. The glassy backgrounds include minute, much altered tabular plagioclases and particles of material which may be leucoxene. Less abundantly are found other minerals which have been mentioned as occurring in the previously described exposures. From this glassy variety the background varies to one which resembles closely the exposures in the north part of Sec. 15, except that alteration has extended farther. In some cases the feldspar has very largely decomposed and the sections are then made up mostly of chlorite and calcite, with some quartz, in which the particles of plagioclase are set.

In nearly all of the rocks of the several areas of this division are porphyritic crystals of feldspar, which is the only mineral that occurs in two generations. They are very numerous in the coarser grained varieties of the area, but are altogether absent in the glassy varieties. This porphyritic feldspar is generally greatly altered and its exact nature can not be determined, but the double angles measured by Pumpelly's method indicate that it is of the same character as the feldspar of the matrix. Its decomposition products are the same as the feldspar of the background; that is, smaragdite, chlorite, epidote, and kaolinite. The rocks of the division are always amygdaloidal, with the exception of the exposures in the north part of Sec. 15. The amygdules are at times very numerous and frequently of quite large size. They are generally of an elongated oval shape, the longer axes of which are parallel and probably indicate flowage in this direction. The filling of the amygdules is one or more of the minerals chlorite, calcite, epidote, or quartz, the latter usually being, when present, chalcedony. Chlorite and calcite are the most plentiful minerals, the two frequently occurring together in the same amygdule in concentric belts. The chlorite is always of a green nonpolarizing variety, or that giving steel-blue interference colors. Often within the chlorite have developed large areas of epidote. By comparing the above descriptions with those of the pebbles and certain of the matrices of the greenstone-conglomerates, it will be seen that there is a remarkable likeness between the various phases of these eruptives and the conglomerates, with the exception that in the conglomerates no diabase-porphyry phase is found. The resemblance between these fine grained eruptives and the greenstone-conglomerates is still further emphasized by veins which cut them, these being composed at times of intricately interlocking quartz, chlorite, and epidote; that is, these sparse veins are almost precisely like the background which contains the apparent fragments of some of the rocks which have been classified with the greenstone-conglomerates. Whether these rocks really belong there, that is, whether these apparent fragments are really genuine or not, is uncertain. If the more numerous ramifying veins of these supposed conglomerates are all secondary this phase of the conglomerate ought to be placed with the basic eruptives of this area.

### SECTION VI.—STRATIGRAPHY.

*Lithological evidence as to equivalence with the main Penokee area.*—The lithological character of the rocks described as belonging to the Iron-bearing member, the fragmental and ferruginous rocks south of the greenstone-conglomerate, and the fragmental and ferruginous rocks north and east of the greenstone-conglomerate, closely resemble belts in the Penokee series to the westward. So far as the Iron-bearing member is concerned there is identity. The ferruginous and fragmental rocks north and south of the greenstone-conglomerates differ from the fragmental rocks to the westward, in that nonclastic is mingled with the clastic material. Aside from this difference, the above belts of the eastern area are the exact parallels of belts in the main area. The lithological evidence, then, indicates that the eastern area belongs to the same great period of time as the Penokee series to the west.

The only question, then, which needs here to be discussed is whether the greenstone-conglomerates belong to this same series. It appears to me that all the facts indicate that they do. The data upon which this opinion is based are as follows: The conglomerates are inextricably mingled and interlaminated with black, cleaved, unmistakably fragmental slates. That these slates and greenstone-conglomerates have a common age can hardly be doubted, for there appears to be every gradation between the two classes of rocks. This fact is strong lithological evidence for placing these rocks in the Penokee succession, where similar slates are so largely developed, and not in the Southern Complex or in the Keeweenaw series to the north, where no such rocks are known, nor in the cherty limestone series, with which they have no apparent connection.

It may be asserted that the greenstone-conglomerates are more altered and obscure than any other rock in the Penokee series. This argument loses its force when the unusual nature of the materials of which they are composed is considered. The great mass of the fragmental rocks of the series is derived from granites, gneisses, mica-schists, hornblende-schists, etc.; in other words, from rocks which are always strongly quartzose and which contain a large quantity of acid feldspar. From materials of this sort quartzites, graywackes, and slates are naturally formed. That the quartz and acid feldspars are often in a very fresh condition is not strange, but it has been seen that even these acid feldspars have extensively, in the Upper slate member, altered to the more basic minerals, mica and chlorite, with the simultaneous separation of quartz and the resultant formation of a mica-schist or chlorite-schist. These mica-schists are unmistakably parts of the Penokee series, and are as much changed from their original condition as is the basic eruptive material of the greenstone-conglomerates, notwithstanding the fact that the latter are composed of materials very readily alterable. Basic eruptive rocks are well known to have undergone extensive changes, even when occurring in solid masses which belong to geologic periods long subsequent to that of the Penokee series. It thus appears that the widespread alteration of the basic detritus in these greenstone-conglomerates is no proof that they are not of the same age as the rocks of the typical succession. Also in the greenstone-conglomerates themselves is found a small quantity of well worn fragmental quartz and feldspar, which in every respect resembles like material in the graywackes and quartzites. It is thus plain that the lithological evidence points toward a classification of the greenstone-conglomerate with a series subsequent to the Southern Complex, a series of clastic rather than crystalline rocks.

Finally, the association and relations of the greenstone-conglomerates to the other classes of rock adjoining, which unquestionably are the equivalent of the main Penokee succession, are such as to make it scarcely conceivable that they could be a part of the eruptives of the overlying Keweenaw series.

*Stratigraphical evidence as to equivalence with the main Penokee area.*— The stratigraphical evidence that the eastern area rocks belong to a series separated both from the schists, gneisses, and granites to the south of them and from the great range of greenstones to the north is precisely like that which proves that the clastic formations to the west belong to a distinct series. Without repeating the argument in detail which is given in another place (Chap. IX, Sec. II), it is only necessary to mention the salient facts which show that the same relations prevail between the three great series of rocks east of the Little Presque Isle that are found to the west.

The schists, gneisses, and granites, mingled with occasional eruptive greenstones, constitute a complex of rocks in the southern part of the area mapped on Pl. XIII. There is no uniformity in the strike and dip of these schists and gneisses. Within a few rods the strike of the rock may change 90°. The dip is also in all directions, the only constant thing being that the angles of inclination are generally high, indicating that the rocks have probably passed through a period of extreme folding. Taken as a whole, the schists and the granites, the latter including gneissoid granites, are in tolerably distinct large areas; but along the lines of contact the two classes of rocks are mingled in inextricable confusion, and included in the large granite area west of Gogebic lake, in several places, exposures of hornblende-schists and chlorite-schists are found. Lithologically, all the rocks belonging in this complex are either massive eruptives or crystalline schists, in which the extreme of foliation and crystalline character is found. Nowhere is there any plain evidence, unless foliated and schistose structure is so considered, that any of them are of fragmental origin. Thus in all respects this complex series is seen to be like the basement rocks upon which the Penokee series to the west rests, and it is therefore a continuation of them.

In strong contrast to this complex are the rocks under discussion. While their strikes vary somewhat as the belts bow north or south, their general course is east and west. Their dips are generally to the north, but in some cases are to the south. This variation of dip has to do with the relation of the belts of rocks included in the series among themselves, but does not affect their relations to the surrounding rocks. We have here, then, as in the western area, a series which is north of and separable from the complex to the south by a fundamental difference of strike. Also the series under discussion is seen to be essentially a mingled nonfragmental and fragmental set, which is for the most part so little changed that its origin is certainly determinable.

Further, as fully indicated subsequently, in Sec. 23, T. 47, N., R. 43 W., Michigan, and in Sec. 28, T. 47 N., R. 42 W., Michigan, are basal conglomerates, and in the latter place the conglomerates rest directly upon the complex below. These unconformable relations between the two sets of rocks are here the same as between the Southern Complex and the westward Penokee succession. The series, then, is an independent conformable one, resting upon an older complex, which served as the basement upon which the newer rocks were formed as fragmental and nonfragmental water-deposited sediments.

It is thus seen that in every particular the facts and the conclusions as to the relations of these rocks and the series below them are the same as in the rocks to the west. This complex to the south and the series under discussion are but eastern continuations of the same two sets to the west already described.

West of Sec. 18. T. 47 N., R. 42 W., Michigan, the rocks of the Eastern area are bounded upon the north by a continuous prominent range of greenstone, which rises abruptly from the lower ground to the south. Through T. 47 N., R. 43 W., Michigan, this range runs almost due east and west. In the next two miles westward it makes north about a half a mile and then again continues westward. It is plain that this greenstone overlies the rocks of the Eastern area. That there is any great or certain discordance between the two series can not be proven from the Eastern area. However, this greenstone range, through the east part of T. 47 N., R. 44 W., Michigan, and through T. 47 N., R. 43 W., Michigan, appears to overlap to some extent the rocks of the Eastern area, which to this degree would indicate an unconformity, but would not be certain proof of one. However this may be, this range is an eastward continuation of the greenstone which overlies the Penokee series to the westward, just as the rocks under discussion are an eastern continuation of that series itself. There is, then, no doubt that the same relations obtain between them that prevail to the west.

The only further point in this connection is whether the formations of the Eastern area are to be placed with the Penokee series proper or with the series to which the Cherty limestone belongs. The lower formation of the Eastern area bears fragments of red jasper at one place, and the upper formation contains much chert detritus, which in all probability was derived from the Cherty limestone formation itself. Consequently the rocks of the Eastern area bear the same relation to the Cherty limestone as do the Penokee series proper. Finally, the outcrops of the iron formation of the Penokee series proper and those of this formation placed with the Eastern area have such relations as to leave little doubt that the two are continuous. It is therefore concluded that the rocks of the Eastern area are the continuation of the Penokee series proper.

*Relations of the belts of the Eastern area to one another.*—It is evident that the rocks of the Eastern area have formed under different conditions from those of the western extension. This is indicated, as has been seen, by the presence, first, of a great thickness of rocks, which are mingled clastic and nonclastic sediments; second, by the presence between the northern and southern boundary of the normal rocks of the area of a great thickness of greenstone-conglomerates; and, third, by numerous southern dips found in the slates and conglomerates. These differences do not seem to be so great, however, as necessarily to preclude a belief in a simple conformable succession like that to the west. At any rate, the expectation of such a succession here is a natural one, and, if this explanation fairly represents the known facts, should be preferred to any which implies either folding or a reference of a part of the rocks contained within the outer limits of the area to other than the Penokee series.

The two evident obstacles to considering the Eastern area as a simple succession are, first, the great width of the series in the eastern part of T. 47 N., R. 44 W., Michigan, as compared with its width a few miles east or west; and, second, the southern dips.

*Great width of parts of the Eastern area.*—The unusual width of the Eastern area in T. 47 N., R. 44 W., and T. 47 N., R. 43 W., Michigan, is almost wholly due to the greenstone-conglomerates and greenstones. It has been seen that the greater part of this area is composed of volcanic products. A considerable thickness is composed of direct surface flows. Another large part is volcanic products, which in places have been mingled to some extent with water deposited sediments. Now, the accumulation of volcanic material may go on with rapidity much greater than that of ordinary sedimentation. For such material to accumulate to a depth of 7,000 or 8,000 feet while a few hundred feet of the Iron-bearing member to the westward were forming is not contrary to known geological facts. The northern boundary of the Eastern area, throughout the district is approximately east and west, with no greater variation than in the main area. The increased thickness of the series is given space by rapid bowing to the southward of the underlying complex. This southern bowing is explicable as resulting from a continuous sinking, which was contemporaneous with and caused by the accumulation of great quantities of ejected material. This bowing is simply the well known geological phenomenon of the inward sinking of the strata about a crater when burdened with a mountain mass of volcanic products.

The sudden bowing of the iron-bearing belt of the series to the south may be due in part to a fault. Upon the whole, it seems not unlikely that such a fault has combined with the extravasation of lava and tuff to produce the present condition of affairs. The strike of the various exposures found in T. 47 N., R. 44 W., and R. 43 W., Michigan, shows distinctly that a bowing to the south has occurred. This is evidenced by the strike of the easternmost exposure of the continuous Iron-bearing member in Secs. 16 and 17, T. 47 N., R. 44 W., Michigan, as well as the strike of the exposures in T. 47 N., R. 43 W., Michigan. It is, however, noticeable that the iron formation rocks in the NW. ¼ of Sec. 30 strike about E. 20° S. The cause of this anomaly is not known. The greatest apparent discordance between the various exposures of the iron formation is between that in the west part of Sec. 23, T. 47 N., R. 44 W., and that in the southwest part of Sec. 25. It is also to be observed that the base of the Keweenaw series, which in T. 47 N., R. 42 W. and 43 W., Michigan, has a nearly east and west trend, and which west of the S. ¼ post of Sec. 11, T. 47 N., R. 44 W., Michigan, also has a very uniform east and west trend, between these two points differs a half mile in position. Thus it is probable that if a fault exists it runs from near the southwest corner of Sec. 25 to a short distance west of the E. ¼ post of Sec. 13, T. 47 N., R. 44 W., Michigan. The existence of such a fault is still further suggested by the position of the great mass of basic eruptives in Secs. 26 and 27, T. 47 N., R. 44 W., Michigan. These exposures are all essentially the same kind of rocks, coarse grained diabases, approaching gabbro. Such rocks would commonly be regarded by petrographers as deep seated ones, which have now reached the surface by erosion. They are remarkably similar to the massive eruptives in Secs 15, 16, and 23, T. 47 N., R. 44 W., Michigan, and they are probably contemporaneous in time, if not actually connected with these rocks. They now lie at the same apparent horizon as the large exposures of typical greenstone-conglomerates just east of them, which are surface accumulations. If the discrepancy between the locations of the iron formation in Sec. 25, T. 47 N., R. 44 W., Michigan, and those in Sec. 23 can be taken as a guide to the amount of throw of the supposed fault, it would reach several thousand feet. If such a fault occurs, it would, to the extent of its throw, lessen the thickness of the formations belonging to the eastern area, as will readily be seen by examining Pl. XIII. Supposing no fault to exist, the maximum thickness of the series, if the succession is a simple one, must be about 11,000 feet in the extreme eastern part of T. 47 N., R. 44 W., Michigan. If we suppose a fault to exist with a throw of 3,000 feet, this would reduce the maximum width to 8,000 feet. East and west of this locality the thickness rapidly lessens. At the center of T. 47 N., R. 43 W., Michigan, 3 miles east, the surface width of the series is about 1 mile, which represents a thickness of about 4,500 feet. In passing farther east, the series continues to narrow until it is almost entirely overlapped by the Eastern sandstone in Sec. 28, T. 47 N., R. 42 W., Michigan. To the west the series also rapidly narrows until it joins the normal Penokee area.

The rapid variation in thickness of the Eastern area may be urged in opposition to the above explanation of its great thickness and of the bowing of the iron-bearing formation to the south. In answer it may be said that the distance from the easternmost to the westernmost exposure of the greenstone-conglomerate is fully 7 miles, and the evidence of disturbance, as shown by the mingling of fragmental and nonfragmental material, extends to twice this distance. Also, when it is considered that the greater part of this thickness is due to greenstone-conglomerates, which are largely volcanic tuffs and lavas, the objection loses its force, for it is well known that this class of material varies greatly in thickness within a short distance.

*The southern dips.*—The slaty phases of the greenstone-conglomerate and the clay-slates north of the greenstone-conglomerate in the W. ½ of T. 47 N., R. 43 W., Michigan, so far as observed, appear to dip south, at least they possess a parting which dips in this direction. This apparent southern dip varies from 55° to 80°. But the southern dips are not universal; for instance, in one exposure in the SE. ¼ Sec. 17, T. 47 N., R. 43 W., Michigan, an exposure has a northern dip, although the slates a short distance southward have the ordinary dip of the locality. Of far greater importance, the jaspery rocks in the south part of Sec. 18, T. 47 N., R. 43 W., Michigan, have an unmistakable northern dip. The other extremely ferruginous rocks in the northern fragmental belts, in Secs. 13 and 14, T. 47 N., R. 44 W., Michigan, are too massive to furnish dips. Whether the apparent southern dips represent true bedding or cleavage it seems impossible to certainly determine from the exposure or from the examinations of thin section. In the cases of one or two ledges showing southern dips, an apparent bedding transverse to this parting was found, but this was exceptional.

All the rocks of the iron-bearing belt situated in the southern part of the Eastern area, from the west part of Sec. 23, T. 47 N., R. 44 W., Michigan, to the northwest part of Sec. 23, T. 47 N., R. 43 W., Michigan, have, so far as observed, a northern dip. The slates prominently exposed in two places in Sec. 21, T. 47 N., R. 43 W., Michigan, below the iron-bearing belt, have unmistakable northern dips, as have also the half fragmental slates and schists interlaminated with the rocks of the iron-bearing belt just above. If we had but the E. ½ of T. 47 N., R. 44 W., Michigan, and the W. ⅔ of T. 47 N., R. 43 W., Michigan, to deal with we would feel inclined to explain the structure by considering the rocks as a synclinal trough, in which the greenstone-conglomerate overlies the fragmental rocks to the north and south of them. This would necessitate that the north arm of the trough, rising into an anticlinal, had again descended, dipping to the north, and that this part of the fold had been removed by an erosion before the beginning of Keweenawan time. We would thus have the simple monocline of the Penokee succession to the west passing into a folded series in the Eastern area. This hypothesis has, however, some serious difficulties to contend with: (1) The rocks on the north and the south sides of the synclinal are quite different in character. (2) Some explanation must be furnished for the northern dips referred to in the north fragmental belt. (3) The high and variable southern dips of the greenstone-conglomerates throughout their whole thickness and close to the northern dips of the rocks of the iron-bearing and fragmental belts to the south must be explained. (4) It would seem that if the Penokee monocline passes into a folded series more definite evidence would be found of the change as the supposed folded part of the area was approached.

If the position is taken that the apparent southern dips represent cleavage rather than bedding the difficulties largely disappear. (1) The rocks in which the inclinations have most value—that is, al' the rocks which belong to the Iron-bearing member or are very ferruginous and banded and consequently take on a slaty cleavage with greater difficulty—have northern dips whether they occur north or south of the greenstone-conglomerates, and these northern dips vary within narrow limits. (2) All the rocks south of the Iron-bearing member, like the quartz-slate of the main Penokee area, have northern dips, and these dips correspond to the inclination of the overlying iron-bearing belt. (3) The considerable variation in strike and the great variation in the apparent southern dips of the clay-slates and greenstone-conglomerates at once lose significance if regarded as cleavage. (4) By regarding the part of the Eastern area which has the southern dips as a simple series it becomes the natural link between the rocks of the Penokee series to the west and those to the east which have only northern dips. (5) By regarding this Eastern area as a simple succession we have the same orderly arrangement between the three great series of rocks which obtains to the westward.

That slaty cleavage should be found in the Eastern area and nowhere else in the Penokee succession is not at all strange, for the slates here are much finer grained and more clayey than those elsewhere found. Sorby has shown that such material is particularly likely to take on a slaty cleavage. Further, the great increase in thickness in the central part of the Eastern area might readily cause at the time of the upturning of the series an increased pressure. That from this or some other cause these rocks have been subjected to unusual pressure is shown by the foliated character of some of the sericite-schists and the arrangement of the particles with their longer axes in a common direction in some of the quartzose slates (pp. 406-408). To the east and west of the central portion of the area, where the pressure has been less, no southern dips are found.

There is one other possible explanation of the southern dips. They may be regarded as overturns. The dip of the Penokee series is usually high, averaging from 60° to 70°. In the neighborhood of Tylers fork it becomes very high, reaching from 70° to 80°, while at one place the slates of the upper series are vertical, if not slightly inclined to the south. It might readily be the case that the rapid widening of the Eastern area and the exceptional nature of the material, caused it to be overturned during the time of its uplifting. Upon the whole, however, it is not so probable that there has been an overturn as it is that the southern dips are due to slaty cleavage. The variations in dip are too wide and the change from southern dips to northern dips too abrupt to be satisfactorily explained by an overturn.

Our conclusion is, then, that the rocks of the Eastern area form, in all probability, a continuous simple conformable succession from south to north, which are the eastern extension of the main Penokee series.

*Sequence of events.*—We are now prepared to give a brief history of the geology of the area and to correlate the belts here found with those to the west. As in the main area, the complex of schists, gneisses, and granites constitute a basement upon which the sedimentary rocks were deposited. This basement was probably uneven, showing variations in topography, as a consequence of which deposition began earlier in some places than in others. The present occurrence of the belts is such as to suggest that the eastern end of the area was higher than the western part and did not receive any deposits belonging to the lower formations.

The exposures of the Quartz-slate member west of the Presque Isle are so numerous as to leave no doubt as to the continuity of this belt. In the

Eastern area its equivalent is found in only two places, within a short distance from each other, in Sec. 21, T. 47 N., R. 43 W., Michigan. So far as present information goes, the Quartz-slate is now probably the oldest continuous sedimentary formation of the area, since nowhere are exposures found which can be referred to the Cherty limestone, unless the ferruginous limestone in the north part of Sec. 23, T. 47 N., R. 43 W., just north of the large exposures of crystalline schists is to be here placed. The thickness of the quartz-slate in Sec. 21 is considerable, and, as has been seen by the description of the exposures (pp. 368–369), they are typical in every way of the like rocks from this member to the west, and can without hesitation be correlated with them.

Following above the quartz-slate are the nonclastic sediments of the Iron-bearing member. The exposures are sufficiently numerous to show that there is but little doubt of its continuity. It outcrops as far east as Sec. 23, T. 47 N., R. 43 W., Michigan, are pure nonfragmental sediments. There is no evidence that the belt has any great thickness in Sec. 25, T. 47 N., R. 44 W., and it is certainly not more than one-half the thickness of the iron-bearing belt to the west, even if the entire space between the hornblende-schists of the underlying complex and the known exposures of the greenstone-conglomerate is entirely occupied by this member. If a part of the unexposed space is occupied by the quartz-slates, the thickness of the iron-bearing formation would here be no more than a fraction of its thickness in the western area. East of Sec. 30, T. 47 N., R. 43 W., in the south part of Sec. 20, and in Secs. 21, 22, and 23, the iron-bearing sediments are spread over a considerable distance north and south, but here they are mingled with mechanical sediments. A comparatively great thickness of such material might be deposited in the time taken for the formation of a thin layer of pure nonclastic sediments. If the iron-bearing belt extends farther than the NW. ¼ Sec. 23, T. 47 N., R. 43 W., it must be exceedingly narrow, for there is but a small space between the exposure of greenstone-conglomerate and the crystalline schists of the Southern Complex.

The deposition of this thin layer of nonfragmental sediment thus traced out did not go on undisturbed, for the flow of porphyrite in Secs. 29 and 30 is plainly interleaved. This interbedded flow of basic eruptive rock is doubtless the cause of the mingling of clastic and nonclastic sediments which is so characteristic of the exposures just to the north and less marked in the exposures in Secs. 21, 22, 23, T. 47 N., R. 43 W., Michigan.

After the deposition of a thin layer of nonclastic sediments with the modifications indicated, but long before the cessation of the nonfragmental sedimentation of the Iron-bearing member of the western area, came the great volcanic outbreak which resulted in piling up the series of eruptive flows, tuffs and interstratified sediments of the greenstone-conglomerate area.

The truly aqueous interstratified rocks doubtless received much of their material from the contemporaneous volcanics. This group of formations is then very similar to the central portion of the Keweenaw series, consisting of basic lava flows, with interbedded sedimentary rocks.[1]

Evidently the center of the volcanic activity was the E. ½ of T. 47 N., R. 44 W., Michigan. To the east this material reaches no farther, or little farther than the NW. ¼ of Sec. 23, T. 47 N., R. 43 W., Michigan. This comparatively short eastern extent of disturbance may have been due to the fact that the higher lands to the east prevented farther extension; for, as has been seen, all of the Eastern area rocks east of this point very probably are at a higher horizon than we have yet reached. To the west, the influence of the volcanic activity extended farther. The accumulation of the volcanic outflows and of the greenstone-conglomerates went on with great rapidity as compared with the exceedingly slow process of nonclastic sedimentation which was continuing to the west in the iron-bearing area. As explained, this accumulation was accompanied by simultaneous sinking of the area thus burdened.

If the above conclusions are correct, a shore line existed not far to the east during the time of the deposition of the Quartz-slate, Iron-bearing and Greenstone-conglomerate belts. It follows that the volcanic center was probably submarine at the inauguration of the igneous action, and was near a shore line, as is usually the case with existing volcanoes.[2]

[1] R. D. Irving: Copper-bearing rocks of Lake Superior. Mon. V, U. S. Geol. Survey.

[2] Since the above was written, further field work north of Crystal Falls, Michigan, has shown the existence of an extensive area, identical in most respects with the greenstone-conglomerate group of the Eastern area, i. e., it consists of diabase, porphyrites, amygdaloids, greenstone-conglomerates and contemporaneous sandstones and conglomerates the material of which was mainly derived from the contemporaneous volcanics.

At or near the cessation of the period of volcanic activity, the clastic and nonclastic sediments which overlie them began to form. How far upward in the Penokee succession the deposition of sediments to the west had extended is not certain, but apparently the period of nonclastic sedimentation of the iron-bearing belt had not ceased, as is indicated by the nature of the fragmental rocks north and east of the greenstone-conglomerates. In the northwest part of Sec. 15, T. 47 N., R. 43 W., Michigan, are unmistakable typical nonfragmental sediments, separable from similar sediments in Sec. 16 by an almost mountain mass of diabase. Exposures in Secs. 13 and 14, T. 47 N., R. 44 W., Michigan, and in Sec. 18, T. 47 N., R. 43 W., Michigan, might fully as well be classified with the nonfragmental sediments of the iron-bearing belt as with any other formation. From Sec. 18, T. 47 N., R. 43 W., Michigan, to the easternmost exposure known in Sec. 28, T. 47 N., R. 42 W., Michigan, the rocks are quite largely nonclastic ones, which contain a considerable portion of iron, either as a carbonate or oxide. This is particularly true of the more southern exposures of the belt, but such materials are also found in the most northern exposures known, near the east quarter post of Sec. 14, T. 47 N., R. 43 W., Michigan.

Above the ferruginous and fragmental slates north and east of the greenstone-conglomerates, followed probably fragmental rocks which were the equivalent of the rocks of the Upper slate belt of the Penokee succession; but if this was the case such material was removed by erosion, and then followed the unconformably overlying Keweenaw series.

Before the Eastern sandstone at the east end of the area, subsequently described, was deposited, the three series of the district were tilted into their present inclined position, and during this time or later underwent great erosion. That the Eastern sandstone is in direct contact with the Eastern area rocks near their base at Gogebic lake, is simply due to the fact that these rocks were more resistant than the Keweenaw and upper Eastern area rocks, and have been left as a cliff against which the Eastern sandstone was deposited. How much more widespread than at present the sandstone has been, we have no means of knowing.

*Mingled fragmental and nonfragmental sediments.*—If the above account represents the facts, it explains how it is that the sharply separated fragmental and nonfragmental sediments of the Western area pass into the mingled sediments so characteristic of the Eastern area. The time was one in which the conditions throughout the great part of the Penokee basin were favorable to nonfragmental sedimentation. When the sea was undisturbed, pure sediments of this class were formed; but in the Eastern area, almost as soon as this period was inaugurated, came a time of intermittent eruptive activity, which formed the masses of porphyrite and greenstone-conglomerate there found. Even when these materials were not being ejected with such rapidity as to preponderate over other varieties of rock, the sea was so disturbed that only for brief intervals, and locally, was it sufficiently clear to form pure nonfragmental sediments. In this part of the basin, the nonfragmental sediments belonging to the iron-bearing formation are interbedded with layers of or mingled with mechanical sediments. Nonfragmental sediments continued to deposit in greater or lesser purity, however, at every favorable occasion throughout the whole of the time of deposition of the eastern rocks, later than the Quartz-slate. The mass of rocks above these slates in the Eastern area is several times thicker than the nonfragmental sediments of the iron-bearing formation to the west. In estimating time equivalents, however, we must take into account the fact that water-deposited mechanical sediments may accumulate much more rapidly than nonfragmental sediments, and volcanic products far more rapidly than ordinary mechanical sediments. This great difference of thickness, then, is no obstacle to correlating the Iron-bearing member to the west with the mass of mingled fragmental and nonfragmental sediments, and the interbedded eruptives and greenstone-conglomerates. The fact that at every cessation of volcanic activity nonfragmental sediments were deposited, which are precisely like the sediments of the iron formation to the west, seems decisive evidence in favor of this correlation. Further, the greenstone-conglomerate itself, as has been seen, has in places phases which have many of the characteristics of the iron-bearing formation, interleaved with other phases which are not at all like the rocks of that member. Finally, the greenstone-conglomerate is not always clearly separated from the ferruginous graywackes and quartzites to the south and north.

*Summary*.—The area east of the center of T. 47 N., R. 44 W., Michigan—or roughly, east of the Little Presque Isle—differs from the simple series described in the previous chapters in many important points. This area was the center of great volcanic activity; consequently the sedimentary succession includes large thicknesses of interstratified lava flows and volcanic tuffs, which are not paralleled by any rocks that are found in the western area. Further, this volcanic material has greatly disturbed the water-deposited sediments in the district, so that it is difficult to certainly correlate the formations east of the Little Presque Isle with those west of it. Another point in which this area differs from the western one is that in one place the relations of the horizontal Eastern sandstone to the Penokee series can be made out.

No exposures certainly belonging to the Cherty limestone member are found within the area. The Quartz-slate member is not known to be continuous in this area. Typical exposures of the formation, which have near the base variegated slates, and for the upper horizon the vitreous quartzite, are found at one or two localities.

The lowest belt which certainly is continuous for some distance is the Iron-bearing member. Even in this wide gaps occur in which no exposures are known. Its typical rocks are almost exactly like those of the iron formation to the west. There is here, however, closer relations between the original siderite and the actinolite and magnetite than to the westward. In this respect the rocks of this belt resemble very closely those of the Animikie iron-bearing formation. The one important point in which this part of the Iron-bearing member differs from that to the westward is that mingled with it is fragmental material. There are all gradations between the pure nonfragmental sediments of the iron belt and the fragmental material of the slate formations; also there are in places interlaminations of the two. It thus is clear that during the time of the formation of the Iron-bearing member there were interruptions, as a result of which the belts of pure nonfragmental, water-deposited sediments are always narrow. Probably resulting from this is the fact that within this area no workable ore deposits have been found, the belt always being narrow, so that the amount of iron in the carbonate present was insufficient when concentrated to form large ore bodies.

The greenstone-conglomerate area varies from a material which is a basic eruptive amygdaloidal flow, through various volcanic or semivolcanic clastics, to rocks which are wholly water-deposited.

North and east of the greenstone-conglomerate is a continuous wide belt of fragmental rocks, which extends nearly to Gogebic lake. The rocks south of this belt vary in their character, being in the western part a porphyrite of such a nature as to indicate that it is a surface flow; through the central part of the area, greenstone-conglomerate, and in the eastern part of the area, the gneisses and granites of the Southern Complex. North of the belt are the eruptives of the Keweenaw series. At one place, just west of Gogebic lake, the Eastern sandstone is the overlying rock. It seems probable that this belt of fragmentals is the equivalent of the northern part of the Iron-bearing member with perhaps the lower part of the Upper slate member to the westward. If it extends farther east than Gogebic lake, it probably passes under the Eastern sandstone.

The rocks of this belt are very largely clay-slates which have an apparent southern dip. In places, however, they become strongly ferruginous, when a northern dip is usually found. The latter are believed to represent true bedding and the southern dips to be secondary cleavage induced by pressure. The rocks have a wide variation in lithological character, running from those which are purely fragmental to those which are purely nonfragmental sediments. The phases intermediate between these two extremes are those most abundant. The fragmentals are very much like those north of the iron-bearing belt in the main area. The mingled nonfragmental materials are the various oxides of iron, siderite, and chert. The rocks, then, vary from those which lithologically belong to the Iron-bearing member to those which are typical of the Upper slate. The iron varies in its combination from an oxide in the western part of the area to a siderite in the eastern part. This is another case in which the widespread occurrence of iron oxide is due to the alteration of a ferriferous carbonate. The basal portion at several places in the eastern part of the belt are recomposed granitic rocks, which consist of firmly recemented granitic debris and are separable from the original rocks only by an examination of the thin sections.

The eruptives of the Eastern area are in several detached exposures, some of them being of large size. A portion of them are porphyrites contemporaneous with the rocks of the series in which they are found; others have the structure of a diabase, or even that of a gabbro, and these are taken to be deep seated rocks. Between these two extremes there is found in various parts of the area intermediate phases. The augite of the diabases has often altered to hornblende, and this secondary hornblende has undergone a new growth. Also, the unaltered augite is not infrequently surrounded by a sheath of smaragdite, the crystallographic relations of the original and secondary minerals being those known to occur between augite and amphibole paramorphic after it.

The rocks of the various belts of the Eastern area, with the exception of the greenstone-conglomerate, correspond closely in lithological characters with those of the Penokee series proper to the westward, the only difference of importance being that in the Eastern area there is more frequently found mingled nonfragmental and fragmental sediments. The greenstone-conglomerates bear such structural relations to the sediments which certainly belong to the Penokee series, are mingled with them so intricately, and are so certainly surface volcanic accumulations, that there is no sufficient reason for placing them elsewhere.

The stratigraphical evidence that the Eastern area rocks belong to a series separated both from the Southern Complex and from the Keweenaw series is precisely like that which proves the clastic formations to the west to belong to a distinct series. Notwithstanding the exceptional width of the Eastern area in certain parts and the southern dips which are found in the slate belt north of the greenstone-conglomerates, it is believed that the succession here is probably a simple conformable one.

The sequence of events in the district seems to have been as follows: As in the main area, the complex of schists, gneisses, and granites, and probably the series to which the Cherty limestone belongs constitute a basement upon which the Penokee succession was deposited. In certain places rocks which are the equivalent of the Quartz-slate member were deposited.

Above the Quartz-slate begins the nonclastic sedimentation of the Iron-bearing member. The deposition of this belt did not go on undisturbed, but alternated with clastic sediments; and long before the whole of the iron-bearing member of the west was built up came the great volcanic outbreak which resulted in piling up the series of flows, tuffs and interstratified clastics of the greenstone-conglomerate area. At or near the cessation of volcanic activity the mingled clastic and nonclastic sediments which overlie them began to form. At this time apparently the Iron-bearing member of the western area had not yet wholly formed. Above the latter followed probably fragmentals which were the equivalent of the Upper slate member; but if this were the case they were wholly or nearly wholly removed by erosion. After a long period of degradation began Keweenawan time. Before the Eastern sandstone at the east end of the area was deposited the three series of the district were tilted into their present inclined position, and during this time and subsequently underwent enormous denudation.

# CHAPTER IX.

By C. R. Van Hise.

## GENERAL GEOLOGY OF THE DISTRICT.



### SECTION I.—FLEXURES AND FAULTS.

*Curving of the layers.*—The curving of the layers of the Penokee series subordinate to its uplifting as a whole, has in the main been of so gentle a nature that they have not been broken. At the west side of R. 3 W., Wisconsin, there are several very sharp bends in the Quartz-slate and Iron-bearing members. There is a somewhat sudden turn in the trend of the layers near the middle of R. 2 W., Wisconsin. West of Sunday lake the nearest known rock in the iron formation is about one-fourth of a mile south of the north quarter post of Sec. 17, T. 47 N., R. 45 W., Michigan. East of the lake the southern boundary of the iron formation is one-fourth mile north of the southwest corner of Sec. 10 in the same township. (Pl. XII.) Consequently the iron belt suddenly swings from an east and west course north more than a half mile in a distance of 1½ miles. In the northwestern part of Sec. 16 is an exposure of green schist belonging to the basement complex; so that most of the northern swing occurs before this point is reached. The relations are such that it is possible to explain this sudden change in direction by a sharp curve, but it is possible that it is wholly or in part due to a fault. Sunday lake and the surrounding low ground make it not easy to settle this question. However, at none of the places mentioned is it known that there has been any actual faulting. Throughout the whole length of the series, which has been subjected to two great orographic movements, no dislocations great enough to make the belt difficult to follow have occurred; but at three places there is pretty decisive proof that faulting has taken place to some extent.

*Fault at Bad river.*—The most considerable fault is that at Bad river, in R. 3 W., Wisconsin. The relations of the exposures and the line of fault have been accurately mapped and described by Prof. Irving.[1] Pl. XXXVI is wholly from data furnished by this map. The explanation is also largely taken from Prof. Irving, it only being modified to correspond with the present understanding of the succession of belts. West of the line marked "Supposed position of fault line" the layers of the Penokee series follow in the regular order. Near the base of the left hand side of the plate are mapped large exposures of granite and gneiss. North of these on Bad river, and very close to the gneiss are exposures of the Cherty limestone member. Next follows the Quartz-slate, which is exposed throughout its whole thickness, having, as usual, as its upper layer a vitreous quartzite. Just above this quartzite follow the exposures, which rise in high cliffs above the river, belonging to the Iron-bearing member. They are so numerous and large that they practically show the whole thickness of the formation. Upon the north side of this bluff is a thin layer of garnetiferous magnetitic slate, which passes into a garnetiferous black slate, plainly constituting the base of the Upper slate member. North of this point are a number of large exposures belonging to this belt. On both banks of Bad river is shown a large exposure of diabase. East of the "Supposed line of fault" the succession of belts in the Penokee series is found to be identical with that just given, the only difference being that but a small part of the

[1] Geol. of Wis. vol. III, pp. 150–152, with accompanying atlas, Pl. xxiii.

Quartz-slate is exposed; however, the characteristic quartzite at its upper horizon is seen. The iron formation shows a practically continuous exposure and at its uppermost horizon is found the peculiar garnetiferous slate, which passes into the garnetiferous black slate at the base of the Upper slate member just as on the west side of the fault. The occurrence of these characteristic layers both north and south of the iron formation—east and west of the supposed fault line—is most fortunate, enabling one to determine the exact limits of that formation and thus to give data for a satisfactory explanation of the distribution. This order is in such perfect accordance upon both sides of this line that there could be little doubt that the belts represented a once continuous set of layers, even if we knew nothing about the series farther to the east and west. But when it is remembered that these several belts stretch in the same order for many miles in both these directions, this former continuity may be considered demonstrated. The distribution of exposures at Penokee Gap can then only be explained as having been caused by a fault between the two sets of exposures, for there is not room between them for accordance to be produced by a bend of the layers, however sharp. The space between the quartz-slates on the west side of the fault and the upper part of the iron formation on the east side is not one-half the thickness of the latter, yet between these two the whole of it must pass if there is not here a fault. The Quartz-slate on the west is seen to be farther north than the northernmost exposure of the magnetite schists, toward which it strikes, whereas it ought to be continuous with the belt of the same kind on the east side of the line marked "supposed line of fault." The amount of discordance is even more strikingly shown by the positions of the exposures of the iron formation. It may be that a part of the discordance can be accounted for by a sudden bowing of the layers, although the strike of the rock gives little indication that this is the case. If the entire dislocation is taken to be due to a fault, the throw must have been at least 900 feet if at right angles to the direction of the strike of the rocks; and if it is diagonal, as is probably the case, must have been more than this. That this fault extends south of the southernmost exposure of the Penokee series and north of the exposures of the basement layer of the black slate is plain, but the layers of the upper slate are so closely like one another, and so little is known of the relations of the rocks of the Southern Complex to one another, that its direction can not, beyond these limits, be made out. If the greenstone upon Bad river is taken to be an interbedded flow, it appears that the fault line passes between this and the black slates east of this place on the railroad; but if it is an eruptive dike cutting across the formation, as is probable, it gives no indication of the location of the fault line.

*Fault at Potato river.*—At Potato river, near the east side of Sec. 19, T. 45 N., R. 1 E., Wisconsin, there is again strong evidence that a fault exists, although here the throw is not so great as at Bad river. The relations of the exposures are exhibited by Fig. 6. Upon the east side of the river is a large exposure of green schist belonging to the Basement Complex. The Quartz-slate is in contact with the schist and extends northward in continuous exposure, with only a very slight break throughout its whole thickness. North of and immediately adjacent to the vitreous quartzite, constituting the uppermost member of this slate, are exposures of the Iron-bearing member. The strike of the slate east of the river is west 20° south. On the west side of the river large exposures of the underlying green schist are noted. North of these follow smaller exposures of quartz-slate, and still farther north the vitreous quartzite, and above this the rocks of the iron-bearing belt; so that east and west of the river we have the exact location of the junction between the quartzite and iron-bearing belt, while east of the river is known the exact contact of the quartz-slates and the underlying schists. Now, it is manifest that the large exposures of green schists west of the river lie directly athwart the course of the quartz-slates. The same is true of the quartz-slate and quartzite on the west side of the river as compared with the rocks of the iron belt on the east side. Here, again it may be suggested that a sharp bowing will explain the structure, and hence a fault is not necessary to explain the facts; but between the slates and the nearest schistose rock there are but 200 feet of space, in which a much greater thickness of slates must pass. Further, there is absolutely no indication by a change of direction of the strike of the slates that any such bowing has here occurred. If the whole of the discordance here is taken to be due to the fault, the horizontal throw amounts to 280 feet, as determined by a transit survey made by Mr. J. Parke Channing, taking as the points of measurement the junctions between the vitreous quartzites and the overlying ferruginous rocks on the east and west sides of the river.

*Fault in the Eastern area.*—In chapter VIII, p. 424, it has been suggested that there is a fault in the east side of T. 47 N., R. 44 W., Michigan, running in a diagonal direction from the southwest corner of Sec. 25 to a short distance west of the east quarter post of Sec. 13. The rocks west of this line have probably been thrown south of the corresponding layers to the east, thus explaining part of the discordance in the rocks of the iron formation, as well as the difference of one-half mile in the southern boundary of the Keweenaw rocks in the eastern part of the township, and also lessening the thickness of the Penokee rocks in this locality, but as the probability of this fault and its structural relations have been fully treated in the chapter referred to, the subject will not be further discussed here.

At all of these places the ground between the exposures is covered on the east and west sides of the fault lines, so that it is not possible to accurately locate them. As is common, the broken layers have readily yielded to erosion and the fault lines in two cases have been utilized by the drainage system of the district.

### SECTION II.—STRUCTURE.[1]

*The Southern Complex.*—The subject proper of this memoir is the conformable succession of rocks which contains the Iron-bearing member, and has therefore often been called the iron-bearing series. It has often been necessary to allude to the series south and north. The latter series has not been given a separate chapter, for the varied rocks there found are parts of the great Keweenaw series which has already been treated in a separate memoir.[2] In chapter II the former rocks have been described in sufficient detail to compare them in their structural features and litho-

[1] The separability of the Penokee series from the Southern Complex and the Keweenaw series by means of unconformities has been maintained by Prof. Irving in several of his publications. (See Literature, Chap. I.) As to these general relations, the only thing added is new evidence supporting these positions.

[2] Copper-bearing rocks of Lake Superior; by R. D. Irving, U. S. Geol. Survey, Monograph V.

logical characters with the various rock belts of the Penokee succession. It has been seen that these rocks are of two general types: first, massive granites and gneissoid granites, and, second, fine grained schists, which technically are gneisses. None of them can properly be said to have a sedimentary strike and dip. All but the granites have a foliation. In the case of the gneissoid granites this foliation is of the coarsest character, but the foliation of the rocks varies from this to that so fine that it is only possible to detect it in the hand specimen by the direction of readiest cleavage. In these latter cases, however, in thin section the schistose structure is just as distinct as in the coarser phases in which it is so easily recognizable. While, then, these rocks have no strike and dip in a proper sense, they have a foliation to which the terms may be applied. It has been said that more often than not this foliation is approximately east and west. However, it has wide variations within narrow ranges (as will be seen by looking at the detailed maps, Pls. v to xiii), and at times the foliation is almost directly perpendicular to the strike of the rocks of the Penokee series. If there are abrupt and sudden changes in the direction of strike, the variation in dip is still more marked, frequently within a few rods varying from a dip in one direction to that in the reverse. Further, while on the maps there are sharp lines of separation drawn between the fine-grained gneisses and the granites and granitoid gneisses, in the field there is at times an apparent transition rather than an abrupt change (pp. 123–125). More often, along the border of the schists are granitic intrusions, and these become more and more numerous in passing toward the granite, until this rock becomes predominant. The great variation in the direction of foliation in the gneisses is readily understood when some of the larger exposures are examined, their banding being extremely contorted and consequently varying greatly in dip within a single exposure. From the foregoing it will be seen that if the rocks included within this belt have a distinct succession it is an extremely complicated one, and that at present we have no data which will enable us to reach even an approximate notion of it. The only structural fact that can be certainly stated is that some of the massive granites and gneissoid granites are intrusives of later age than the green schists.

When the rocks of the Southern Complex are examined in thin section they are seen to be of completely crystalline kinds. Such massive rocks as the granites and syenites are now regarded as eruptive. The origin of many of the thinly foliated schists and gneisses is not known. It is enough here to say that, as indicated (pp. 125–126), nowhere in this area is there any sufficient evidence to show that any of them are of a fragmental character. Certain of the gneisses of this area have such relations with the massive syenites and granites that they may be considred as of eruptive origin; so that all that can be said as to the original condition of these rocks is that a large proportion of them are eruptive while the origin of others is unknown. The rocks to the south of the Penokee series are, then, a set of massive rocks and crystalline schists having a peculiar complex contact and neither certainly possessing a sedimentary structure of any kind. This Southern Complex, as a whole, may be taken as the basement group of the district.

*The Cherty limestone and Quartz-slate members.*—To the north of this complex are the belts of the Penokee series and the Cherty limestone. In chapters III to VIII these rocks have been described in detail. Here it will be necessary to recapitulate such of the facts as bear upon their relation to another and their relation to the rocks to the south and north of them. The lowest formation is a cherty limestone. This rock is found in large exposures at various places from near Atkins lake, T. 44 N., R. 5 W., Wisconsin, to T. 47 N., R. 44 W., Michigan. In its greatest development it is about 300 feet thick. It appears to be a tolerably continuous formation throughout its western portion, but in the eastern half of the district it is found only here and there. Next in order to the north is the Quartz-slate member. This formation is a fragmental one in which the particles are chiefly quartz and feldspar. In the vicinity of the cherty limestones it frequently carries a considerable quantity of material from this member, even becoming at times a conglomerate. This cherty limestone and the slate belt are, however, in apparent conformity with each other, so that while there certainly was an erosion interval between the two there was found no evidence that the Cherty limestone was closely folded. The case is analogous to that of the relations of the Penokee and Keweenaw series. It will be shown that such an erosion interval implies a considerable physical break.

The narrowness as well as the permanence of the Quartz-slate member is strongly brought out by Pl. II. Here is a belt of rocks which in surface width is upon an average not more than 400 to 450 feet, and the thickness of which is not more than 350 to 400 feet. Its maximum thickness east of Sunday lake is not more than 800 feet. In chapter IV the remarkable essential likeness of the various parts of this belt is indicated. Its southern part is a layer of green, brown, gray and red quartz-slates. Its uppermost layer is a vitreous quartzite. In whatever part of the range a section is made across the belt, its essentially fragmental character is at once discoverable, the rocks being comparatively little changed since they were originally deposited. The induration of both the quartzite and the slates has been explained to be due to the enlargement of quartz-grains and to metasomatic changes of the feldspar.

*Unconformity between the Southern Complex and the overlying Cherty limestone and Quartz-slate.*—There is, then, between the Quartz-slate and the rocks to the southward the great fundamental difference between rocks which are easily provable to be of clastic origin and those which are completely crystalline schists and massive eruptives. There can be nowhere a wider lithological difference in the characters of two sets of rocks than this. But more remarkable than the lithological simplicity of the Quartz-slate are its straightforward field relations. This slate once seen is easily recognized. It always dips northward, varying within narrow limits. Take the strike of any ledge and follow the direction either to the east or to the west with a little latitude of movement and almost invariably another ledge of like rock is found within a short distance if exposures are at all plentiful. The only part of the area in which natural exposures within the belt were not found has been penetrated and exposed by mining operations, so that its continuity can be with certainty asserted. It is true it bows locally from its general course, and in two or three places it is somewhat faulted, but the variation is never sufficient to lose the belt. As one traverses this range north and south at short intervals, the complexity and variety of the lithological characters and of the strikes and dips of the rocks of the Southern Complex and the likeness, simplicity, directness, and uniformity of this slate belt now just north of the granites and now in contact with the crystalline schists are most striking. These facts impress one so strongly that it is safe to say that no one can pass through this experience without having the conviction forced upon him that there is a great structural break between the quartz-slates and the complex series to the south. Such a general relation, it seems to me, is more significant than the direct abutment of the schistose structure of one rock against another; more significant than actual structural breaks seen by the eye in any single exposure; more significant than any basal conglomerate; yet, as will be seen, all of these subordinate proofs of unconformity have been found at various places in this district.

The above paragraph contrasting the lithological characters and stratigraphical relations of the Southern Complex and the Quartz-slate is applicable with almost equal force to the relations of the Southern Complex and Cherty limestone. The only modification that need be made is that the Cherty limestone is not so continuous as the Quartz-slate, so that one is not so strongly impressed with the absolute necessity for a discordance between the two in order to adequately explain their field relations.

The relations of the eruptive massive syenites and granites to the adjacent schists and to the Cherty limestone and Quartz-slate are such as to show that the schists and massive rocks are vastly older. That the granites should intricately intersect the schists and yet for many miles be immediately adjacent to the Cherty limestone and Quartz-slate, yet never cut them, is inconceivable on any other hypothesis than that they were in this position before the deposition of that belt of rocks. It is, further, all but universally believed that the coarse grained granites and syenites are a class of rocks which have crystallized under great pressure and therefore at depth. If this be true they must have been subjected to great erosion in order that the Cherty limestone and Quartz-slate could have been deposited directly upon them, and they are therefore immensely older than the latter rocks. The independent relations, also, of the green schists to the quartz-slates are such as to show that between them is a great interval of time. It has been said that the fibers of the schist run in every possible direction and that in certain cases they abut directly against the slates. These schists may be eruptive or fragmental, but in either case their schistose structure was induced before the deposition of the slates upon them, for it is impossible that rocks could be so profoundly altered and yet the slates of much the same mineral composition in contact with them be unaffected. If they are eruptives the time required for their change from fresh rocks to extremely foliated altered ones must have been very great. If they are fragmental their metamorphism to completely crystalline rocks must have taken as great a time. So that on either hypothesis they are immensely older than the Quartz-slate which overlies them, for the rocks of this formation have neither a schistose structure nor a crystalline character.

West of Potato river, T. 45 N., R. 1 E., Wisconsin, no actual contacts between the Southern Complex and the Penokee rocks are known. At Penokee gap the green schists are found very close to the overlying Cherty limestone. The latter, as usual, dips to the north and strikes approximately east and west. The green schists to the south also have a nearly east and west strike, but their dip is southward. This being the case, the fibers of the gneisses, unless there is here an exceedingly sharp fold of which there is no evidence, abut sharply against the overlying beds, and thus there is here strong, although not conclusive evidence, of unconformity.

At Potato river, fortunately, the underlying schists and the overlying Quartz-slate are found in direct contact with each other. Here the Quartz-slate, rising in low cliffs, is exposed throughout its entire thickness upon the east side of the river (Fig. 5). For some distance the green schists to the south are also exposed, and the actual contact between the two is seen on the bank at intervals for a vertical distance of 75 feet, while the contact is continuous for the lower 25 or 30 feet. The slates are all of the normal character, dipping to the northward at an angle of about 70°. The green schist has no proper dip and strike, and yet it has a strongly schistose character. Its fibers abut almost perpendicularly against the layers of the slate, as shown by Fig. 6, reproduced from a carefully made drawing on the ground. So sharp is the junction line between the two rocks that it can usually be located to the fraction of an inch, and hand specimens were obtained in part from both formations. The surface of the green schist at the beginning of the formation of the conglomerate is seen to have been somewhat irregular (Fig. 7), and between it and the ordinary slates is a layer of basal conglomerate varying from a few inches to several feet in thickness. It, however, quickly grades into the ordinary slate of the district, as though this place were at the bottom of a comparatively level shallow sea, rather than adjacent to a shore. This conglomerate contains a few white quartz and jasper pebbles, the former sometimes being ten inches in diameter; but the great mass of the fragments, and especially all of the large bowlders (which reach occasionally five feet in greatest length), are from the underlying green schist. Moreover, the conglomerate proves that the schistose character of the underlying rock had been fully attained before the deposition of the slates; for the schistose structure of the fragments is as well developed as in the ledge below. A fragment broken from such a schist is naturally longer in the direction of its fibers than transverse to them. That the material does break in this manner was proved in obtaining specimens. The green schist fragments of the conglomerate are generally longest in the direction of schistosity. Now, fragments of this sort, when broken from the basement rock and laid down as a part of the conglomerate, would naturally lie with their longer direction parallel to the horizon; and this has been the case, for, as shown in Fig 7, nearly all of the larger fragments lie with their greatest length parallel to the then sea floor, that is, *the schistose structure of the fragments is at right angles to that of the ledge from which they were derived.* Now, if this schistose structure had been developed subsequently to the formation of the conglomerate, it would have been parallel in both the fragments and basement rocks. So far as a basal conglomerate and unconformity in structure at a single place can indicate a time gap between two formations, this locality indicates it. If the underlying rock was a sedimentary one it must have been folded and extensively eroded to change it to a crystalline schist and bring its foliation in a vertical position at surface. If it was an eruptive rock it has been most profoundly altered, and its alteration, as just shown, must have taken place before the formation of the conglomerate. Such an alteration would hardly take less time than its transformation from a clastic. So in whatever light it is regarded this basement rock is vastly older than the conglomerate and slates which rest upon it.

At the west branch of the Montreal, T. 46 N., R. 2 E., Wisconsin, green schists are again found in contact with the rocks of the quartz-slates. The contact[1] here exposed is of much smaller size than at Potato river and to that extent is less satisfactory, but even here all the essential facts are the same. A basal conglomerate is found, the fragments of which are very largely from the green schist; this conglomerate quickly varies into the normal slate of the regior, as at Potato river; the fibers of the green schist abut against the conglomeratic slates.

Just south of the Aurora mine the Quartz-slate is exposed in direct contact with the granite. The basal horizon is here a cherty slate which does not take on a conglomeratic aspect. The granite surface is plainly one of erosion and into its pre-Penokee joints and cracks the detritus of the Quartz-slate has sifted.

A short distance north and west of the east quarter post of Sec. 15, T. 47 N., R. 46 W., Michigan, on the railroad spur of the Palms mine is another contact between the Southern Complex and the Penokee rocks. Here the junction is between granite and a conglomerate belonging to the Quartz-slate member. A ledge of massive granite is faced by a conglomerate, which penetrates the clefts and hollows of the granite. In the granite fresh microcline and chlorite are abundantly contained. The fragments of the conglomerate are mainly granite, but chert, jasper and quartz are also found. These fragments are in part well rounded, but mostly are angular, as is common when near their source. Much of the feldspar of the fragments is beautiful, fresh microcline. Green chlorite in well defined masses is also plentiful. It is certain that this debris was derived from the granite. The coarse grained granite at this place plainly constituted the surface rock when the conglomerate was formed and contributed material to it. North and east of the conglomerate, after a short covered space, are found the ordinary phases of slates of the Quartz-slate member, dipping north at their normal angle. The time gap here between the conglomerate and granite must be taken to be great if it is conceded that the presence of normal granite at the surface is proof that it is an old rock.

About 700 steps south and 75 steps east of the northwest corner of

[1] This contact was first described by Dr. T. C. Chamberlin. See Literature, pp. 43, 44.

Sec. 13, T. 47 N., R. 46 W., Michigan—i. e., about 2 miles east of the conglomerate just described—is a somewhat similar occurrence. Here a sedimentary rock in a layer from two to three feet in thickness is found upon the northern face of a cliff of granite. The specimens were unfortunately destroyed by fire, so that thin sections have not been studied, but the field relations are the same as near the Palms mine.

Passing eastward, the next contact between the Southern Complex and the Penokee series is east of Sunday lake. In a test trench, about 200 steps east and a short distance south of the north quarter post of Sec. 15, T. 47 N., R. 45 W., Michigan, is exposed the contact between the lower green schist and a quartzite, the lowest horizon of the quartz-slate at this point. The schists are finely foliated and contain white quartz veins. The strike of the fibers of the schist does not correspond to that of the overlying succession, but abut against the quartzite at a rather sharp angle. Here the exposure is small and artificial, and the conditions do not appear to have been favorable to the formation of a basal conglomerate.

In the NE. $\frac{1}{4}$ of Sec. 23, T. 47 N., R. 43 W., Michigan, the rocks of the Southern Complex approach very close to those of the Penokee series, and a beautiful basal conglomerate is exposed in the latter. The underlying rock is here a coarse gneissoid granite. It is separated only a few paces from large exposures of a recomposed granitic rock. This recomposed phase of basal conglomerate, in the field and hand specimen, so closely resembles the crystalline rock of which it is the cemented debris that the two might readily be confused; but when examined in thin section they are readily distinguished, the fragmental character of the one and the thoroughly crystalline character of the other being apparent. This recomposed rock varies into a conglomerate containing, besides the numerous granite fragments, pebbles of white quartz and a green schist, and then upward into the ordinary slate and quartzite of the district. That the material of this fragmental rock is here derived from the underlying gneiss and gneissoid granite there can be absolutely no doubt, the major portion of the fragments being precisely like these rocks.

A short distance west of this point a thin layer of ferruginous limestone is found but five steps north of a coarse gneiss. The fact that the conglomerate adjacent bears fragments of both the Basement Complex and also chert fragments, indicates the probability that this limestone belongs to the Cherty limestone and that it, in common with the Basement Complex, has yielded fragments to the Quartz-slate.

Passing eastward, in Sec. 24, T. 47 N., R. 43 W., Michigan, test-pitting has exposed a rock which is again a recomposed granite, and the coarse granitoid gneiss itself is found but a short distance to the southward. The relations here are plainly the same as those in the northeast part of Sec. 23.

Near the center of Sec. 28, T. 47 N., R. 42 W., Michigan, the easternmost known exposures of the Penokee succession occur, and here is a beautiful instance of a basal conglomerate in direct contact with the underlying granite. The profile of the rock exposures here is shown by Fig. 12. The granite and gneissoid granite have evidently formed a cliff against which the basal conglomerate has been deposited. The contact between the granite and conglomerate strikes north 30° west, and the granite dips back into the hill at an angle of 75°, so that the contact between the two gives the granite an appearance of overhanging the conglomerate. If the strata were turned back to their original condition this would not be the case; we should have a conglomerate resting upon an ordinary slope. The hill faces north of east. The conglomerate upon the face of the cliff at its upper part is about 6 feet in thickness and its face is nearly vertical. The granite-schist ledge continues for some distance beyond the point at which the conglomerate is found in a direction south 30° east. At intervals along this face conglomerate is found. At times it is so fine grained as to become an ordinary quartzite. The underlying rocks in this vicinity are of both the granitic and schistose classes, the former, however, being predominant; which explains the fact that the conglomerate is mostly composed of granite debris, but also contains fragments of green schist. It might be concluded from this exposure that the conglomerate was underneath the granite if the

FIG. 12.—Basal conglomerate in contact with granite in Sec. 28, T. 47 N., R. 42 W., Michigan.

nature of the fragments of the conglomerate and the subsequent tilting of the rocks were disregarded. We have here, however, nothing but what is known to occur at any sea cliff in which its detritus becomes a part of an unconformable newer series of rocks. In the immediate vicinity of this cliff, a short distance to the northwest, is a ravine in which the contact between the crystalline and fragmental series is again found. The fragmental rock is at this place a recomposed granite which so closely resembles the rock from which it is derived that it is impossible in the field to locate the exact junction line. In thin section the fundamental difference between the two rocks is apparent at a glance. Here practically all the material of the fragmental rock was derived from the granite immediately underlying it.

A little farther to the northeast (near the center of the north half of the NW. $\frac{1}{4}$, Sec. 28) a chert-conglomerate is found in several places but a few paces from the granite. These chert-conglomerates are in all essential respects like that found near the Palms mine, already described. While it includes a large quantity of granite debris, including quartz, feldspar, biotite, and complex areas composed of these minerals, it has a cherty background which contains abundant angular chert fragments. It appears that here, as near the Palms, the Quartz-slate member has derived material from both the Southern Complex and the Cherty limestone.

From the foregoing it appears that there are definite proofs of a stratigraphic break between the Southern Complex and the Penokee series at ten places. Two of the localities (see Pl. II), both being actual contacts accompanied by basal conglomerates, are above the Western schist, the lowest layer of the upper series here being the Quartz-slate. Two of the localities, both again being contacts, one accompanied by a basal conglomerate, are above the Central granite, the lower rocks of the upper series here being again the Quartz-slate. One of the places is above the Eastern schist, the contact being found, but no basal conglomerate appearing. The lowest layer of the upper series is here the quartzite, which occasionally appears at the base of the Quartz-slate. Finally, five of the localities are above the Eastern granite, basal conglomerates or recomposed granites occurring at each locality, while at two of the places are actual contacts.

At these contacts the lowest member of the upper series is the Quartz-slate in different phases. When it is remembered that it is exceedingly difficult and unusual to find actual contacts between unconformable series, even when there is the same certain general evidence of the unconformity that is found in this district, the above number must be considered extraordinary. It is also noticeable that the contacts are widely distributed, and in about an equal number of cases the schists and the granites are the underlying formations.

No actual contact between the Southern Complex and the Cherty limestone has been found. However, at Penokee gap and in Sec. 23, T. 47 N., R. 45 W., Michigan, the two are exposed close together. At the first place the rock of the Southern Complex is a schist; at the second it is a granite gneiss. At the former the schist and the limestone dip in opposite directions, the schist inclining 30° to the south and the limestone 65° to the north.

But there is yet further evidence as to the magnitude of this unconformity. It is certain that the complex basement upon which the newer series was laid down was nearly horizontal. When it is remembered that this Southern Complex is here resistant massive granite and there soft foliated schistose rocks, it is plain that the forces of erosion had nearly exhausted themselves, i. e., that a "base level" of erosion had been nearly attained, before the newer series began to form. When we consider what is involved in this, it strongly reenforces what has gone before as to the great time gap which must have intervened between these older formations and the lower fragmental rocks. The proof of the existence of this nearly level plain lies in the small variation in thickness of the Quartz-slate and the Cherty limestone. The difference of elevation in the basement throughout its whole extent east and west probably was not more than a few hundred feet at the time the Cherty limestone began to form. This formation is found here and there in detached exposures for a distance of many miles. Its maximum thickness is now 300 feet. In the sea floor there was probably at the time when the limestone was deposited no greater variation in elevation than the thickness of this formation as it then existed.

At the beginning of the deposition of the Quartz-slate member of the Penokee series proper the case was even more striking. This layer, averaging 300 or 400 feet in thickness, but in one place reaching twice this amount, at no point is known to be much less than 300 feet in thickness. It forms a continuous belt throughout most of the extent of the series, and where missing has been swept away by erosion, as have the higher members at such places. It is certain, then, that the variation in elevation of this ancient land surface at this time was little or no more than 300 feet, except, perhaps, in the eastern part of the Eastern area, where it is not clear that the slates there occurring as the lower layers of the Penokee series are the equivalents of the Quartz-slate to the westward.

A rock basin composed of diversified crystalline schists and massive rocks 90 miles in diameter and having no elevations greatly exceeding 300 feet is rare, and it is universally believed that the complex areas in which this is the case have been subjected to enormous denudation. The amount of erosion in such regions is often compared to that necessary to reduce lofty mountains to mere stumps. Before the beginning of the deposition of the Penokee series proper it is clear that the Southern Complex was thus brought nearly to a plane.

To summarize, the proofs of unconformity above the Southern Complex are as follows: First, belts of sedimentary rocks strike across the country, being now in contact with one variety of underlying rock, now in contact with another, always keeping their course, never being penetrated or interfered with by any of the southward lying rocks (excluding, of course, the later basic dikes), whether schistose or granitic intrusions in the schists. Second, these underlying rocks are either massive ones which are presumably igneous or are schists in which the extreme of foliation and crystalline character is found, while the overlying Penokee rocks are plainly water deposited sediments. Third, in ten places above the Basement Complex are basal conglomerates or recomposed rocks. Seven of these places show the actual unconformable contacts. The detritus is mainly identical in character in each case with the material of the rock upon which it rests, showing that the basement rocks must have reached their present condition before the formation of the lowest overlying member. When the basement rocks are green schists their foliation had been developed and they had been truncated; when they are granite, if formed at depth, it had reached the surface by erosion. Fourth, the fact that the horizon at which the underlying complex is in contact with the Penokee series proper does not vary more than 300 or 400 feet at the outside is the clearest sort of evidence that the underlying rocks had nearly reached a "base level" before the beginning of the deposition of the Penokee series.[1]

*The unconformity between the Cherty limestone and the Penokee series proper.*—In the description of the Quartz-slate (Chapter IV) it was seen that at a number of places this member contains in its basal portions abundant debris derived from the chert of the Cherty limestone, becoming in several places a genuine chert-conglomerate. This derivation is indicated by the lithological likeness of the pebbles of the conglomerate and the chert of the limestone, as well as by the fact that these conglomerates are usually found near some of the exposures of the limestone. At Penokee gap the Quartz-slate rests directly upon the Cherty limestone, being here a recomposed quartz-rock nearly all of the debris of which comes from the immediately subjacent member.[2]

Beginning at the west and passing east these recomposed rocks or conglomerates have been found at Penokee gap, mount Whittlesey, Potato river, near the Palms mine, and east of Sunday lake at several points in Secs. 10, 14, and 15, T. 47 N., R. 45 W., Michigan. In all these cases the chert pebbles derived from the Cherty limestone are well rounded and in exactly the same condition as the chert now is in the limestone. These pebbles appear to be clear evidence that the limestone had become cherty before the deposition of the lowest member of the Penokee series proper.

[1] The time gap implied by such an unconformity as the above is fully discussed by Prof. Irving, U. S. Geol. Survey, 7th Annual Report, pp. 390-443. Suffice it here to say that it is clearly shown that an unconformity of this sort indicates "a lapse of time long enough to cover (1) the folding of the lower series, (2) its elevation into a land surface, (3) a long continued denudation," and (4) its depression under the sea. "In other words, it indicates an interval of more or less extended orographic movement, with its accompanying * * * denudation." In this case it is plain that the orographic movement is of a most extended character.

[2] Geology of the Eastern Lake Superior District, R. D. Irving. The recomposed rock is Irving's IIB, Geol. Wis., vol. III, pp. 109, 110.

The parallel distribution of the detached outcrops of the Cherty limestone and the continuous belt of Quartz-slate is evidence that the orographic movement between the two in the Penokee district was not of a complicated character. Also tending in the same direction is the similarity of the dip of the limestone and the Penokee series proper. While in some places the limestone appears to have a flatter dip than the Penokee series, this is not so marked as to suggest an unconformity between the two were it not that other data point in this direction. Taking all the facts into account, it is concluded that there was a considerable time interval between the Cherty limestone and the Penokee series proper. In this interval the limestone was consolidated, and if the chert is a segregation formed from scattered organic remains, or was introduced from outside, this also occurred. The Cherty limestone and Basement Complex were raised above the sea and erosion began. The amount of material removed it is impossible to estimate. It is only known that the Cherty limestone in some places is 300 feet thick, in others is absent. The presence of occasional pebbles of jasper in the conglomerates of the Quartz-slate suggests that upon the limestone was once a higher formation of a different character which was subsequently wholly carried away. After this time of erosion the land was again depressed below the sea and the lower part of the Penokee series proper began to be deposited. The lack of marked discordance in the bedding of the Cherty limestone and the Quartz-slate is no evidence that the time gap between the two was not long enough to have produced a most pronounced discordance, for this Penokee area may have been a part of a plain removed from zones of important folding and thrusting which may have occurred simultaneously in other districts.

*The Iron-bearing and Upper slate members.*—Thus far the relations of the Southern Complex to the two lower members of the Penokee series and the relations of the latter to each other have been spoken of. Above the quartz-slate follows in perfect conformity the Iron-bearing formation. This member, like the major part of the Cherty limestone, has been shown to be of a nonfragmental character. The change from the fragmental Quartz-slate to the Iron-bearing member is always abrupt. The uppermost member of the former has been said to be a coarsely crystalline quartzite. It is plain that at the final stage of the formation of this member there was a clear sea, only well rolled quartz grains being deposited. This implies sorting of the material and therefore less rapid accumulation. It is probable that this change of condition was accompanied by a gradual sinking of the sea bed. Naturally following the clearing up of the water have come the nonfragmental sediments of the iron belt. As has been shown (pp. 247–248) they are analogous to limestone formations in many respects. The uniformity in width of this belt is noticeable throughout its western three-fourths. In its eastern part, where there are considerable variations in thickness, the irregularities have been explained to be due to contemporaneous volcanic activity.

Above the Iron-bearing member next succeeded the great thickness of fragmental Upper slate. At Tylers fork these slates show their present maximum thickness, nearly 13,000 feet. East and west of this point the belt gradually narrows until it is cut off, at the west near Numakagon lake and at the east near Sunday lake, by the overlying Keweenaw rocks. The relations between the Iron-bearing formation and the upper slates are the same as those between the latter and the underlying quartz-slates; that is, they are two formations which are in perfect comformity, as is shown by the strike and dip of many exposures in both belts. The change from this iron formation to the mechanical sediments of the Upper slate was rather the abrupt, although not so sharp as the change from the Quartz-slate to the Iron-bearing member. The three members mentioned with contemporaneous eruptives constitute the Penokee series. By an examination of Pl. II, it is seen that they are not all continuous throughout the district traversed by them; but wherever the series is present one formation follows another, except in the Eastern area in the order mentioned in conformable succession, so that they are properly placed together as a group of formations.

*The unconformity at the base of the Keweenaw series.*—North of this Penokee series are found the eruptive and fragmental rocks of the Keweenaw series. The rocks of the latter immediately north of the former are usually bedded surface eruptives; but from Black river, in the east part of T. 47 N., R. 46 W., Michigan, to near the Montreal river, in the basement layers of the Keweenaw series, has been seen at various points a red sandstone or quartzite. That there is a great time gap between the Southern Complex and the Penokee series has just been shown. That there is also a time interval, although not so vast a one, between the iron-bearing and the overlying Keweenaw series, is equally clear. In any single section this discordance is not plain, for the Keweenaw rocks north of the Penokee series, like the latter, have as a whole a northern dip at a high angle.[1] The eruptive character of the basement member of the Keweenaw series for most of the distance, and its northern inclination, make it more difficult to prove an unconformity between the two than between the Penokee series and the Southern Complex. The proof here rests entirely upon broad field relations; unless the conglomerate, placed provisionally at the top of the Upper slate (pp. 305, 326), belongs with the Keweenawan. This conglomerate lies but 200 steps south of the Keweenawan greenstone. It is separated from the typical biotitic slate (p. 326) of the Upper slate member by an unexposed interval of 280 steps. The pebbles, ranging up to eight or ten inches in diameter, are mainly of white quartz, but flint and black hornstone are also abundant. The most probable source of the last two are the Cherty Limestone and Iron-bearing members of the Penokee series. While it can not be asserted whether this conglomerate belongs to the Upper slate, or at the base of the Keweenawan, the latter alternative is the more probable, and if this be true, the rock may be considered a basal conglomerate.

Beginning at the west end of the Penokee succession, and following the contact of the two series of rocks to the eastward, it becomes evident that there is a considerable break between them. Near the northeast corner of Sec. 20, T. 43 N., R. 7 W., Wisconsin, characteristic eruptives of the Keweenaw series, as found by Mr. Charles E. Wright,[2] are upon the north side of Numakagon river, and a gneissoid granite of the underlying complex upon its south bank. It is not certain that rocks belonging to the Penokee series are not between, but there is no proof of this or of their existence to the westward for a long way; so this point may be taken as the western-

[1] Copper-bearing Rocks of Lake Superior, pp. 225–234, R. D. Irving, U. S. Geol. Survey, Monograph, vol. v.

[2] Geol. of Wis., vol. III, p. 300.

most one at which it is probable that rocks of this series will be found. As a matter of fact, the westernmost known exposure is in the SE. ¼ of Sec. 24, T. 44 N., R. 6 W., Wisconsin, about 11 miles north of east of this point. In Sec. 16, T. 44 N., R. 5 W., Wisconsin, the eruptive rocks of the Keweenaw series at one point are immediately north of the rocks of the Iron-bearing member, while between them there is little space in this township for the rocks of the Upper slate member. Proceeding eastward the exposures found in the NE. ¼ of Sec. 23, T. 44 N., R. 5. W., Wisconsin, are the last known in the Penokee series for fully 6 miles. For this distance the country is low and swampy. The next exposures to the eastward are found in Sec. 24, T. 44 N., R. 4 W., Wisconsin. No attempt is made to map the Penokee series in this interval, as the only indications of its existence are somewhat feeble magnetic attractions,[1] which may be due to the magnetite of a basic eruptive. It is not even certain but that the entire succession is here cut off by the overlying series. There are numerous exposures of coarse gabbro in the southern part of Sec. 24, T. 44 N., R. 5 W., Wisconsin (see Pl. v), a short distance east of the granites in the south part of Sec. 23. In Secs. 22 and 23, T. 44 N., R. 4 W., are again exposures of gabbros a short distance from the granite to the south and east. We have no evidence which will enable us to locate these greenstones as a part of the Keweenaw series or as intrusive rocks in the Penokee or underlying series. If they are regarded as Keweenaw rocks, that series must here be conceived not only to take the place of the Penokee succession, but to occupy at least half a mile of the area where one would expect to find the underlying complex. This structure would imply an erosion not only sufficient to remove all of the rocks of the Penokee series, but to have cut a valley of very considerable depth into the Southern Complex in the interval between Penokee and Keweenaw time. This unusual amount of erosion is not incredible, but the relative locations of the ledges in the south part of Sec. 24 and in the northeast part of Sec. 23 are such as to give an almost incredible steepness to this hypothetical gorge. Another possible explanation of the relations is, that the Penokee rocks are absent by erosion and that there has been here a double

[1] Geol. of Wis., vol. III, pp. 278–281.

fault with a southward throw, by means of which a section of the Southern Complex has been set off from the corresponding rocks east and west. But this assumption of both unusual erosion and faulting has no positive facts in its favor, and it seems, in the lack of definite evidence, that it is probable that the Penokee series is continuous and that the greenstones adjacent to the granite in this area are intrusive within them, rather than a part of the Keweenawan basement flow.

About half a mile west of the east range line of R. 4 W., Wisconsin, numerous exposures of the iron formation are again found. The known thickness of the Penokee series is here about half a mile, while it may be considerably thicker. At the center of Sec. 18, T. 44 N., R. 3 W., Wisconsin, the series is at least three-fourths of a mile wide. Just east of English lake this width has become more than a mile. This widening of the series goes on continuously until Tylers fork is reached, T. 45 N., R. 1 W., Wisconsin, where its maximum thickness is found. In passing eastward from this stream the series gradually narrows with great uniformity until a short distance west of Sunday lake, in the west part of T. 47 N., R. 45 W., Michigan, where the Upper slates have disappeared. From this point to the middle of T. 44 W., Michigan, the overlying Keweenaw rocks are in direct contact with the Iron-bearing formation. At one place just east of Sunday lake this formation can not be exposed for more than a third of its width. Through townships 44 W., 43 W., and 42 W., Michigan, the greenstone ridge constituting the basement of the Keweenaw series passes nearly in an east and west direction, with the exception of 1½ miles in the east part of T. 47 N., R. 44 W., Michigan, and here the discrepancy is explained (pp. 424, 425) as being probably due to a fault. In these townships the immediately underlying rock is a mingled fragmental and nonfragmental one which, as explained (p. 431), is probably the equivalent of the upper part of the Iron-bearing member to the west.

That the Penokee series could have been deposited to a thickness of about 14,000 feet at Tylers fork, and at other points be only 1,000 feet thick, or entirely absent, is not at all probable. This is especially true, as it is the lower 1,000 or 1,500 feet of the series which is found whenever any part is present. As already explained, the persistence of the Quartz-slate and Iron-bearing members in nearly uniform thicknesses shows that at the time of their deposition there was for this distance an approximately level basin. If no part of the upper slates and iron formation have been swept away by erosion, we must believe that there was inaugurated before the end of the latter period an orographic movement which formed a synclinal trough, the center of which was Tylers fork, and thus a great thickness of upper slates there accumulated, while to the east and west the thickness became less and less until it finally disappeared, as well as a part or the whole of the lower members of the series. That a great earth movement of this sort could occur without disturbing the perfect conformity of the formation of the series is improbable. The discordance in the strikes of the layers would indicate the change, but as all the members are in apparent perfect accordance, one layer has followed upon another without disturbance. This being the case, the Penokee series was originally probably of rather uniform thickness, and doubtless this thickness continued both east and west of the points at which the series can now be traced; for there are many reasons for believing that this district was a part of a great basin which extended to the Marquette district on the east and to the quartzites of the Chippewa valley on the west.

The relations just sketched can, then, have but one meaning—that a great unconformity separates the Penokee and Keweenaw series. This is the only possible explanation of the facts that the Keweenaw series is above an Upper slate member 13,000 feet thick at Tylers fork, and east and west not a great distance is above a belt much thinner, while a little farther east and west this slate disappears altogether, and yet a little farther to the west the lower members are hidden, and west of Numakagon lake the Keweenaw series apparently rests directly upon the Southern Complex. During this intervening period the rocks of the Penokee series were raised above the sea, and then suffered long continued denudation until in places the entire succession was carried away, exposing the underlying rocks. How thick the series as a whole was at the beginning of this erosion there is no available evidence, but the amount of material swept away at Numakagon lake was 14,000 feet more than at Tylers fork, while the difference in amount of erosion between the last place and Sunday lake is scarcely

1,000 feet less. Probably the series must have been everywhere thicker than at the present time at any place. The amount of erosion during this period was, then, in some places measured perhaps by twice 10,000 feet. During the progress of this erosion it is possible that the series was gently bent into a synclinal trough, the center of which was in the vicinity of Tylers fork and the eastern end near Sunday lake. This suggestion is made as an explanation of the difference in the amount of erosion, those parts naturally being eroded most which were at highest elevations.

The time gap, then, between the Penokee and the Keweenaw series must have been sufficient for a widespread orographic movement and deep denudation—a vast lapse of time; so that while the unconformity between these two series is not nearly so great as between the Penokee series and the Southern Complex, yet it stands as one of the greater time gaps in geological history.

*The Eastern sandstone and the unconformity at its base.*—The only remaining terrane in which we are concerned in this memoir is the Eastern sandstone, which (as shown by Pl. I), extending from Keweenaw bay to a long distance west of Gogebic lake, conceals a broad strip of the older formations. The low ground north of the trap range, in the north part of T. 47 N., R. 44 W. and 43 W., Michigan, is the southern boundary of this sandstone. As T. 47 N., R. 42 W., Michigan, is reached, near Gogebic lake, this low ground swings rapidly to the southward, and it was early in this study suspected that here the Eastern sandstone is the surface formation, but no natural exposure was found which would either prove or disprove this suspicion. However, test pitting in the NW. ¼ of Sec. 28, T. 47 N., R. 42 W., Michigan, has shown the sandstone to there exist. The basal conglomerates there found at the junction of the Penokee series with the underlying granites have already been described, pp. 394–395, 409. In this interesting locality is still another basal conglomerate which belongs to the Eastern sandstone. In the test pits close to the outcrops of the Penokee series and the Southern Complex the conglomerate is coarse, and its matrix is somewhat indurated, it being necessary to resort to blasting in sinking. Upon exposure to the air the matrix of the conglomerate disintegrates, as a result of which a heap of sand, pebbles, and bowlders of various sizes is found about each test pit, although parts of the rock hold together with sufficient firmness to yield large specimens of the conglomerate. The pebbles and bowlders are well rounded. The character of the pebbles indicates that they have been derived from the Southern Complex, the Penokee and the Keweenaw series. From the last are coarse red indurated sandstones, amygdaloids, coarse grained basic eruptives, quartz-porphyries, and other varieties of rock. From the Penokee series the pebbles are more numerous than from either of the others, as would be naturally the case since the exposed conglomerate is in contact with these rocks. The pebbles belonging here are lean ore, banded jasper, magnetitic schist, chert, chert-breccia, recomposed granite, and quartzite, the induration of which is due to the enlargement of quartz-grains. From the Basement Complex pebbles and bowlders are also very numerous, comprising white vein quartz, gneiss, granite, and many varieties of crystalline schist. The pebbles from all of these sources are characteristic of the series from which they are derived. To describe them in detail here would be but to repeat the lithological descriptions given of them in the treatment of the formations of the district. It is, however, to be remembered that in this area no crystalline schist, gneiss, or granite has been found anywhere except in the Southern Complex; no jasper, magnetitic schist, chert-breccia, lean ore, or recomposed granite has been found in other than the Penokee series, while quartz-porphyry and certain phases of the basic eruptives have been found nowhere but in the Keweenaw series; so the evidence is as clear as any lithological evidence can be that the various pebbles have been derived from the sources assigned them. The test pits show, so far as the rock has any stratification, that it lies in a horizontal position, and the character of the basal conglomerate alone would be sufficient to prove that we have to deal with the Eastern sandstone. Further, the relation of the underlying rock to the sandstone is shown in one test pit. After passing through a thickness of 24 feet of the conglomerate just described, the shaft penetrated the chert-breccia of the Penokee series (p. 406) clearly proving that this rock is earlier than the conglomerate. Again, a short distance northeast of these test pits are others in sandstone which in every respect is like the ordinary red Eastern sandstone, and which show, so far as it is possible in test pits, the rock to be in a horizontal position. The Penokee series is not absolutely cut off by the sandstone, but its breadth at one point in the northwest part of Sec. 28, can not be more than 200 or 300 feet, and it is probable that farther south the entire succession is overlain by it.

It is clear, then, in the upward passage to this Eastern sandstone that another great unconformity has been passed. First, the sandstone is in a horizontal position, lying directly upon the upturned edges of the Penokee series and presumably having the same relations to the Keweenaw series. Second, this sandstone contains abundant fragments derived from the Southern Complex, Penokee-Gogebic, and Keweenaw series. From what has gone before it is manifest that in order that this should be the case the whole Keweenaw and Penokee series must have been tilted and have suffered vast erosion in order that the base of the latter and the underlying series—once probably buried under many thousands of feet of sediments—could reach the surface and furnish these fragments. Since the sandstone is horizontal it is plain that the two upper series were tilted to their present inclination and eroded before the deposition of this sandstone. The final part of the erosion furnished the material of which the sandstone is made. This unconformity is one, then, which in magnitude is probably equal to if not greater than the geological break between the Penokee series and the Southern Complex.[1]

*Résumé of geological history.*—We are now prepared to give a résumé of the geological history of the district of which the Penokee series is a part. The oldest rocks are the great Southern Complex. Of the origin of a part of them little is known, but, whatever their genesis, before the beginning of the deposition of the Penokee series there was a long period during which earth movements and erosion acted upon them. This

[1] The discordance between the eastern sandstone and the Keweenaw series has been long maintained by eminent geologists, though denied by others. This position was first taken by Brooks and Pumpelly in 1872 (On the Age of the Copper-Bearing Rocks of Lake Superior. Am. Jour. Sci., 3d series, vol. III, pp. 428–432). The last exhaustive and convincing treatment of this question is by Profs. R. D. Irving and T. C. Chamberlin (Bull. U. S. Geol. Survey No. 23). Upon Keweenaw point it has been maintained that the pebbles in the sandstone do not imply a great break because of eruptive origin. At Gogebic lake are nearly all the phases of pebbles of the three great series of rock of the region. That they should be abundantly contained in the sandstone in the condition which they are now found *in situ* can not be explained upon any other hypothesis than a great unconformity.

erosion continued until they were reduced nearly to a plain throughout the distance from Numakagon lake to lake Gogebic. The district was then submerged. The conditions prevailing were quiet ones, for almost immediately there began forming at the bottom of the sea the nonfragmental rocks of the Cherty limestone member.

Between the Cherty limestone and Quartz-slate there was an erosion interval which may mark a time break of considerable magnitude. It is even probable that above the Cherty limestone member were deposited other formations which have been entirely removed. While in the lower part of the Quartz-slate member a considerable amount of material—even sufficient to form basal conglomerates—has been derived fromthe Cherty limestone, the great mass of the material came from the gneiss-granite Basement Complex. Where the Cherty limestone is now absent the basal conglomerates found contain fragments which are almost wholly from the granite and gneiss. These conglomerates have been discovered at a number of localities and may be nearly continuous. The character of the sediments was very uniform for some time, although there were to a certain extent variations in conditions, thin beds of feldspathic sandstone being interlaminated with beds of shale.

After a time there was a clearing up of the waters and an assorting of materials, as a result of which well rounded quartz grains only were deposited, and this layer now constitutes the pure vitreous quartzite composing the upper 50 feet of the member.

After the deposition of this thin layer of sandstone there was again a change of conditions by which fragmental sedimentation ceased and the nonfragmental chemical or organic sediments of the iron belt began to form. During this period the conditions were again uniform, the material everywhere, except in the Eastern area, at all horizons appearing to be a cherty ferriferous carbonate. During the time of the accumulation of the 800 feet of the Iron-bearing member it is probable that the bed of the ocean continued steadily to subside.

Again a change of conditions came about, resulting in the deposition of fragmental layers. The passage from the nonclastic iron formation to the clastic slates was not so abrupt as the change from the quartz-slates to the iron formation, but in most localities it took place within a comparatively short distance. From this time onward the accumulating beds of the Penokee series were very uniform in character. The material deposited constitutes the Upper slate member. This member, in places more than 10,000 feet in thickness and making up at least six-sevenths of the whole series when at its maximum thickness, is in turn graywacke and graywacke-slate, mica-schist and mica-slate, with less frequent clay-slates. The original material for all of these phases of rocks was very largely quartz and feldspar, the only differences being the relative proportions of the two minerals and their fineness of comminution. Thick beds of fine grained black clay-slates and graywacke-slates show that through a large proportion of the area the material was very finely pulverized. From Penokee gap and westward the original rock has been metamorphosed into a mica-slate or mica-schist. Here the material furnished by the underlying gneiss and granite was almost wholly feldspar. This peculiarity is explained by the fact that the area of granite and granitoid gneiss stretching to the south and west is very strongly feldspathic. After the deposition of at least 12,000 feet of these materials, and perhaps other kinds of sediments which have been subsequently swept away, came the end of Penokee time.

The district was then elevated above the sea, gently folded, and suffered a long period of atmospheric denudation. The erosion was sufficient at the west and east ends of the district to entirely remove the series. What fraction of it has been removed at its place of present maximum thickness is unknown. Following the Penokee series came the great succession of eruptive and fragmental layers which built up the Keweenaw series. This series has been already treated in a monograph of the Geological Survey,[1] and nothing will be here said as to the conditions which prevailed or as to the succession. But the probable connection between the eruptives of this series and the dikes of the Penokee series is to be noted. The little altered diabases of the Southern Complex and those of the Penokee series have been described in detail and their relations to the containing formation given (chapter VII). It has been seen that these same dikes have been profoundly altered in the iron formation, where they have been subjected to

[1] Copper-Bearing Rocks of Lake Superior; by R. D. Irving, U. S. Geol. Survey, Monograph V.

long continued leaching. In that part of the Penokee series which has been the seat of mining operations, the large number of these dikes and the fact that they cut the containing formations perpendicularly are shown by the descriptions, pp. 271–275 and Pls. xxx and xxxi. That these diabases are the pipes through which has passed, from deep within the earth, the vast amount of material which formed the basic volcanic flows of the Keweenaw series can hardly be doubted. The trap range north of the Penokee series is a set of rocks varying, it is true, greatly in structural character, being here amygdaloids and there diabases and gabbros, but in chemical composion these rocks are practically the same as those that are found in the form of dikes within the Penokee succession.

After or during Keweenaw time began the orographic movement, accompanied and followed by erosion, which made the synclinal trough of lake Superior, and which upturned and truncated the whole great thickness of formations constituting the Keweenaw and Penokee series. We have no measure by which to estimate the time required for this work, but it was sufficient to bring to the surface a continuous succession of beds more than 50.000 feet thick.

Prior to this time, during it, and subsequent to it went on the alterations which changed the rocks of the Penokee series from their original condition to their present somewhat metamorphosed one. There is no means of placing the time at which the change from the feldspathic fragmental rocks to the mica-schists occurred. There seems to be tolerably clear evidence that the transformation of the cherty iron carbonates to the many phases of rock now found in the formation took place during the uplifting and erosion or subsequent to it.

After the Penokee and Keweenaw series had assumed their present inclined position and had suffered vast erosion, there was deposited upon their upturned edges the Eastern sandstone, which now cuts them both off just west of Gogebic lake.

*Why the district is given a separate memoir.*—The reason is now more apparent than at any time before for giving this Penokee district a separate memoir. It stands out in the lake Superior country unique in its simplicity and isolation. It is a great series of water deposited sediments, the origin of which has been for the most part determined. The rocks have simply been tilted to the northward at an angle most convenient to determine the succession of belts. It is without any subordinate fold whatever, so that traversed anywhere, excluding the Eastern area and Cherty limestone, if sufficient exposures are found, the succession of its belts can be made out, one following the other in conformity. This series is terminated on the east by the unconformably overlying horizontal Eastern sandstone; it is terminated on the west by its being entirely swept away by erosion, the Keweenaw series directly underlying the Southern Complex. It is marked off from the underlying granitic and gneissic rocks by one of the greatest unconformities of geology. The proof of this unconformity, as evidenced by broad relations and by numerous localities in which actual contacts are found, is of the clearest possible sort. To the north of the Penokee rocks is a third independent set of formations, the Keweenaw series, which is separated from the former by a time gap only inferior to that just mentioned.

*Depth and metamorphism.*—The Penokee series furnishes an instructive lesson as to the depth to which rocks can be buried and still be slightly affected by metamorphosing processes. The series itself is 14,000 feet thick. It was covered before being upturned by a great thickness of Keweenaw rocks. This series at the Montreal river is estimated[1] to be 50,000 feet thick. Adding this to the known thickness of the Penokee series we have a thickness of 64,000 feet, or more than 12 miles. The Penokee rocks were, then, buried to a great depth, the exact amount depending upon their horizon and upon the stage in Keweenaw time when the tilting and erosion which brought them to the surface was inaugurated. That the synclinal trough of lake Superior began to form before the end of the Keweenaw period, and consequently that the Penokee rocks were not buried under the full succession, is more than probable. However, they must have been buried to a very great depth—at least several miles—and thus subjected to high pressure and temperature, notwithstanding which they are comparatively unaltered. In the quartz-slates near the bottom

[1] Copper-Bearing Rocks of Lake Superior; by R. D. Irving, p. 230, U. S. Geol. Survey, Monograph V.

of this pile the feldspars have, it is true, in large measure decomposed to chlorite, mica, and quartz. Also the quartzite of the upper part of this formation has been indurated by the enlargement of the quartz-grains. The alteration in parts of the Iron-bearing and Upper slate formations has locally been more extensive. But the clastic character of the fragmental belts is usually seen at a glance under the microscope. The pressure to which these rocks have been subject, the amount of which one dares hardly to estimate in figures, has not been sufficient to distort the quartz-grains in any degree; nor has it been sufficient to give a schistose structure to the quartz-slates. It is a probable deduction from these facts that the weight alone of any ordinary amount of superincumbent rock is not sufficient to develop schistose structure. The schistosity found in the various fragmentals of the Marquette, Menominee, and Vermilion lake districts, and in some places in the Eastern area of the Penokee series, must have been developed in connection with the dynamic action of folding to which they have been subjected.

### SECTION III.—CORRELATION.

Throughout this memoir the terms Archean, Laurentian, Keewatin, Huronian, etc., have been avoided. Certain of these words have been so differently used by different writers that it was thought best to free the discussions involved in this book from misapprehensions which would result from their use. The structural relations of the series considered are so perfectly distinct that no evidence or use of names from other localities is necessary in order to make out the succession of belts within the Penokee district itself, or the relations of the series to one another. Before closing, however, it is necessary that some reference be made to other series, which have been designated by these and other terms, and an indication be given of our judgment as to their proper use, and where the series considered would fall under that usage.

*Equivalency of Penokee series proper with Animikie series.*—As the opening step a comparison will be made with the Animikie series (see Pl. XXXVII), the equivalency of which with the Penokee series proper is as plain as the equivalency of any two areas of detached rocks in a single geological basin can possibly be in which clear paleontological evidence is lacking.

It has been seen that, above the Cherty limestone of the Penokee district is an erosion interval and perhaps a considerable structural break. In the Animikie district we know of no equivalent to this member, and in what follows it is excluded from the discussion. The Penokee and the Animikie rocks have a parallelism in lithological characters which is remarkable. This parallelism has already been discussed, but the main facts are here repeated. Not only is there a general likeness between the specimens from the two districts, but almost every phase of rock from the Animikie series can be matched by specimens from the Penokee series. In the Animikie district the formations underlying the iron-bearing belt are not extensively exposed, and consequently little is known of the Animikie equivalent of the Quartz-slate of the Penokee series. But along the lower Current river, near Port Arthur, Ontario, occur quartz-slates underlying the Iron-bearing member which resemble certain phases of the Penokee quartz-slate. Beginning with the iron formations, the parallelism between the two series is almost exact. The irony beds upon Gunflint lake, where are found the best known exposures of the formation, are in their lower parts jasper, magnetite-actinolite-schist, and cherty ferruginous rocks containing more or less iron carbonate. Higher up are thick deposits of thinly bedded cherty iron carbonate. All these varieties of rock are found in the iron formation of the Penokee series, and at many places the order of succession is the same. Above the iron-bearing belt in both districts is a great thickness of fragmental clay-slates and graywacke-slates which are again practically identical in character. It is true that in the western part of the Penokee district mica-schists have developed from these slates, but the original condition of these rocks was essentially like that of the unaltered phases.

Underlying both the Animikie and the Penokee series is a complex of granites and schists, the unconformity between which and these series is of the most pronounced character. That the Animikie series is thus separated from the underlying rocks has been seen by all who have studied it, and, considering this general agreement, the proof of this unconformity will not be here repeated. Above both series follow the Keweenaw rocks. In both districts, in passing at any place from the underlying rocks to the Keweenaw series in section, the two are in apparent conformity; but when the lines of contacts between the iron-bearing and the Keweenaw series are followed for some distance, both with the Animikie and Penokee series, this apparent conformity is found to be illusory; that is, the Keweenaw series is now in contact with one member of the underlying series and now with another, until in both districts at one or more places the entire iron-bearing series is entirely cut off, the Keweenaw rocks coming directly in contact with the Basement Complex.[1] This means that between the deposition of the Penokee and Animikie series and the outflows of Keweenaw time there intervened a period of erosion which was sufficient in places to entirely remove the two former and to cut in some places deeply into the older rocks themselves. There is, then, an immense time gap between these series and the overlying Keweenaw rocks, although this unconformity does not approach in the length of time involved to that separating them from the underlying schists and granites.

The Animikie series, in its most typical development, extends from Gunflint lake, along the national boundary between Minnesota and Ontario, to Thunder bay, lake Superior. The Penokee series lies upon the opposite side of lake Superior. The latter is a simple unfolded succession, dipping to the northward under the lake. The Animikie is another such succession, dipping to the southward under the same body of water. There is, then, little doubt, considering all the facts, that the two series represent a single period in the history of the synclinal trough which forms the basin of lake Superior.[2] The relations and likeness of the Penokee and the Animikie series have been dwelt upon at length as showing the breadth of the geological basin in which the deposition of like rocks was taking place simultaneously. The equivalency here shown is a long step in understanding the equivalency of other rocks in the lake Superior basin.

*Equivalency of Penokee and Marquette series.*—A comparison of the

[1] For full discussion of the proof of the unconformity between the Animikie and Keweenaw series see R. D. Irving: On the Classification of the Early Cambrian and pre-Cambrian Formations, 7th Annual Report U. S. Geol. Survey, pp. 417–423. If the Keweenaw series simply were in contact with the gneisses and granites it might be held that we have only to do with an overlap, but its contact—now with one horizon of the Animikie, now with another—can only be explained by an unconformity.

[2] R. D. Irving: Copper-Bearing Rocks of Lake Superior, U. S. Geol. Survey, Monograph v, 1883, pp. 410–418.

Penokee and Marquette successions shows that between the two there is a very close correspondence.

Unconformably below the clastics of these districts is a crystalline Basement Complex composed of schists, gneisses and granites. Within the pre-Keweenawan clastics in each district is a second physical break. In the Penokee district the series below the break is known to be represented only by a single formation, the Cherty limestone. That other higher formations once here existed is indicated by the presence of fragments of jasper and quartzite in the lowest horizon of the Quartz-slate. These jasper fragments occur in the basal conglomerate of the Quartz-slate at Potato river, at two localities near the Palms mine, and at one place in the Eastern area. Usually the pebbles are not of large size, but occasionally they are several inches in diameter. Quartzite pebbles are even more abundant than those of jasper. It is, therefore, probable that the three sedimentary formations of the Lower Marquette series were once represented by equivalent members in the Penokee district.

The correspondence of the members of the Penokee series proper with those of the Upper Marquette is complete. The Upper Marquette and Penokee series, looked at broadly, are great slate formations, both of which contain, near the base, an iron-bearing horizon. In the Penokee series that portion of the slate overlying the ore formation has been called the Upper slate member, and that below it the Quartz-slate member. The lower part of the Quartz-slate is a quartzite and conglomerate which corresponds to the quartzite and conglomerate forming the base of the upper Marquette series. The upper most horizon of the Penokee Quartz-slate is a narrow layer of persistent quartzite which does not appear to be represented in the Marquette district. The character of the ore-bearing member is identical in both districts, being unquestionably derived from a lean cherty carbonate of iron. The characteristic rocks of both are now the iron carbonates, cherts containing bands and shots of ore, and the iron ores. The chief differences between the two are that in the Penokee district the actinolite-magnetite-schists are more prevalent, that the iron-bearing formation is more persistent, and that its ore bodies are more abundant. Connected with these facts is perhaps the presence of the upper horizon of quartzite in the Quartz-slate, which shows that a clearing up of the waters occurred before the beginning of deposition of the iron-bearing sediments. A still further analogy between the Penokee and Upper Marquette series is the presence in both of abundant surface volcanics. We have, then, in the two districts the following parallel descending pre-Keweenawan succession:

| *Penokee.* | *Marquette.* |
|---|---|
| Upper slate, locally mica-schist. | Upper slate, rather extensively mica-schist. |
| Iron-bearing formation. | Iron-bearing formation. |
| Quartz-slate; upper horizon persistent quartzite; central mass a slate; lower part often conglomeratic, bearing fragments of lower series, either Cherty limestone or Basement Complex, and locally a quartzite. | Lower slate; lower part quartzite or quartzite conglomerate, bearing fragments of lower series, either lower Marquette or Basement Complex. |
| Unconformity. | Unconformity. |
| Eroded away. | Iron-bearing formation. |
| Limestone. | Limestone and lower quartzite. |
| Unconformity. | Unconformity. |
| Basement complex. | Basement complex. |

*Comparison with other series.*—As is well known, in the region about lake Superior are other areas containing limestone, quartzites, graywacke, graywacke-slates, mica-slates, mica-schists, volcanic clastics, and the peculiar phases of rock of the iron-bearing formations. The positions of these various areas as shown upon Pl. I, are designated, respectively, by H, $H_2$, $H_3$, $H_4$, etc. These have been known in the past as the original Huronian district, the Marquette, Felch Mountain, Menominee iron-bearing districts, the St. Louis slates, the Chippewa valley quartzites, the Black river Iron-bearing schists, the Baraboo quartzites, the Sioux quartzites, and the folded schists of Canada, including the Vermilion series.

The relations of these series to one another and to the Penokee series, less closely related with the Penokee district than are the Animikie and the Marquette, are fully considered in a bulletin of the United States Geological Survey on the Algonkian and Archean.[1] As a result of the discussion there given, the relations of the series of these different districts are tabulated as follows:

[1] C. R. Van Hise: Correlation papers, Algonkian and Archean. Bull. 86, U. S. Geol. Survey.

*Table showing relations of Penokee succession to that of other Lake Superior districts.*

| General. | Lake Superior region. | Michigan and Wisconsin. Penokee. | Western Ontario. | Northern Minnesota.* | Michigan. Marquette. | Michigan. Felch mountain. | Michigan. Menominee. | Wisconsin. | Iowa, South Dakota and southern Minnesota. |
|---|---|---|---|---|---|---|---|---|---|
| Algonkian. | Keweenawan. | Keweenawan. | Nipigon | Keweenawan. | | | | Keweenawan. | |
| | Unconformity. | Unconformity. | Unconformity. | Unconformity. | | | | Unconformity. | |
| | Upper Huronian. | Penokee proper. | Animikie and upper Kaministiquia. | Animikie and Upper Vermilion. | Upper Marquette. | | Western Menominee. | Chippewa quartzites. Baraboo quartzites. | Minnesota and Dakota quartzites, surrounded by fossiliferous series. |
| | Unconformity. | Erosion interval | Unconformity. | Unconformity. | Unconformity. | | Inferred unconformity. | Unconformity. | |
| | Lower Huronian. | Cherty limestone. | Keewatin, (in part at least) and lower Kaministiquia. | Lower Vermilion. | Lower Marquette. | Felch mountain Iron bearing series. | Menominee proper. | Black river falls iron-bearing schists? | |
| | Unconformity. | Unconformity. | Unconformity. | Unconformity? | Unconformity. | Unconformity. | Unconformity. | Unconformity? | |
| Archean. | Mareniscan. | Southern Complex. (Separated in mapping into (1) fine grained schists Mareniscan and (2) granites and granite-gneisses, Laurentian, showing characteristic eruptive contact. | Coutchiching? | Coutchiching? | Basement complex. (Not yet separated in mapping.) | Basement complex (Not yet separated in mapping.) | Basement complex. (Not yet separated in mapping.) | Basement complex. (Not yet separated in mapping.) | Minnesota river valley gneiss and granite. |
| | Eruptive unconformity. | | Eruptive unconformity. | Eruptive unconformity. | | | | | |
| | Laurentian. | | Laurentian | Laurentian | | | | | |

* This succession is analogous to that given by Dr. Alexander Winchell (Some Results of Archean Studies, Alexander Winchell. Bull. Geol. Soc. of America, 1890, vol. I, p. [illegible]) except that the Vermilion and Ogishki conglomerates and associated clastics would be placed by him in the Keewatin rather than in the Huronian or Animikie. Vermilion series, as we use it, applies to the iron-bearing and associated rocks, while the crystalline schists are designated by Coutchiching.

To give in full the reasons for the positions assigned to these various series and the underlying and overlying rocks would be but to repeat the discussion before referred to. In the above table the Penokee series proper, including the Quartz-slate, Iron-bearing, and Upper slate members, is placed as the equivalent of the Upper Huronian, Upper Marquette, Upper Vermilion, and the quartzites of Wisconsin, Minnesota, and Dakota, primarily on structural and secondarily on lithological grounds, while the Cherty limestone at the base of the series, being separated by a considerable erosion interval from the Penokee series proper, is regarded on grounds of a similar character as equivalent to some part—probably a lower part—of the Lower Huronian, Lower Kaministiquia, Lower Vermilion, Lower Marquette, and equivalent series. The position assigned to this formation is warranted because of the very considerable time break between the Cherty limestone and the Penokee series proper.

The Penokee series and those series equivalent to it constitute a part of the great Algonkian system, and the Southern Complex is Archean.

# PLATE XIV.

## PLATE XIV.—FROM THE SOUTHERN COMPLEX.

FIG. 1. Biotite-granite. Specimen 9639, slide 4228. From the NE. ¼ of the NE. ¼ Sec. 20, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 25. The section shows the strongly feldspathic character of the rock and the abundance of nonstriated feldspar, although striated feldspar, both microcline and plagioclase, are seen. The dark areas are largely biotite.

FIG. 2. Biotitic granitoid gneiss. Specimen 9674, slide 3394, 0 steps N., 160 steps W., of the southeast corner of Sec. 23, T. 44 N., R. 5 W., Wisconsin. Upon the Marengo river. In polarized light, × 25. The section shows the alteration of feldspar into biotite and quartz. Large, irregular, much altered areas of orthoclase and plagioclase are contained in a fine groundmass composed of quartz and biotite. The aggregates of these minerals, besides filling the interspaces, cut into the larger feldspar areas, so that there is a gradation from the fine grained background into the feldspar. In certain cases this alteration has extended quite to the centers of the feldspar individuals. This figure suggests that the rock was once very much more strongly feldspathic than at present—perhaps as strongly feldspathic as the rock in the previous figure—and that the alterations have changed it into a strongly biotitic and quartzose rock. The foliation which is now apparent in the rock may also be one of the results of this alteration.

FIG. 3. Hornblende-schist. Specimen 9050, slide 2776. From near the northwest corner of Sec. 35, T. 46 N., R. 2 E., Wisconsin. In polarized light, × 25. The groundmass of the section is composed of finely crystalline, closely interlocking quartz and hornblende. Within this groundmass are numerous large roundish areas of feldspar, which are now on their outer parts apparently altering into quartz and hornblende. The appearance of the feldspar suggests a fragmental character, but however closely examined, nothing else in the section gives additional light upon this question. If any of the hornblende schists of the Southern Complex are clastic (but this is doubtful), this is probably one of them.

FIG. 4. Hornblende-gneiss. Specimen 9060, slide 2921. From the south part of the SW. ¼ Sec. 33, T. 46 N., R. 2 E., Wisconsin. In ordinary light, × 25. The light background is composed of finely crystalline quartz mingled with a good deal of feldspar, the latter commonly being in larger areas than the quartz and often having roundish outlines. These facts are not apparent in the figure. The slide is reproduced to show the peculiar character of the hornblende individuals. They run from minute fibers up to tolerably large blades which have extremely ragged outlines. They cut the quartz and feldspar through and through. Their appearance is such as to suggest that they are now in the process of growth, and in thin section the relations of the hornblende and quartz to the feldspar further suggest that from the feldspar these minerals have developed. If all of the minerals now present are original, the hornblende must certainly have been the first to crystallize, so thoroughly does it penetrate the others; but this is very much less probable than that it has developed as the last mineral of the rock and subsequent to its consolidation.

Fig. 1.—Biotite-granite.

Fig. 2.—Biotitic granitoid gneiss.

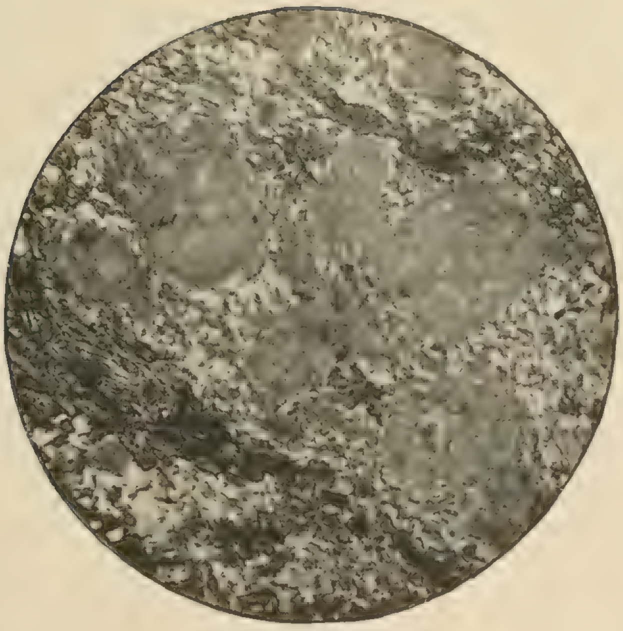


Fig. 3.—Hornblende-schist.

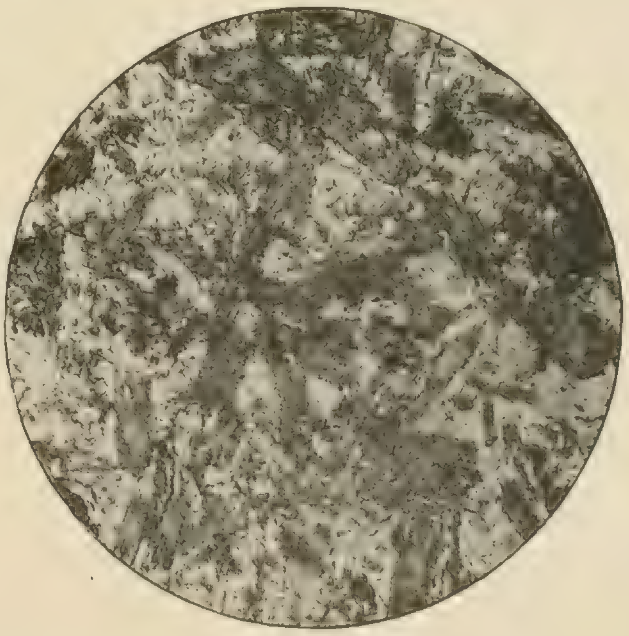


Fig 4.—Hornblende-schist

THIN SECTIONS FROM THE SOUTHERN COMPLEX

PLATE XV.

## Plate XV.—From the Southern Complex.

Fig. 1. Hornblende-granite. Specimen 12873, slide 5504. From the NE. ¼ of the SW. ¼ Sec. 23, T. 47 N., R. 47 W., Michigan. South of Aurora mine. In polarized light, × 25. The strongly feldspathic character of the granite of the Southern Complex, shown by Pl. xiv, Fig. 1, is again brought out, although more quartz is present than in the previous figure. A larger proportion of the feldspar is microcline. The pegmatitic structure of quartz and feldspar is nicely shown in one place. The dark areas are mostly hornblende. In one individual twinning is seen.

Fig. 2. Hornblende-biotite-syenite. Specimen 7615, slide 2070. From near the northeast corner of Sec. 27, T. 47 N., R. 47 W., Michigan. In ordinary light, × 25. A coarsely crystalline feldspathic background is apparent. The individuals of feldspar are large and fit in much the same manner as does the feldspar in the massive syenites and granites from this vicinity; but in this rock it is cut through and through with hornblende and biotite, which are arranged approximately with their longer axes in a common direction and thus give the rock its foliation. The relations suggest the secondary development of the hornblende and biotite within the feldspar by dynamic metamorphism.

Fig. 3. Biotite-gneiss. Specimen 7529, slide 1963. From a short distance south of the north quarter post of Sec. 18, T. 47 N., R. 45 W., Michigan. In polarized light, × 25. The section is composed of small particles of nearly uniform size, consisting of quartz and feldspar mingled with biotite. The roundish and yet closely fitting character of the quartz and feldspar is nicely shown. There are also seen a few larger roundish grains of quartz. This is one of the rocks of the Southern Complex which has a strong fragmental appearance, and yet there is no certain evidence that it is clastic. The particles now perfectly fit one another, therefore they could not thus have been mechanically deposited. None of them show evidence of enlargement, so the crystalline appearance can not be accounted for in this way.

Fig. 4. Hornblende-gneiss. Specimen 9458, slide 3077. From near the south quarter post of Sec. 16, T. 47 N., R. 45 W., Michigan. In ordinary light, × 25. The background of the section is composed of small, perfectly fitting, roundish granules of quartz and feldspar in nearly equal quantity. Contained within this groundmass are numerous large crystals of hornblende, which in transverse sections often have well developed crystal outlines, the forms being usually the pinacoid and unit prism. Each individual of hornblende includes many grains of quartz and feldspar. The hornblende must have been here the last mineral to develop, since it includes so large a proportion of the other minerals. Its relations to the other minerals taken in connection with its crystal forms make its occurrence analogous to such metamorphic minerals as garnet and staurolite.

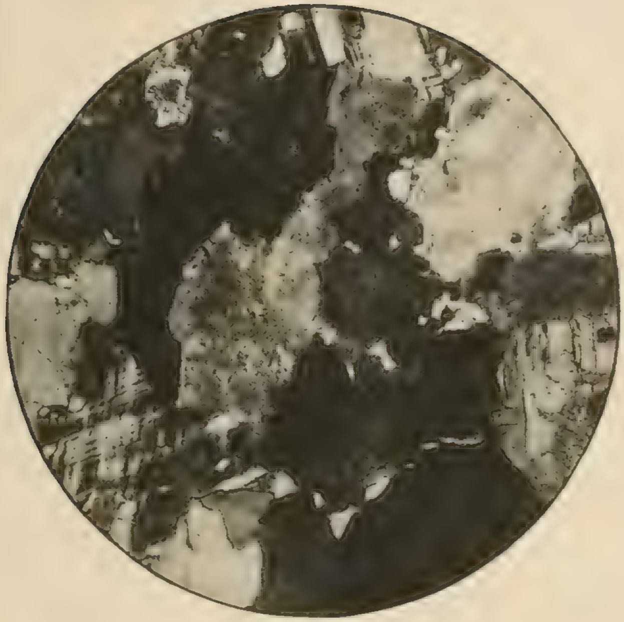


Fig. 1.—Hornblende-granite.

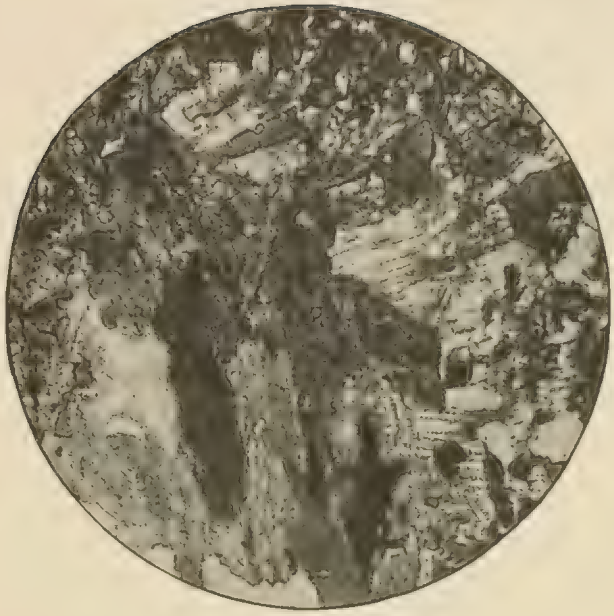


Fig. 2.—Hornblende biotite-syenite.

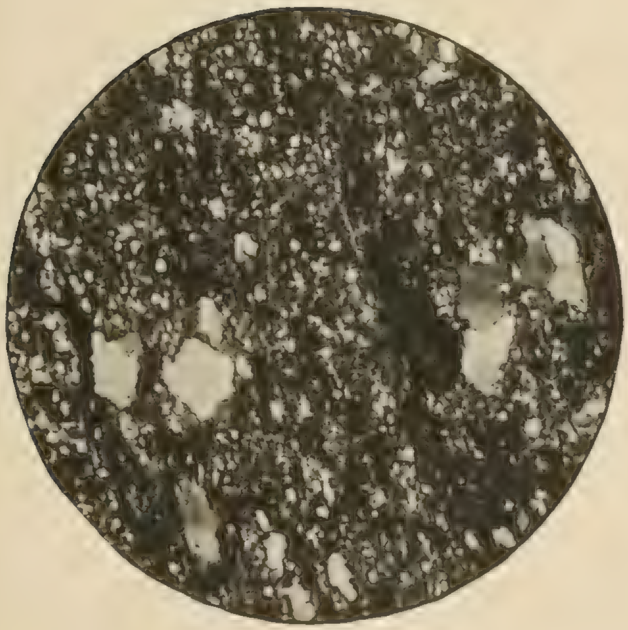


Fig. 3.—Biotite-gneiss

Fig. 4.—Hornblende-gneiss.

THIN SECTIONS FROM THE SOUTHERN COMPLEX.

PLATE XVI.

## Plate XVI.—From the Cherty Limestone Member.

Fig. 1. Tremolitic dolomite. Specimen 9678, slide 3165. From the NW. ¼ of Sec. 22, T. 44 N., R. 5 W., Wisconsin. In ordinary light, × 60. The finer grained part of the section shows the evenly granular appearance characteristic of the massive limestones and dolomites. In one part of the figure is coarsely crystalline carbonate and a broad blade of tremolite. The section chances to be so cut that this mineral appears in part as a mere film, below which the vague outlines of the particles of dolomite are seen. (See p. 135.)

Fig. 2. Cherty limestone. Specimen 7485 A, slide 1934. From the SE. ¼ of Sec. 18, T. 47 N., R. 44 W., Michigan. In polarized light, × 60. The central band of the figure is largely granular dolomite, in which is, however, a considerable quantity of chert. This dolomite is interlaminated with two layers of nearly pure chert, one of which is much more finely crystalline than the other. (See p. 137.)

Fig. 3. Concretionary chert. Specimen 9434, slide 3131. From the NW. ¼ of Sec. 41, T. 47 N., R. 45 W., Michigan. In polarized light, × 60. A fine grained chert. The minute mosaic characteristic of chert when viewed in polarized light is nicely shown. The material is arranged in a vague concretionary fashion, areas composed of very finely crystalline silica being surrounded by borders of more coarsely crystalline quartz. Although imperfectly shown in the figure, the latter has to some extent the radial fibrous arrangement of chalcedony. (See p. 137.)

Fig. 4. Chert. Specimen 9424, slide 3064. From the NW. ¼ of Sec. 14, T. 47 N., R. 45 W., Michigan. In polarized light, × 60. The section shows very well the variations in fineness of grain of the more coarsely crystalline varieties of chert. It is wholly composed of completely individualized quartz, the intricate interlocking of which is well shown and which is in strong contrast to the appearance presented by quartzites in which the interspaces have been filled by the enlargements of fragmental quartz. (See p. 137.)

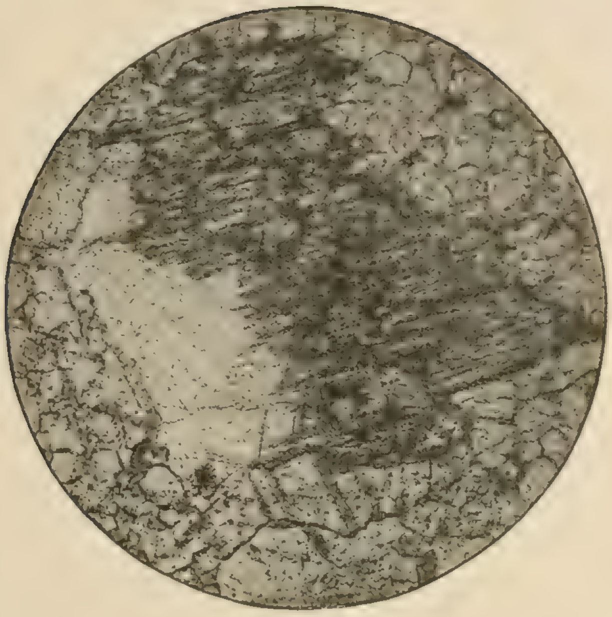


Fig. 1.—Tremolitic dolomite.

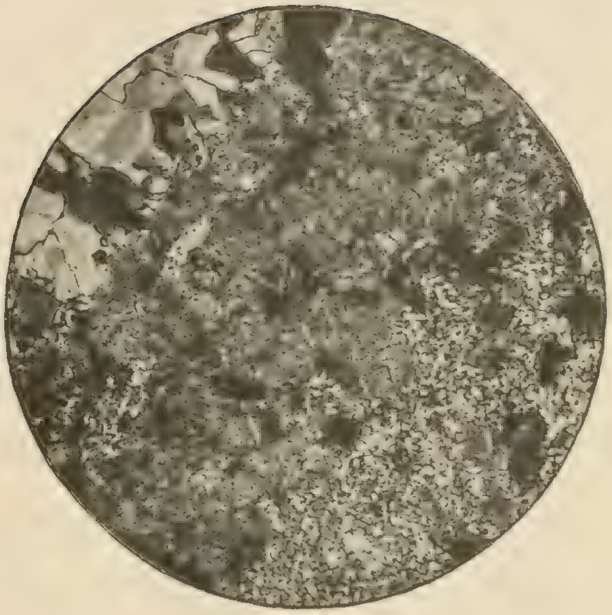


Fig. 2.—Cherty limestone.

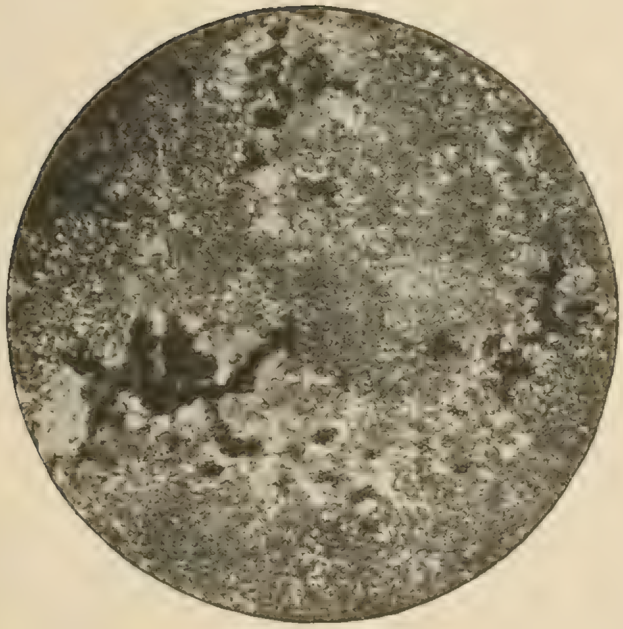


Fig. 3.—Concretionary chert.

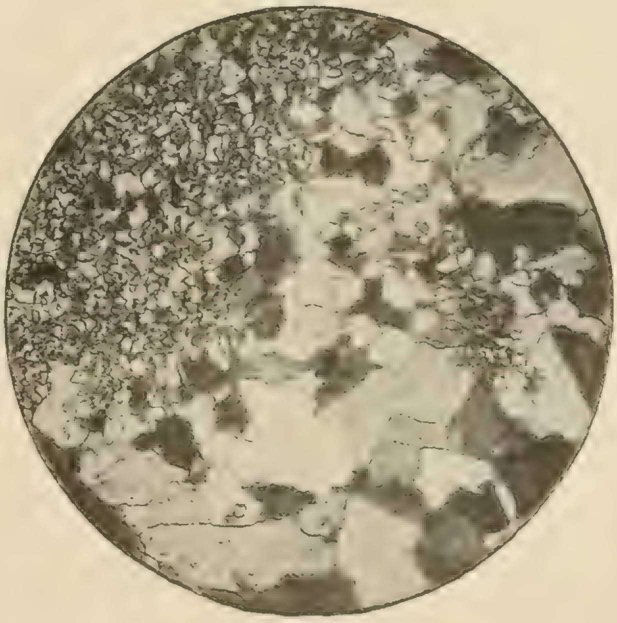


Fig. 4.—Chert.

THIN SECTIONS FROM THE CHERTY LIMESTONE MEMBER

PLATE XVII.

## Plate XVII.—From the Base of the Quartz-Slate Member.

Fig. 1. Chert containing fragmental quartz. Specimen 9534, slide 3140. From the NW. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 30. The background of the section is composed of finely crystalline quartz. In it are contained large well rounded grains of quartz, one of which has plainly received a second growth. In the lower part of the figure is a complex rounded area of chert not greatly different from the matrix in which it is set. (See pp. 157–158.)

Fig. 2. Quartzose chert. Specimen 9535, slide 3141. From the same place as Fig. 1. In polarized light, × 60. The center of the figure shows in the cherty background a large quantity of magnetite. In the exteriors of the large fragmental grains of quartz are very numerous minute needles which are taken to be actinolite. In certain cases these actinolite needles are included only in the enlargements of the quartz grains, but in others appear to penetrate rather deeply into the cores. This occurrence strongly suggests that actinolite may develop in such a manner as to penetrate quartz the latter, of course, being simultaneously removed. (See pp. 157–158.)

Fig. 3. Chert-conglomerate. Specimen 9419, slide 3127. From the SW. ¼ of Sec. 14, T. 47 N., R. 45 W., Michigan. In polarized light, × 60. The background of the conglomerate is a chloritic quartz-slate, the quartz-grains of which at many places distinctly show the enlargements. The large roundish area with the spotty appearance is a part of one of the smaller of the chert fragments which, in the form of pebbles and bowlders, are very abundantly contained in the rock. (See p. 169.)

Fig. 4. Green-schist conglomerate. Specimen 9175, slide 2991. From the SE. ¼ of Sec. 19, T. 45 N., R. 1 E., Wisconsin. In polarized light, × 60. The figure is from the Potato river basal conglomerate. For the most part it consists of three large fragments of green schist, which in one case very distinctly shows the schistose structure. These fragments are set in a matrix consisting very largely of small roundish quartz-grains, mingled with which are quite numerous well defined crystals of magnetite.

(See p. 159.)

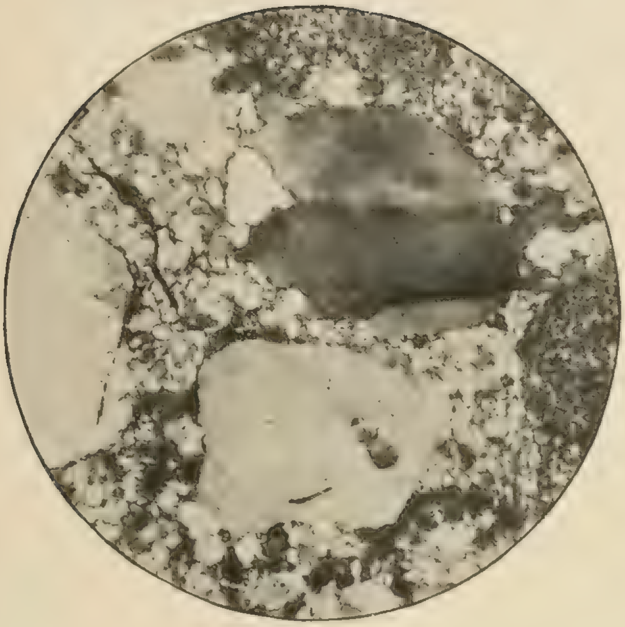


Fig. 1.—Chert containing fragmental quartz.

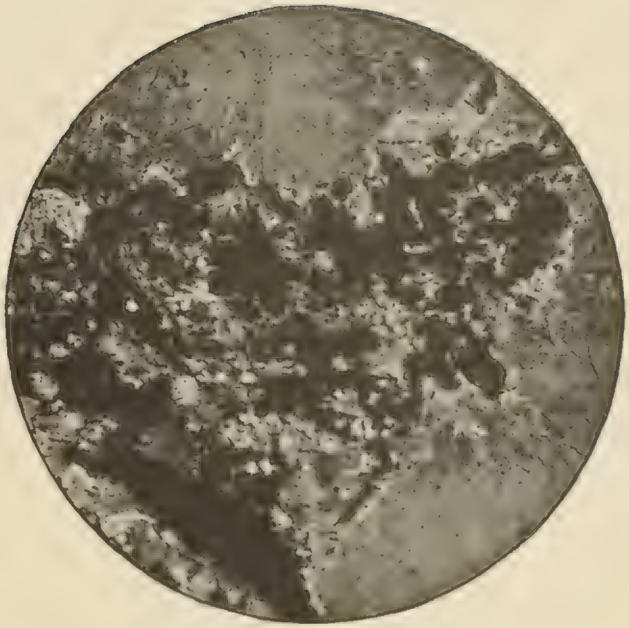


Fig. 2.—Quartzose chert.

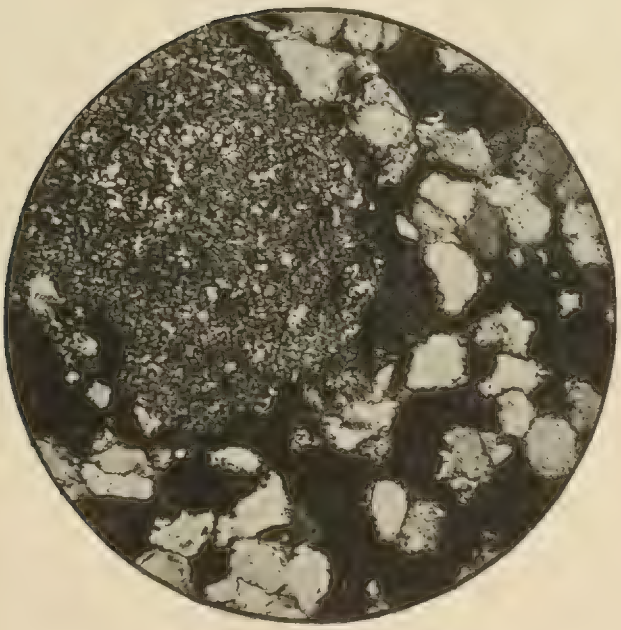


Fig. 3.—Chert-conglomerate.

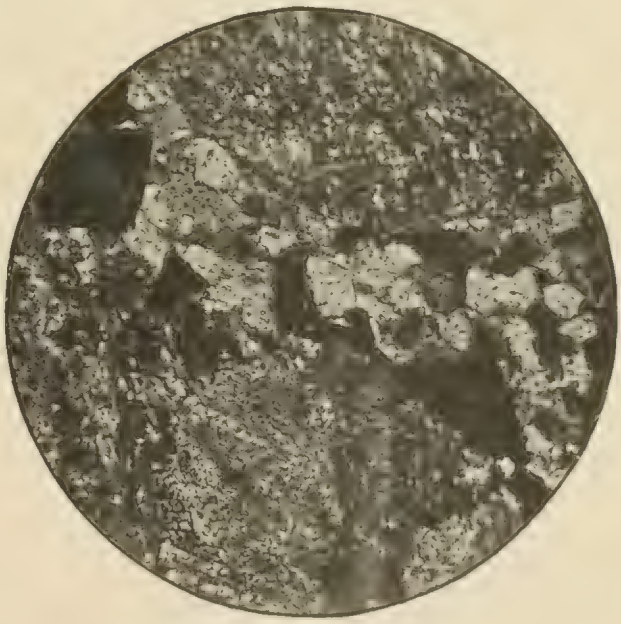


Fig. 4.—Green schist and conglomerate.

THIN SECTIONS FROM THE BASE OF THE QUARTZ-SLATE MEMBER

PLATE XVIII.

## Plate XVIII.—From the Quartz-Slate Member.

Fig. 1. Graywacke-slate. Specimen 9442, slide 3071. From the SW. ¼ of Sec. 10, T 47 N., R. 45 W., Michigan. In ordinary light, × 60. The figure represents a typical average grained graywacke-slate. The rounded fragments are in about equal quantity quartz and feldspar. Chlorite is the chief insterstitial mineral. (See pp. 165–166.)

Fig. 2. The same in polarized light. The orthoclase is in most cases separable from the quartz, in that it lacks the perfect clearness and uniformity of color which each grain of that mineral shows. The striated feldspars are nicely shown. (See pp. 165-166.)

Fig. 3. Cherty slate. Specimen 9641, slide 3310. From the NW. ¼ of Sec. 13, T. 47 N., R. 46 W., Michigan. In polarized light, × 60. The background of the section is an ordinary chloritic slate. It contains, however, in certain layers numerous large well rounded fragments of quartz and chert, both of which are well shown in the figure. (See pp. 164–165.)

Fig. 4. Sericitic and chloritic slate. Specimen 9523, slide 3091. From the SE. ¼ of Sec. 16, T. 47 N., R. 46 W., Michigan. In polarized light, × 60. The section illustrates one of the rather uniform fine grained feldspathic quartz-slates. The small roundish areas are in part quartz and in part feldspar. The dark material is mostly chlorite and grains of quartz and feldspar, which chance to be near the point of extinguishment. (See p. 164.)

Fig. 1.—Graywacke-slate.

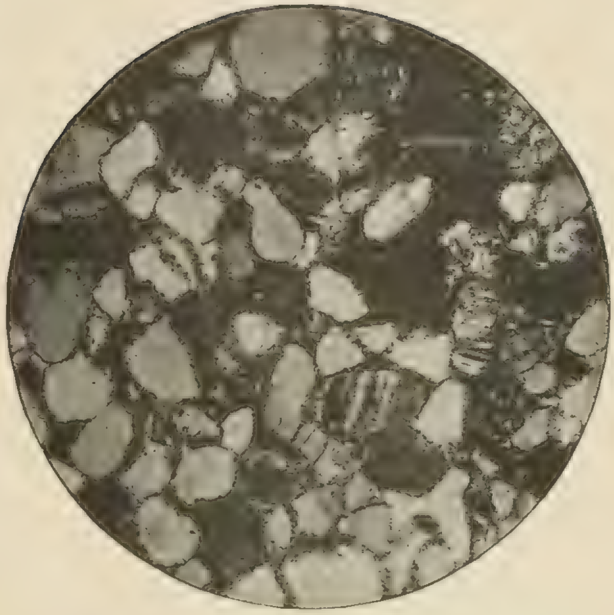


Fig. 2.—Graywacke-slate in polarized light

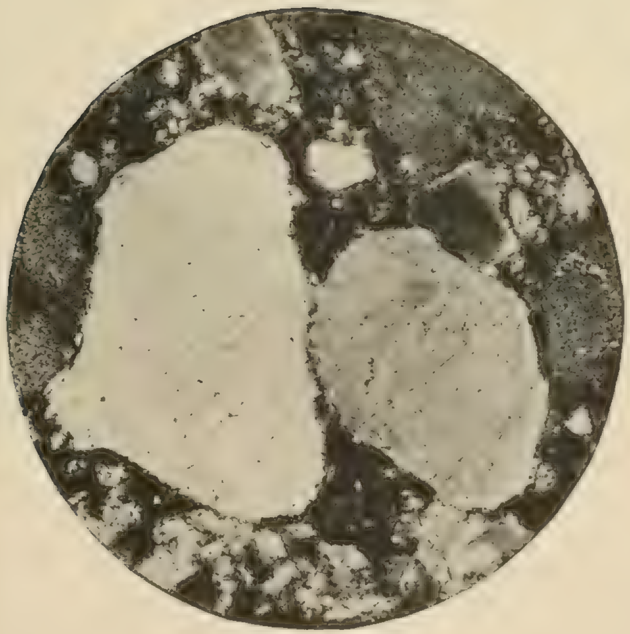


Fig. 3.—Cherty slate.

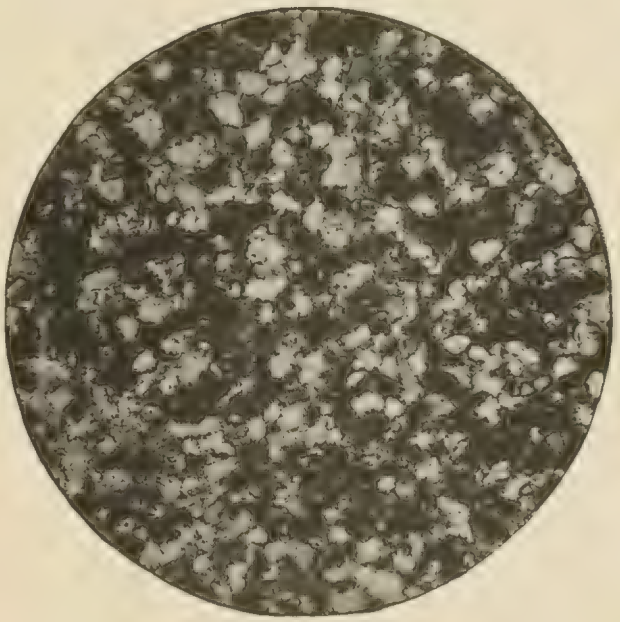


Fig. 4.—Sericitic and chloritic slate.

THIN SECTIONS FROM THE QUARTZ-SLATE MEMBER

# PLATE XIX.

## Plate XIX.—From the Quartz-Slate Member.

Fig. 1. Biotitic chlorite-slate. Specimen 9565, slide 3098. From the NW. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 60. Many small oval and angular particles of quartz are contained in a matrix consisting very largely of chlorite, with which is, however, a small amount of biotite. The angularity of the quartz-grains is very noticeable. This is in some cases due to the enlargement of the quartz-grains, but often they were thus angular when deposited. The figure has a more crystalline appearance than the section from which it was taken, from the fact that the cores of the quartzes which have undergone a second growth are not strongly marked off from the enlargements, although in thin section they are easily distinguished. (See p. 158.)

Fig. 2. Biotite-slate. Specimen 9641, slide 3154. From the NE. ¼ of Sec. 17, T. 44 N., R. 3 W., Wisconsin. In ordinary light, × 60. A few grains of quartz with general roundish forms, although now minutely angular by enlargement, are contained in a background which consists almost wholly of biotite and quartz. In the light irregular areas quartz is predominant, and elsewhere biotite. While the fragmental character of this rock is not evident in the figure, it is plain in thin section. The rock, however, is one of the most crystalline of the biotite-slates which are found in the Quartz-slate member. It is wholly possible that the irregular whitish, roundish areas now composed of quartz and mica represent original fragmental grains of feldspar. (See p. 156.)

Fig. 3. Sandstone. Specimen 9004, slide 2880. From the NW. ¼ of Sec. 27, T. 47 N., R. 47 W., Michigan. In ordinary light, × 60. Quartz in roundish and irregular fragmental grains, is the predominating constituent, although feldspar is important. The abundant interstitial material is so heavily stained with oxide of iron that it is difficult to determine what other minerals are present. (See p. 163.)

Fig. 4. Argillaceous shale. Specimen 7504, slide 1946. From the NE. ¼ of Sec. 15, T. 47 N., R. 45 W., Michigan. In ordinary light, × 60. The section shows one of the finer grained and more clayey phases of the Quartz-slate member. On one side of the figure recognizable fragments of quartz and feldspar are the chief constituents. Upon the other side extremely finely divided clayey minerals are preponderant. (See p. 167.)

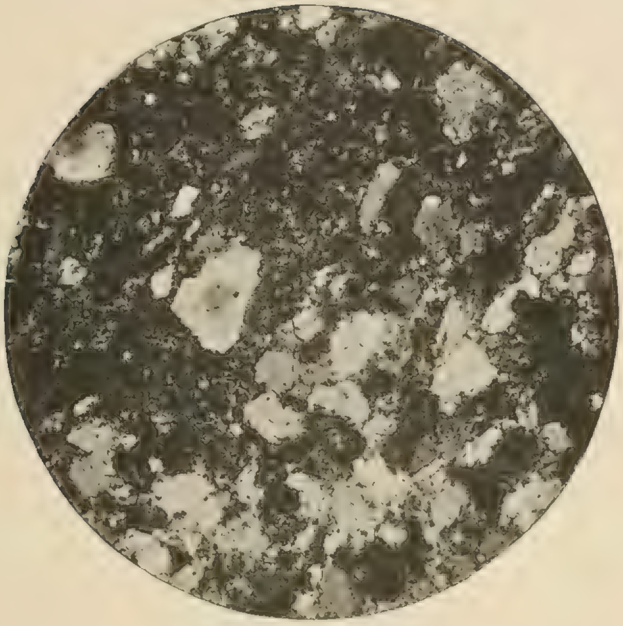


Fig 1.—Biotitic chlorite-slate.

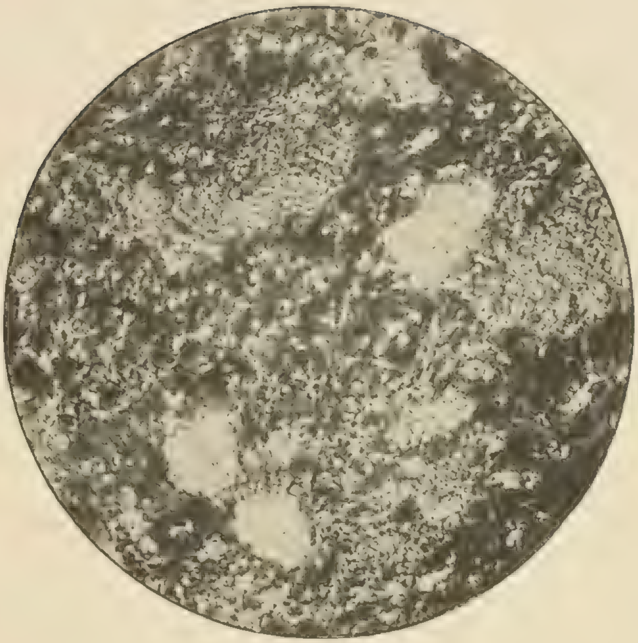


Fig. 2.—Biotite-slate.

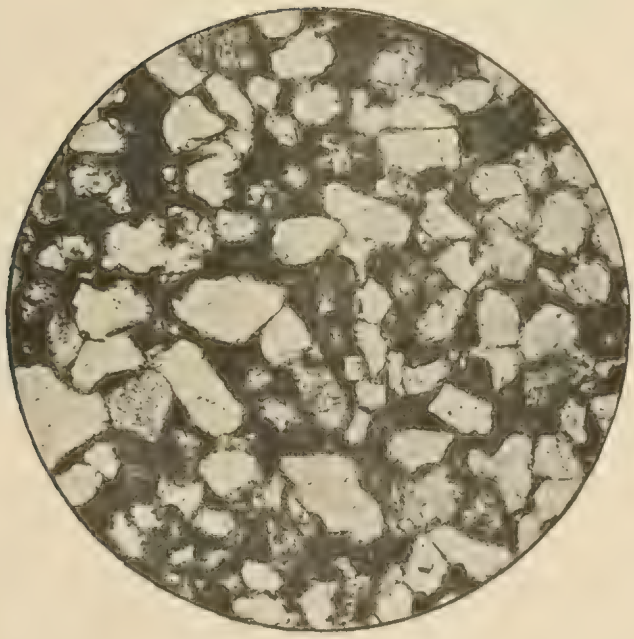


Fig 3.—Sandstone.

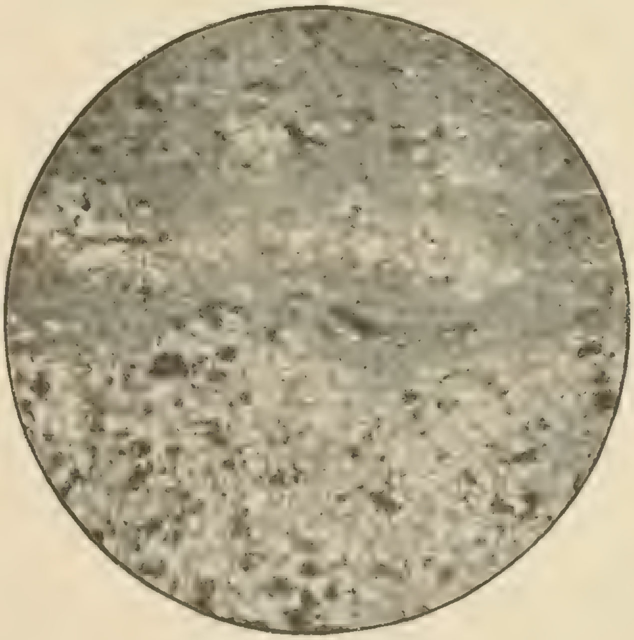


Fig. 4.—Argillaceous slate

THIN SECTIONS FROM THE QUARTZ-SLATE MEMBER

PLATE XX.

## Plate XX.—From the Upper Horizon of the Quartz-Slate Member.

Fig. 1. Quartzite. Specimen 9082, slide 2780. From the east side of Sec. 19, T. 45 N., R. 1 E., Wisconsin. In ordinary light, × 25. The rock is a vitreous quartzite, and yet the figure shows with perfect distinctness the outlines of each of the rounded grains of sand just as they were originally deposited. (See p. 160.)

Fig. 2. The same, in polarized light. The cause of the present strong and vitreous character of the quartzite is clearly shown by this figure. Each of the grains of quartz has added to itself other quartz until the grains have met and interlocked. This is a fine instance of the induration of a sandstone by simple enlargement of the original grains. (See p. 160.)

Fig. 3. Ferruginous quartzite. Specimen 9154, slide 2801. From the SW. ¼ of Sec. 27, T. 46 N., R. 2 E., Wisconsin. In polarized light, × 25. The rock is again a vitreous quartzite, which has, however, a brown color. The outlines of the original grains are distinctly seen as in Fig. 1. The color of the rock is due to the oxide of iron located in the interstices. (See p. 162.)

Fig. 4. The same, in polarized light. As in Fig. 2, each of the rounded grains of quartz has been enlarged. The interlocking of these enlargements has been interfered with by the included iron oxide, so that the rock is not so vitreous and strong as that from which Figs. 1 and 2 are taken. (See p. 162.)

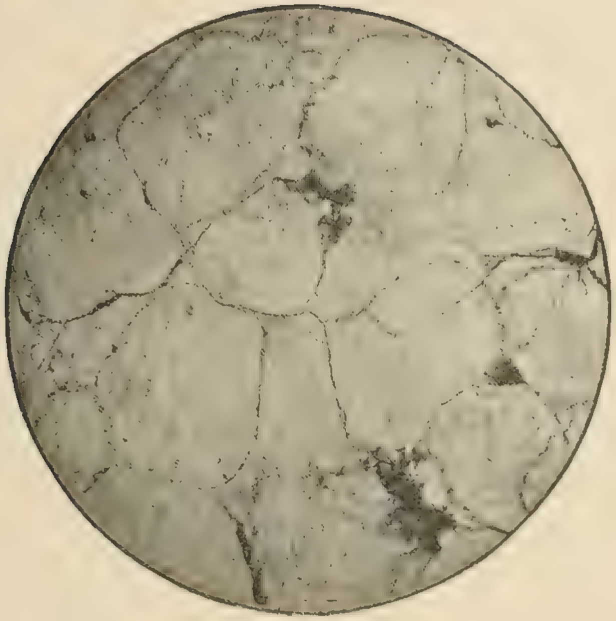


Fig. 1.—Quartzite.

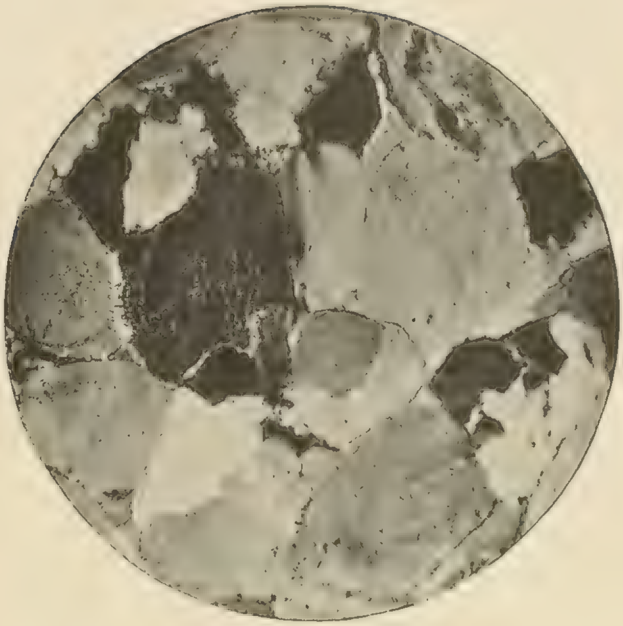


Fig. 2.—Quartzite, in polarized light.

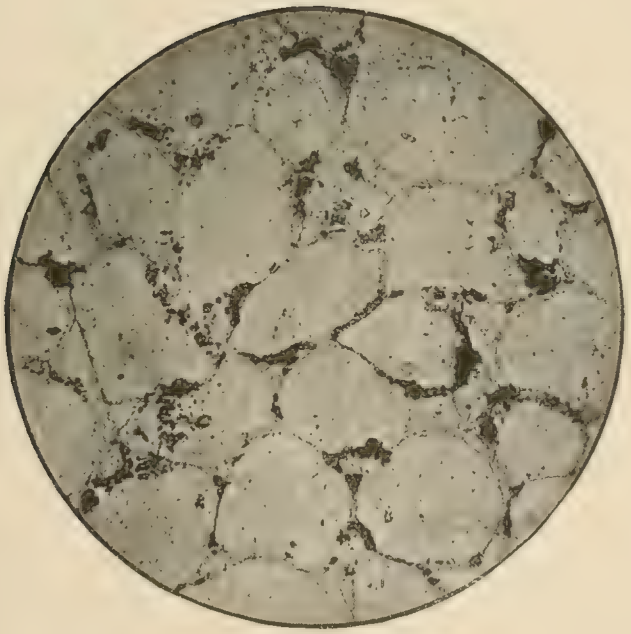


Fig. 3.—Ferruginous quartzite.

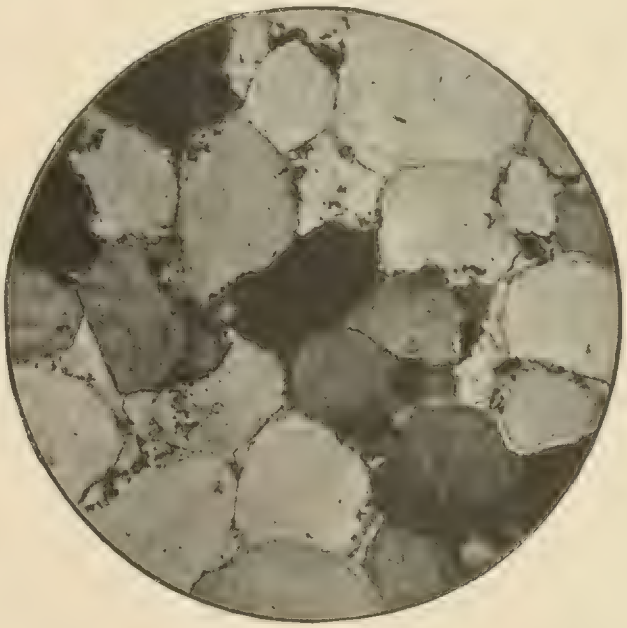


Fig. 4.—Ferruginous quartzite, in polarized light.

THIN SECTIONS FROM THE UPPER HORIZON OF THE QUARTZ-SLATE MEMBER

# PLATE XXI.

## Plate XXI.—Sideritic Rocks, from the Iron-Bearing Member and from Lawrence County, Ohio.

Fig. 1. Sideritic chert. Specimen 9814, slide 3880. "Limestone ore." Lawrence county, Ohio. In ordinary light, × 25. The section has a cherty background, which contains large oval and roughly rhombohedral areas of iron carbonate. It is introduced here in order to compare this carbonate with those of the Penokee and Animikie districts.

Fig. 2. The same, in polarized light. The fine mosaic character of the cherty background is here exhibited. The outlines of the carbonate areas become less distinct than in the previous figure.

Fig. 3. Sideritic slate. Specimen 9191, slide 2996. From the NE. ¼ Sec. 6, T. 45 N., R. 2 E., Wisconsin. In ordinary light, × 60. The section is cut transversely to the lamination of the rock. The hand specimen is very thinly and regularly laminated. The laminae are seen to be somewhat irregular. The obscure dark and light portions are both iron carbonate, which differ chiefly in the inclusions which they contain. The minute white particles are chert and amorphous silica. (See p. 237.)

Fig. 4. Sideritic and ferruginous chert. Specimen 9474, slide 3082. From Sec. 13, T. 47 N., R. 46 W., Michigan. In ordinary light, × 60. The section shows the alteration of iron carbonate into iron oxide. The background is chert. Upon one side of the figure are rhombohedra of little altered siderite. Upon the other are black pseudomorphous areas which are composed of somewhat hydrated hematite. Between the two are gradation phases. (See p. 237.)

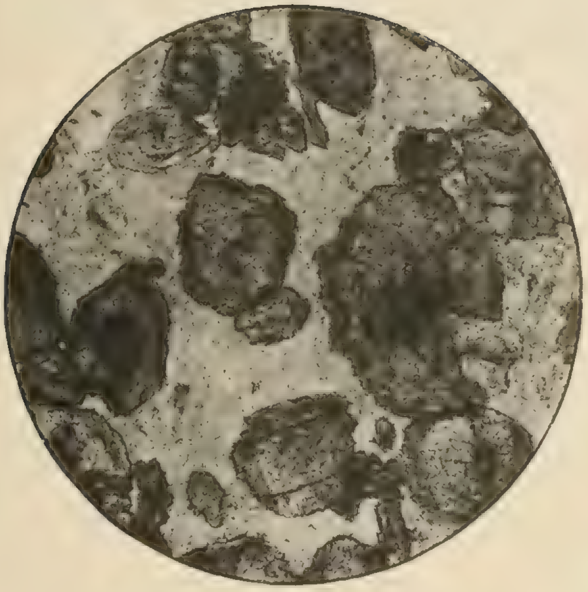


Fig. 1.—Sideritic chert.

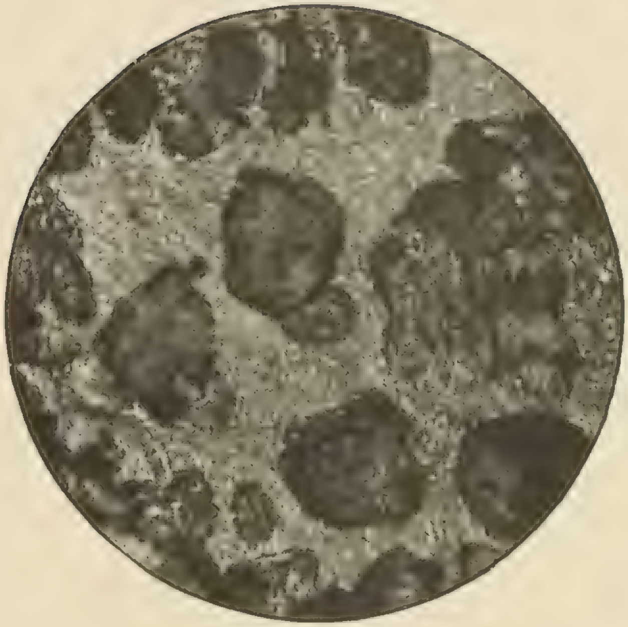


Fig. 2.—Sideritic chert, in polarized light

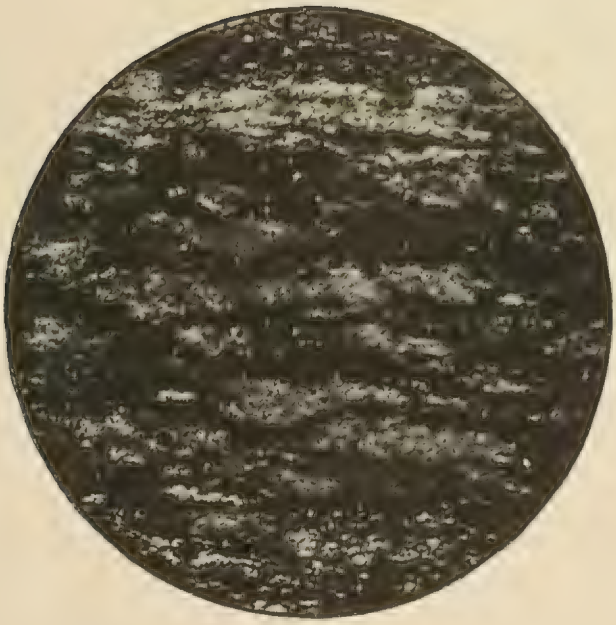


Fig. 3.—Sideritic slate.

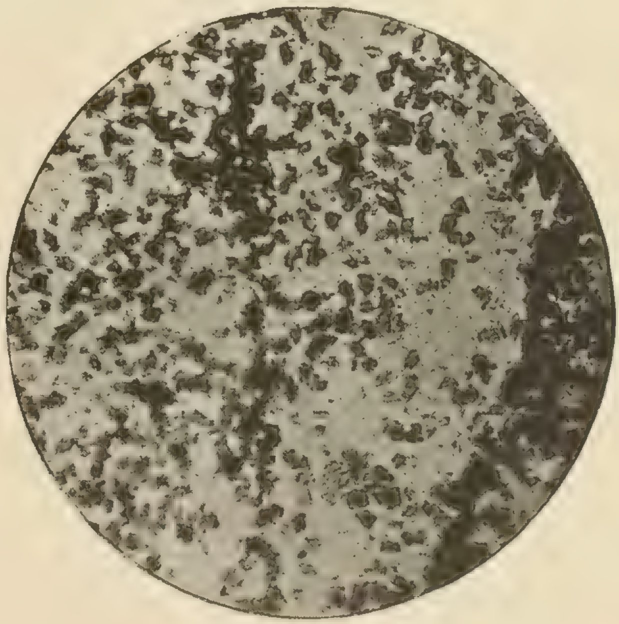


Fig. 4.—Sideritic and ferruginous chert

THIN SECTIONS OF SIDERITIC ROCKS FROM THE IRON-BEARING MEMBER AND FROM LAWRENCE COUNTY, OHIO.

# PLATE XXII.

## PLATE XXII.—FERRUGINOUS CHERTS FROM THE IRON-BEARING MEMBER.

FIG. 1. Concretionary chert. Specimen 9048, slide 2886. From the SE. ¼ Sec. 27, T. 46 N., R. 2 E., Wisconsin. In ordinary light, × 25. In a cherty background are beautiful concretions, which are composed of concentric rings of iron oxide and chert. One concretion particularly is very fine, showing many closely packed concentric rings. Silica is seen breaking across these rings in a few places. (See pp. 227–228.)

FIG. 2. The same, in polarized light. Here the cherty background appears as a fine mosaic. The quartz in and about the concretions is more coarsely crystalline than the average of that in the matrix. One concretion has as a nucleus comparatively closely crystalline quartz. This variation in the character of the silica is suggestive that the fine spotty silica is perhaps original. The concretions, as shown by subsequent plates, have been produced from iron carbonate, and as the iron oxide formed from the carbonate, the remaining space was occupied by silica, which crystallized in larger particles than the supposed original silica. (See pp. 227–228.)

FIG. 3. Brecciated chert. Specimen 7622, slide 2072. From the Montreal river, between Michigan and Wisconsin. In polarized light, × 25. The background is again cherty, and contains within it many small, rather perfect rhombohedra of siderite, which have altered to a greater or less degree to iron oxide. Contained in this groundmass are irregular areas which do not have a concretionary structure, but appear to be true fragments in this matrix. One of the areas is severed in every direction by numerous ramifying veinlets of silica. The same thing is to a less degree noticeable of others of these areas. That this cutting silica is secondary can hardly be doubted. (See pp. 230–231.)

FIG. 4. Ferruginous and brecciated chert. From the same locality as the last. In polarized light, × 25. The background is chert, as in the previous figure. In this background are found perfect concretions and brecciated areas. One of the latter shows plainly its fragmental character. It is built up of laminæ which are approximately parallel and have evidently been broken from a regularly laminated rock and here deposited. In this figure and the previous one we have clearly a mingling of fragmental and nonfragmental material, the fragmental portion of which is possibly derived from the immediately underlying iron-bearing beds. (See pp. 230–231.)

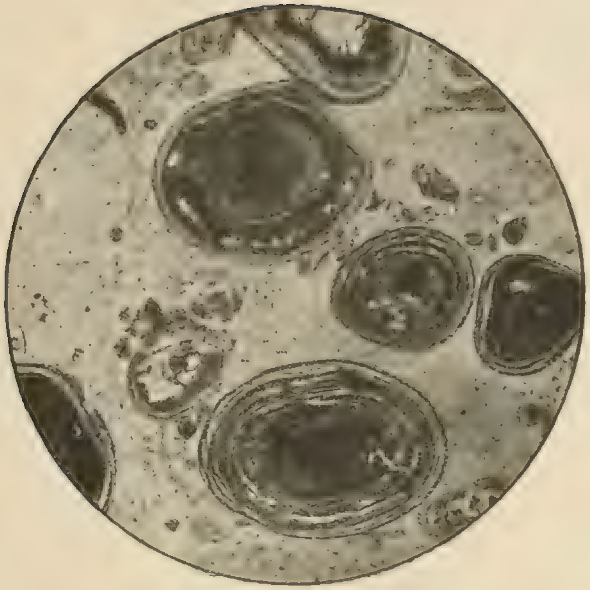


Fig. 1.—Concretionary chert.

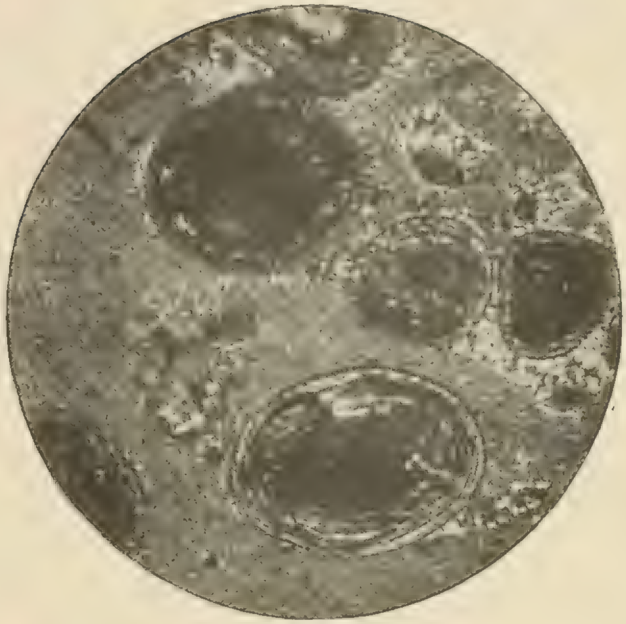


Fig. 2.—Concretionary chert, in polarized light.

Fig 3.—ceraecd trBchert.

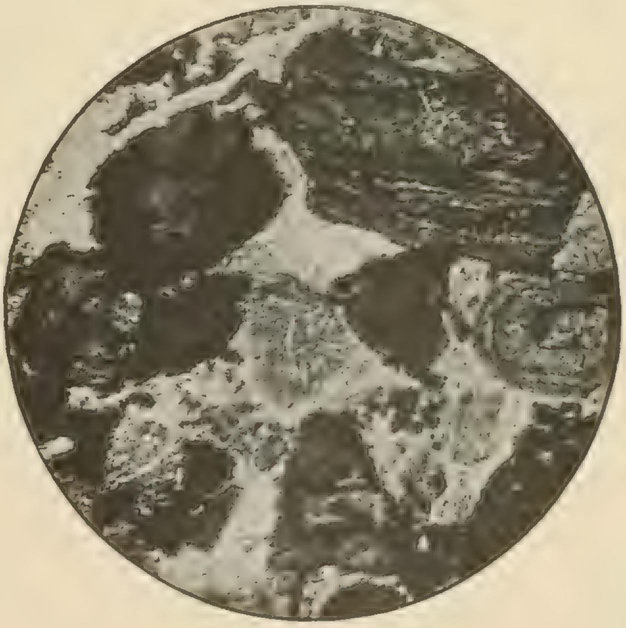


Fig. 4.—Ferruginous and brecciated chert

THIN SECTIONS OF FERRUGINOUS CHERTS FROM THE IRON-BEARING MEMBER

# PLATE XXIII.

## Plate XXIII.—Ferruginous Cherts and Actinolite Slates from the Iron-Bearing Member.

Fig. 1. Ferruginous chert. Specimen 9081, slide 4206. From the SE. ¼ of Sec. 24, T. 45 N., R. 1 W., Wisconsin. In ordinary light, × 25. The cherty background contains areas which are in part roughly oval or roundish, but are more largely exceedingly irregular. These areas are composed of quartz and iron oxide, the latter being mostly hematite, the remainder magnetite. The regular areas suggest concretions, the history of which has been given. The irregular areas resemble fragments, but are probably of chemical and dynamic origin and have formed within the rock itself. They doubtless represent original iron carbonate areas. This carbonate has largely changed to oxide, but has also to some extent been leached out, thus leaving cavities. After or before the completion of this process silica has entered and filled the cracks and cavities. The result of this oxidation, solution, and silicification, combined with movement, has been to put in the place of well defined areas of iron carbonate the exceedingly irregular forms presented by the figure. (See p. 223).

Fig. 2. The same, in polarized light. The relations just mentioned are here again observed. It is further seen that the background, instead of being finely spotty and perhaps partly amorphous, as in the previous plate, is completely crystalline. That there has been an extensive rearrangement and entrance of silica, is shown, even more plainly than in the previous figure. (See p. 223.)

Fig. 3. Actinolitic schist. Specimen 9555, slide 3190. From Penokee gap; NW. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin. In ordinary light, × 25. A quartzose background contains very numerous minute needles of actinolite and many particles of magnetite, the latter being roughly concentrated into bands, one of which with a part of another is shown in the figure. The figure represents a typical rock of this kind. (See pp. 218–219).

Fig. 4. The same, in polarized light. The completely crystalline character of the quartzose background appears, and the intricate manner in which this material is cut by needles of actinolite is perceived by comparing this figure with the preceding. (See pp. 218–219).

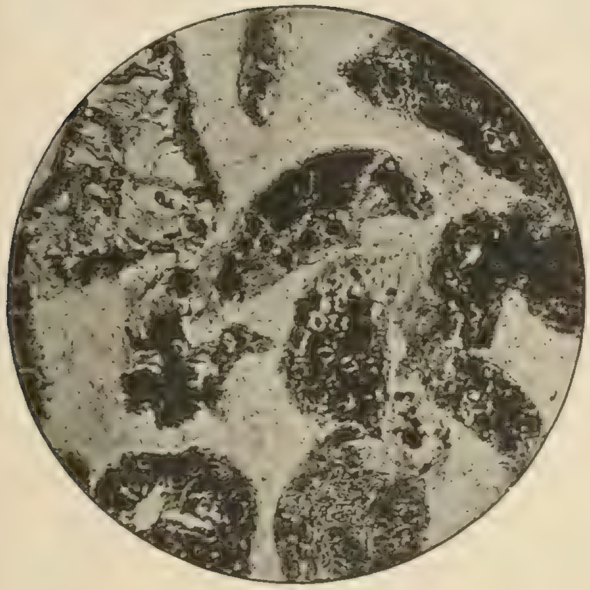


Fig. 1.—Ferruginous chert.

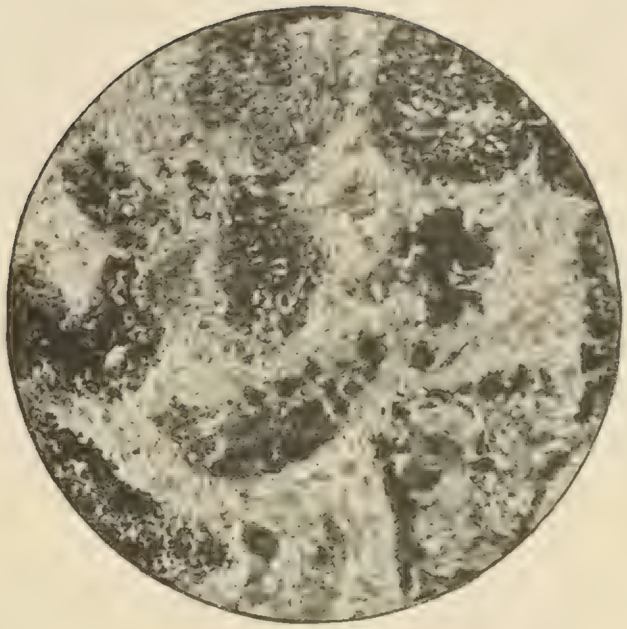


Fig. 2.—Ferruginous chert, in polarized light.

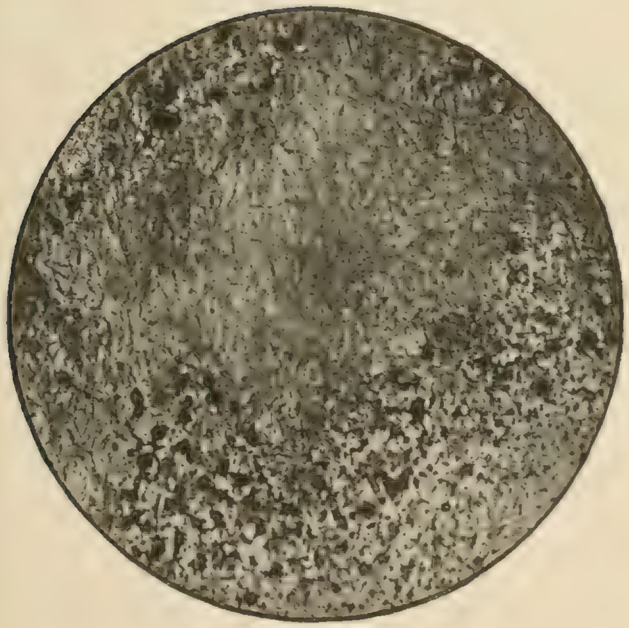


Fig. 3.—Actinolitic schist.

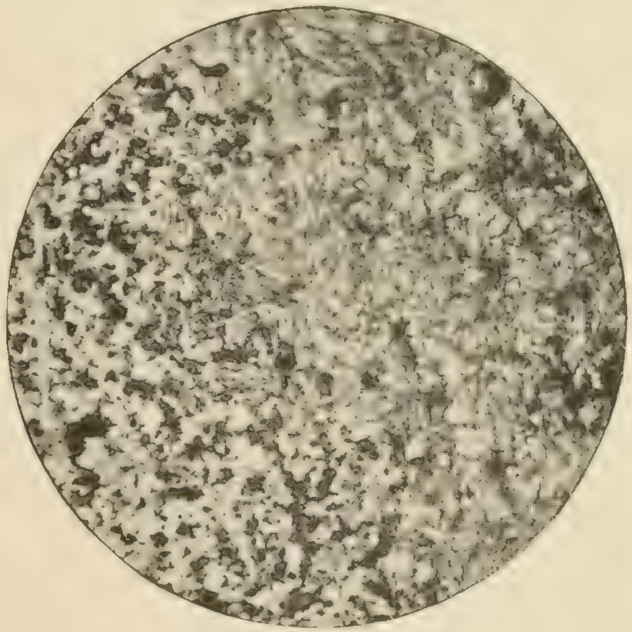


Fig. 4.—Actinolitic schist, in polarized light.

THIN SECTIONS OF FERRUGINOUS CHERTS AND ACTINOLITIC SLATES FROM THE IRON-BEARING MEMBER.

PLATE XXIV.

## Plate XXIV.—Actinolite Slates from the Iron-Bearing Member of the Penokee Series and Cherty Iron Carbonates from the Vermilion Series.

Fig. 1. Actinolite-magnetite-schist. Specimen 9558, slide 3191. From Penokee gap; NW. ¼ of Sec. 14, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 25. Magnetite and quartz are the most abundant constituents, but minute needles of actinolite are seen radiating from the magnetite areas. The rock is a regularly banded one, and while this is not strongly marked in the thin section its distinct lamination is apparent. The rhombic form of many of the magnetite areas is seen. These probably represent sections of octahedra. (See p. 218.)

Fig. 2. Actinolitic slate. Specimen 9680, slide 3167. From the SE. ¼ of Sec. 20, T. 44 N., R. 5 W., Wisconsin. In polarized light, × 25. This is an actinolitic slate in which the concretionary arrangement of the various constituents is shown. The close association of actinolite and magnetite is apparent, the minute actinolite needles frequently radiating from the magnetite particles. The actinolite is manifestly prior to the quartz in crystallization, as the individuals of the latter are penetrated in every direction by the actinolite needles. This figure is particularly noticeable on account of the very coarsely crystalline character of the quartzose background. It runs between the concretions in such a manner as to make it evident that it must have crystallized subsequent to their formation. We have here, then, an illustration of the complete rearrangement of the silica originally present and the probable introduction of a good deal of silica from an extraneous source. (See p. 216.)

Fig. 3. Cherty iron carbonate. Specimen 8726, slide 3367. From Vermilion lake, Minnesota. In ordinary light, × 25. This shows very finely the alternation of bands of chert and iron carbonate. The darker belts are nearly pure siderite, and the lighter ones almost pure chert. The cherty belts are seen to contain minute rhombohedra of carbonate, and they cut across the carbonate belts in such a manner as to imply a rearrangement of silica originally present and the introduction of additional silica, or both. The figure is here introduced in order that the cherty carbonates of other districts may be compared with those from the Penokee series. (See p. 260.)

Fig. 4. The same, in polarized light, × 50. It is seen that the cherty background is completely crystallized; that is, contains no amorphous material and is made up wholly of quartz. The intricate manner in which the quartz anastomoses, cutting the iron carbonate, shows conclusively that to some extent it is later than the siderite, while it has probably been extensively rearranged. (See p. 260.)

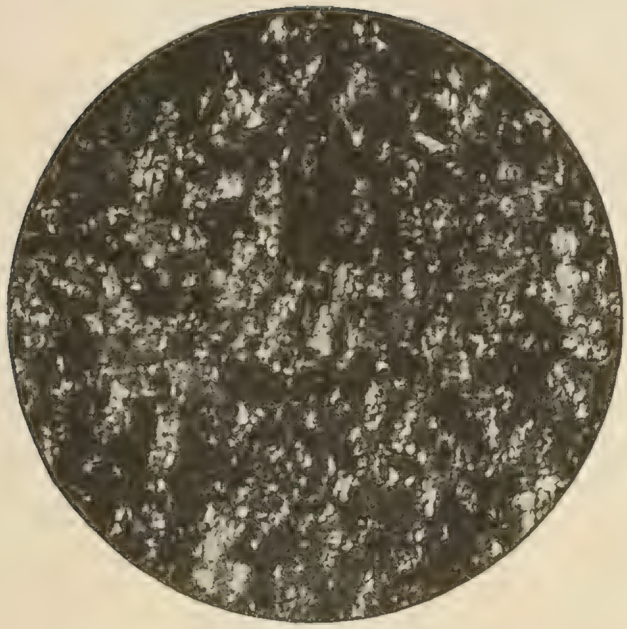


Fig. 1.—Actinolite-magnetite schist.

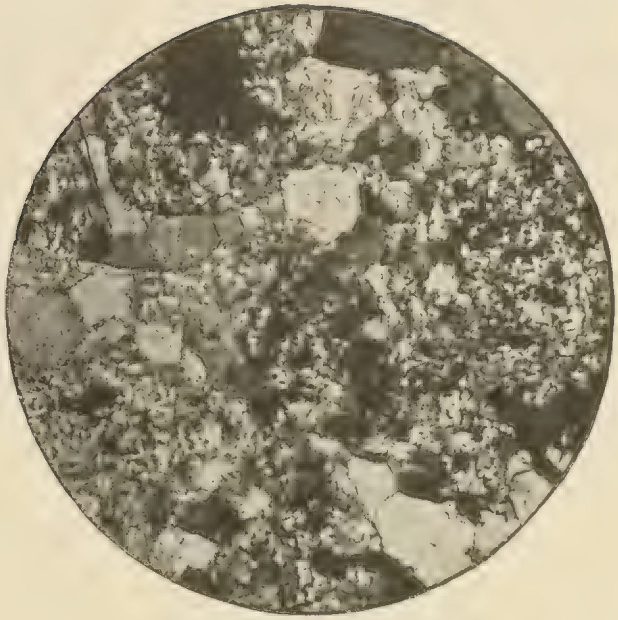


Fig. 2.—Actinolitic slate.

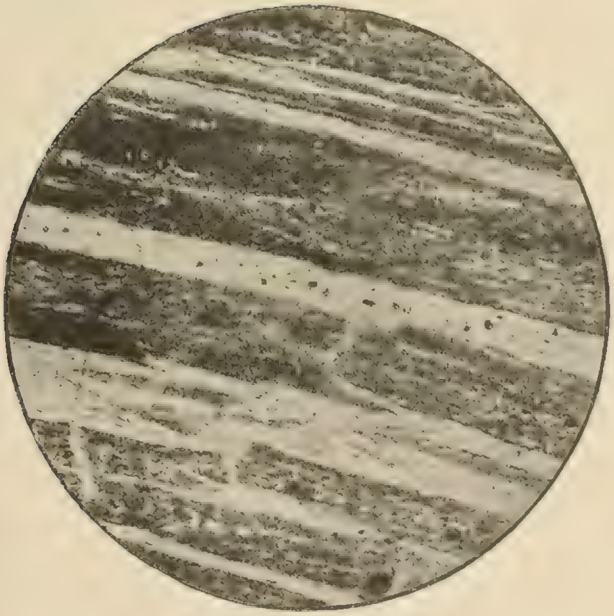


Fig. 3.—Cherty iron carbonate.

Fig. 4.—Cherty iron carbonate, in polarized light

THIN SECTIONS OF THE ACTINOLITIC SLATES FROM THE IRON-BEARING MEMBER OF THE PENOKEE SERIES, AND CHERTY IRON CARBONATES FROM THE VERMILLION SERIES.

PLATE XXV.

## Plate XXV.—Sideritic Slates from the Animikie Series.

Fig. 1. Cherty iron carbonate. Specimen 10172, slide 3422. From Dawson's road, Port Arthur, Canada; Animikie series. In ordinary light, × 60. The figure well illustrates the appearance of one of the richer Animikie cherty carbonates. Throughout most of the section iron carbonate is the chief constituent, and the manner in which the individuals are packed together is well shown; when surrounded by chert they show perfect rhombohedral forms. Alteration of iron carbonate to iron oxide has begun. (See p. 264.)

Fig. 2. Sideritic chert. Specimen 6138, slide 1173. From north shore of Gunflint lake, T. 65 N., R. 3 W., Minnesota; Animikie series. In ordinary light, × 25. The figure illustrates the formation of iron oxides, pseudomorphous after siderite. A background of chert contains numerous small roundish and rhombohedral areas of siderite and iron oxide. Between the little altered and wholly altered siderite a complete gradation is seen. (See p. 264.)

Fig. 3. Actinolite-siderite-slate. Specimen 10579, slide 5188. From the east side of north arm of Gunflint lake, Minnesota; Animikie series. In ordinary light, × 25. This section is from one of the typical Animikie slates. The thinly laminated character of the rock is well shown. Its background consists in about equal proportions of actinolite and siderite, mingled with a little chert. The dark colored material comprises all three of the oxides of iron. (See p. 263.)

Fig. 4. The same, in polarized light, × 25. The figure is from another part of the section, which shows the termination of a thick layer of nearly pure chert. Such lozenge-shaped cherty areas within the Animikie slates are very common and are frequently of large size. In the cherty background are seen rhombic outlines of siderite. The light colored border between the slaty laminæ and the chert is mostly actinolite. This relation is suggestive that the actinolite has resulted from a reaction between the silica and siderite. The laminæ of the slate are seen to curve about the chert area. A short distance from this nodule the laminæ are parallel, as represented in the previous figure. (See pp. 263, 265.)

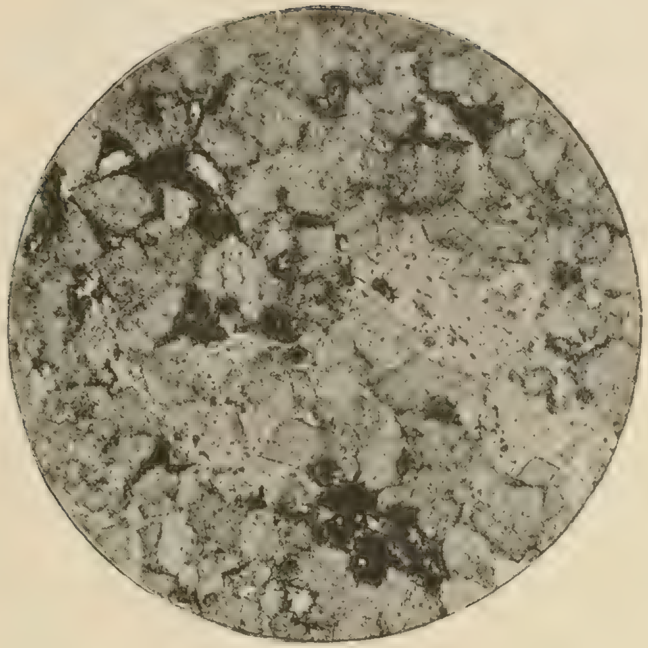


Fig. 1.—Cherty iron carbonate.

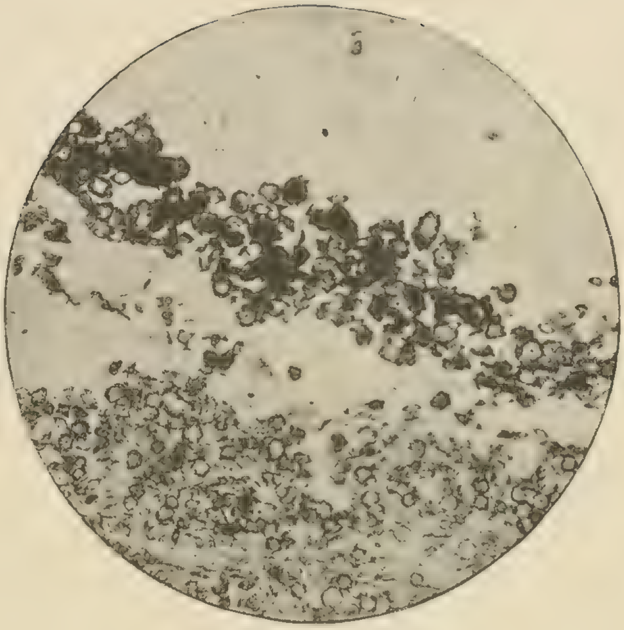


Fig. 2.—Sideritic chert.

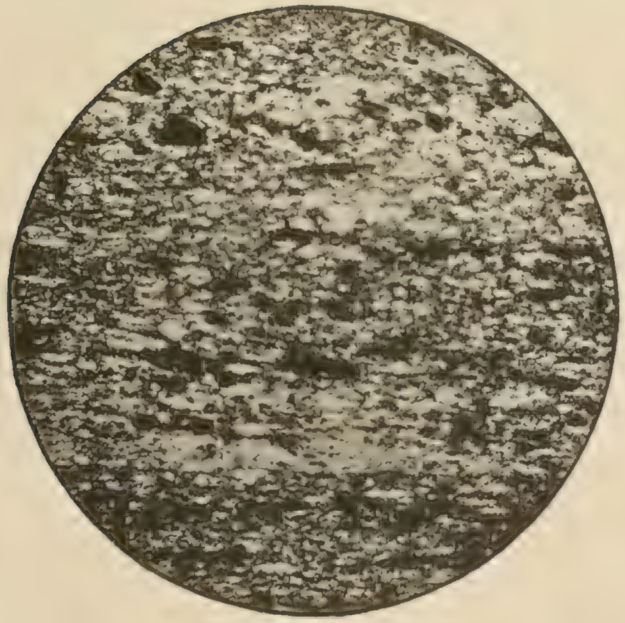


Fig. 3.—Actinolite-siderite slate.

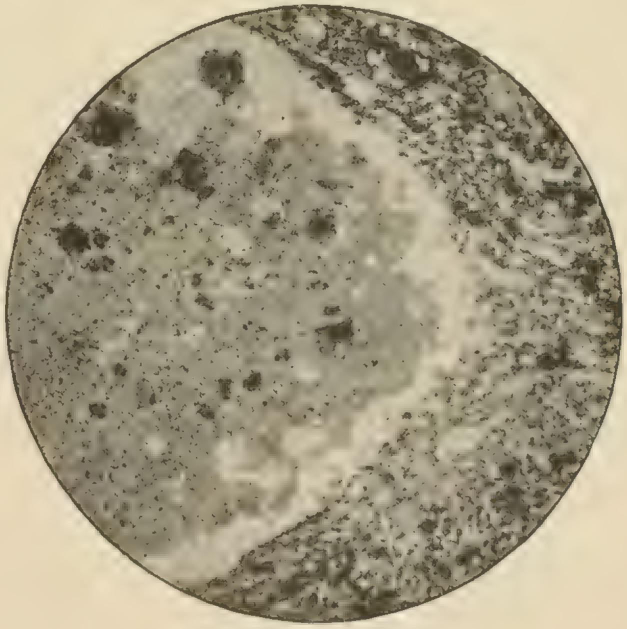


Fig. 4.—Actinolite-siderite slate, in polarized light.

THIN SECTIONS OF SIDERITIC SLATES FROM THE ANIMIKIE SERIES.

PLATE XXVI.

## Plate XXVI.—Ferruginous Cherts and Iron Carbonates from the Animikie Series.

Fig. 1. Concretionary chert. Specimen 10577, slide 4997. From north side Gunflint lake; Animikie series. In ordinary light, × 25. The complex concretionary structure so characteristic of the ferruginous cherts is here beautifully shown. The concretions are closely packed together, the amount of material between them being relatively small. This interstitial substance is chiefly chert, but it contains numerous rhombohedra of siderite. The oxides of iron are mostly limonite and hematite, but with them is mingled some magnetite. The arrangement of these iron oxides with reference to one another is usually somewhat irregular, but occasionally the magnetite and hematite are in alternate layers. (See p. 264.)

Fig. 2. The same, in polarized light, × 60. Another part of the same section is here shown, the enlargement being greater. One of the concretions is seen to be compound; that is, the larger belts of iron oxides inclose two smaller concretions. Within the concretions the quartz, like the iron oxide, is seen to have a banded arrangement. The background is very finely crystalline, but the silica is mostly or wholly individualized. (See p. 264.)

Fig. 3. Ferruginous chert. Specimen 10576, slide 5186. From the Gunflint beds. In ordinary light, × 25. The section illustrates the sharp alterations which sometimes occur between fine grained evenly laminated cherty carbonate and ferruginous chert, with a well developed concretionary structure. The fine grained part is composed of exceedingly crystalline and amorphous silica, and of siderite in minute rhombohedra. In the concretionary part of the section no carbonate remains. Within the concretions the quartz is somewhat coarsely crystallized. (See p. 264.)

Fig. 4. Sideritic chert. Specimen 6138, slide 1173. Also from the Gunflint beds. In polarized light, × 25. The semiamorphous and chalcedonic phases of silica which are found in the ferruginous rocks are nicely shown. The darker colored part of the figure consists chiefly of siderite and iron oxide, pseudomorphous after it. (See p. 264.)

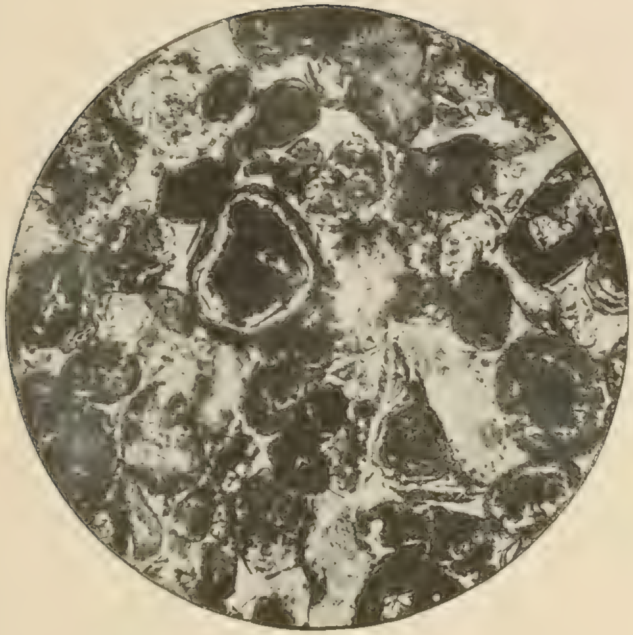


Fig. 1.—Concretionary chert.

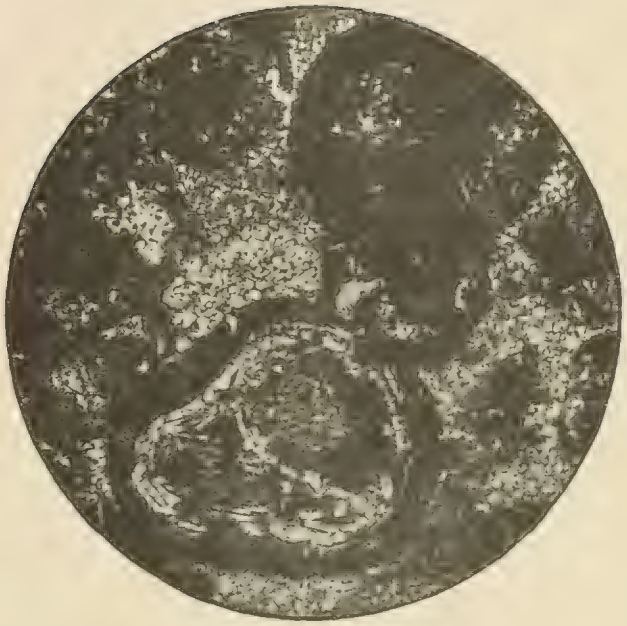


Fig. 2.—Concretionary chert, in pola

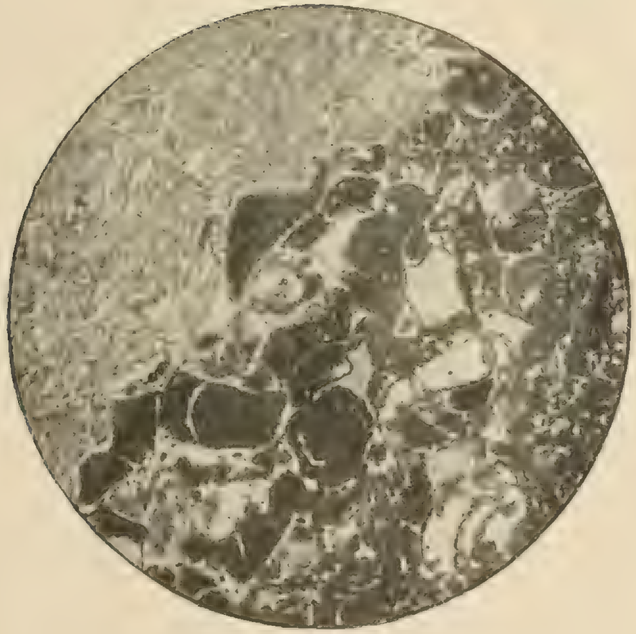


Fig. 3.—Ferruginous chert.

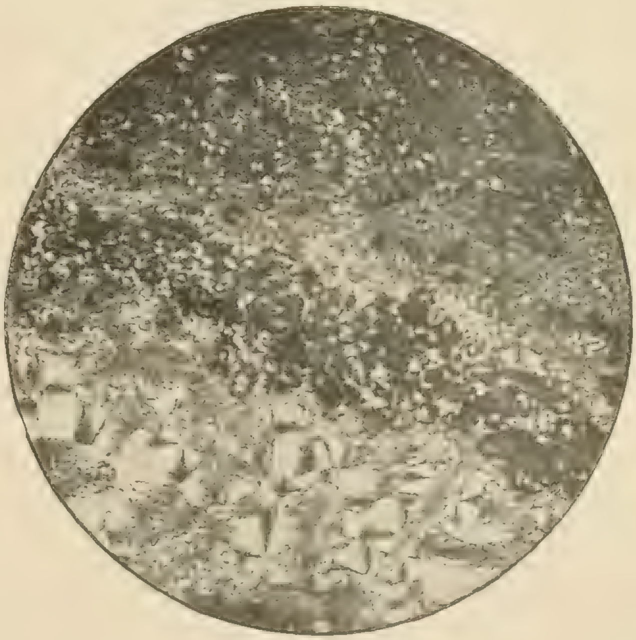


Fig. 4.—Sideritic chert.

THIN SECTIONS OF FERRUGINOUS CHERTS AND IRON CARBONATES FROM THE ANIMIKIE SERIES

PLATE XXVII.

## Plate XXVII.—Formation of Concretions in Iron-Bearing Member.

Fig. 1. Sideritic chert. Specimen 12508, slide 5522. From Sec. 16, T. 47 N., R. 46 W., Michigan. In ordinary light, × 25. A cherty background contains numerous roundish and rhombohedral areas of siderite. This siderite has begun to alter to opaque black oxide of iron. In places in the section this alteration has gone far, and roundish forms are produced which are imitative of the shape taken by the original carbonate, although to a considerable extent this carbonate has been replaced in its alteration by silica. (See p. 232.)

Fig. 2. Sideritic chert. Specimen 7622, slide 2072. From the Montreal river, between Wisconsin and Michigan. In ordinary light, × 25. A background of chert contains numerous rhombohedra of siderite of greatly varying sizes. The siderite has altered to a considerable extent to oxide of iron, and illustrates the formation of concretions as in the previous figure, but the stage of growth is more advanced. In one case a nearly solid oval area of oxide of iron has been produced by the alteration of one of siderite. In several other areas the oxide of iron forms a ring about the siderite inclosed. In still others the oxide of iron, while it is scattered somewhat irregularly through the areas, as a whole retains the form of the original siderite areas, although the space once occupied by the siderite is taken in part by silica. In the large complex concretion the series of alteration thus illustrated has been completed. It contains at present no siderite, but consists of a series of concentric rings of iron oxide which have a siliceous background. This concretion is cut by a vein of silica, as are also three other areas on one side of the figure. These veinlets have clearly formed after the development of the concretionary areas. (See pp. 230–231).

Fig. 3. Another part of the same section, × 25. The figure again illustrates the formation of concretions of iron oxide from original siderite areas. This concretionary arrangement of the iron oxide is shown in nearly all of the siderite individuals, but is shown in a particularly fine manner by the large area in the middle of the figure. Enough siderite remains so that its rhombohedral cleavage is nicely shown. Upon the outer part of the area is a tolerably continuous ring of black oxide of iron, beyond which are other imperfect larger rings of red and black oxides of iron. The alteration in the interior of the area has to some extent followed the cleavage lines, and we thus have an explanation of the irregular forms in the interiors of the concretions of the previous figures. It is to be further noted that the forms of the rings in the concretions do not conform to those of the original siderite area, but form regular ovals. (See pp. 230–231.)

Fig. 4. Ferruginous chert. Specimen 9009, slide 2765. From the same exposure as Figs. 2 and 3. In ordinary light, × 25. This figure illustrates the result of an almost complete oxidation of the siderite areas, only a trace of that mineral remaining. The whole space that it once occupied is taken by reddish brown hematite and a small amount of silica. The greenish areas are probably chlorite. (See pp. 228–230.)

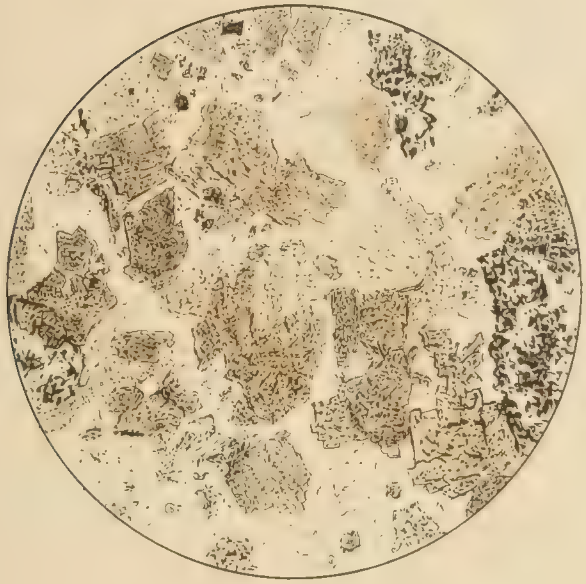


Fig. 1

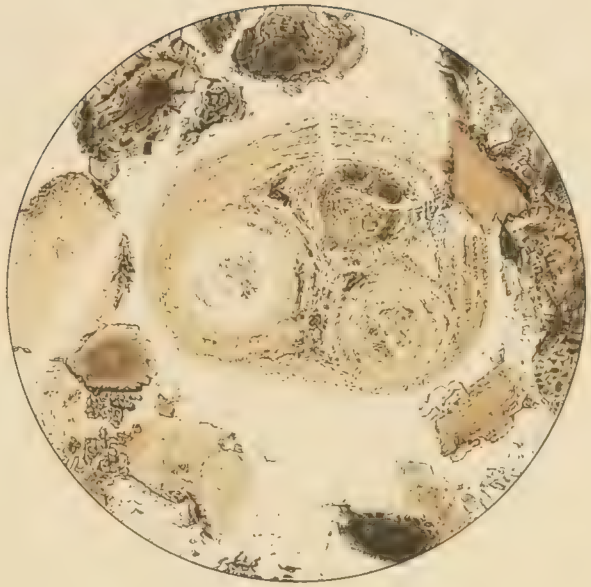


Fig 2

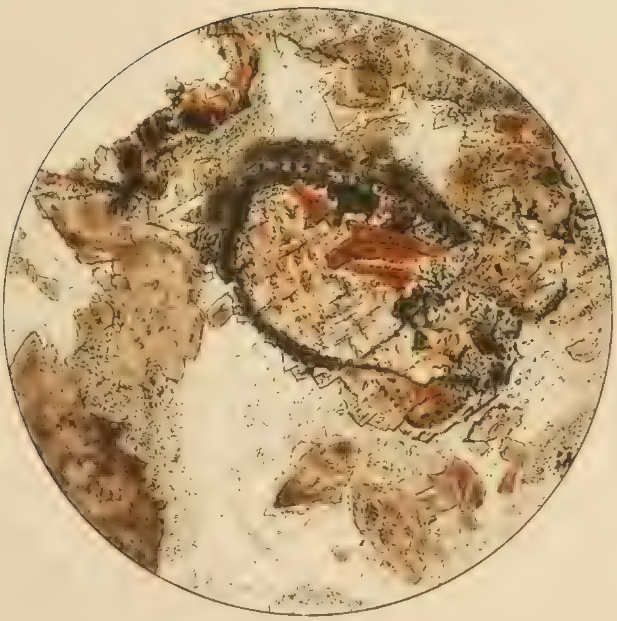


Fig. 3.

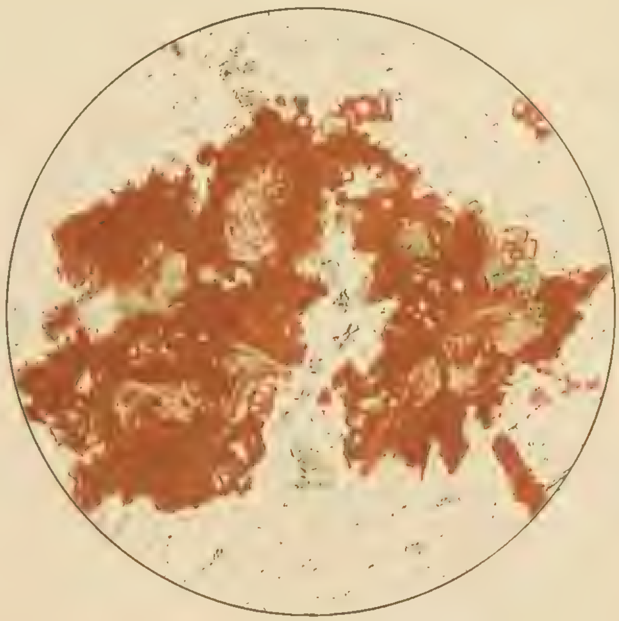


Fig. 4.

THIN SECTIONS SHOWING FORMATION OF CONCRETIONS IN IRON-BEARING MEMBERS.

# PLATE XXVIII.

## Plate XXVIII.—Magnetitic and Actinolitic Slates from the Iron-Bearing Member.

Fig. 1. Actinolitic slate. Specimen 9620, slide 3147. From Tylers fork, NE. ¼ of Sec. 33, T. 45 N., R. 1 W., Wisconsin. In ordinary light, × 165. The figure shows the rhombohedral shape of a complex area of actinolite and magnetite and the close association of these minerals. The exterior of the area in the center of the figure is mostly magnetite, mingled, however, with some actinolite, while the interior is pure actinolite. That this area represents an original rhombohedron of iron carbonate is very probable. (See pp. 220–221.)

Fig. 2. Magnetitic concretionary chert. Specimen 9625, slide 3150. From Tylers fork, NE. ¼ of Sec. 33, T. 45 N., R. 1 W., Wisconsin. In ordinary light, × 60. A cherty background contains roundish, oval, and roughly rhombic outlined areas. The iron oxide in these areas is mostly magnetite, in the form of crystals. The magnetite is often concentrated upon the exteriors of the areas, projecting somewhat into the cherty background. The forms of the areas at once suggest the carbonate areas of Pl. xxi, Figs. 1 and 2, and Pl. xxvii, Fig. 1, and each doubtless now occupies the place once taken by siderite. In the alteration to magnetite the individuals grew beyond the outer borders of the siderite areas, but the forms as a whole were maintained. A considerable amount of silica must have entered, as the magnetite occupies but a small part of the space once taken by the carbonate. (See pp. 222–223.)

Fig. 3. Banded magnetitic jasper. Specimen 12791, slide 5477. From Sec. 11, T. 47 N., R. 45 W., Michigan. In ordinary light, × 25. The white background is a completely individualized but finely crystalline chert. The part containing the abundant red hematite is in hand specimen a brilliant red jasper. These jaspery bands alternate with the black ones, which, instead of hematite, consist of magnetite, mostly in well defined crystals. The change from magnetite to hematite is gradual. (See pp 239–240.)

Fig. 4. Actinolitic slate. Specimen 9555, slide 3190. From Penokee gap, NW. ¼ of Sec. 11, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 165. The section is a typical actinolitic slate. The quartz is completely crystallized. The magnetite has mostly well defined crystal outlines and is manifestly the first mineral to crystallize, being scattered uniformly through the section without any regard to the actinolite and quartz, and therefore included by both of them. The actinolite is in its characteristic blades and sheaf-like forms, having a radial arrangement of its fibers. It is as plainly the second mineral to crystallize, as needles of actinolite everywhere penetrate the quartz, but never the magnetite. The quartz constitutes a background for the magnetite and actinolite, and includes them in such a manner as to make the conclusion certain that it must in the main have crystallized subsequently to the formation of the magnetite and actinolite. (See pp. 218–219).

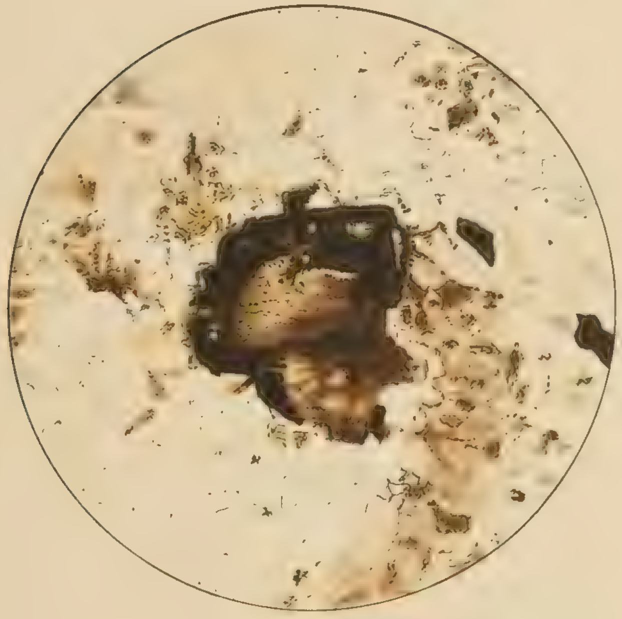


Fig. 1

Fig 2.

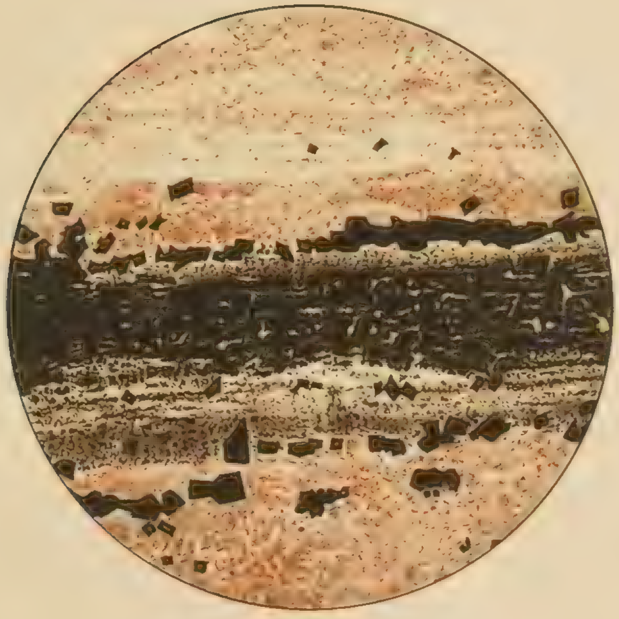


Fig 3.

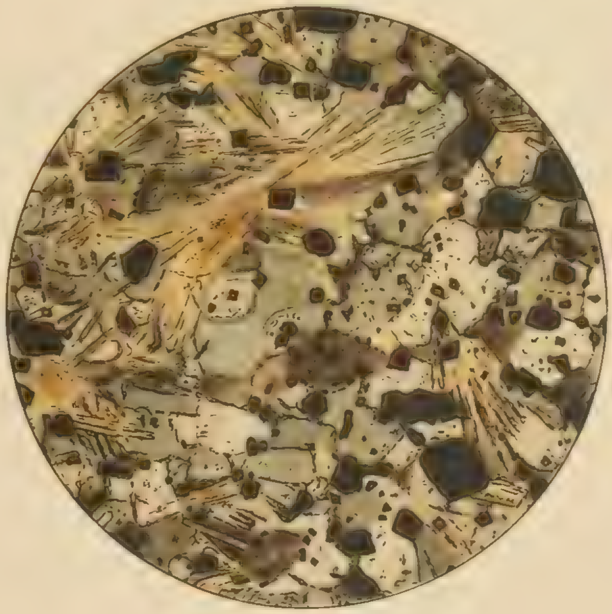


Fig 4

THIN SECTIONS OF MAGNETITIC AND ACTINOLITIC SLATES FROM IRON-BEARING MEMBER.

# PLATE XXIX.

## Plate XXIX.—From the Iron-Formation of the Animikie Series and from Lawrence County, Ohio.

Fig. 1. Concretionary chert. Specimen 10577, slide 4997. From north side Gunflint lake; Animikie series. In ordinary light, × 60. The photographs, Figs. 1 and 2, Pl. xxvi, are reproductions from the same section as this figure. It is drawn, however, to show more exactly the relations of the various oxides of iron to the cherty background. In the first place veins of chert intricately intersect the oxides of iron in such a manner as to show that the silica entered after the iron oxides had formed. The magnetite in the concretions is sometimes in nearly continuous bands, but in other parts is mingled intimately with the hematite. If the large area takes the place of one of iron carbonate, at different times the circumstances were favorable for the production of each of the iron oxides in preponderating quantity. (See pp. 265–266.)

Fig. 2. Actinolitic slate. Specimen 7012, slide 2081. From the SW. ¼ of Sec. 23, T. 65 N., R. 4 W., Minnesota; Animikie series. In ordinary light, × 25. The relations of the magnetite, actinolite, and quartz are here nicely shown. The magnetite is plainly the first mineral to crystallize, frequently having crystal outlines, and being included within both the other minerals. The close association of actinolite and magnetite is again illustrated, the two combined having usually roundish or oval forms. The silica cuts the section in such a manner as to give it in places vein-like forms, which must have developed subsequently to the formation of the magnetite and actinolite. (See p. 266.)

Fig. 3. Actinolitic and sideritic slate. Specimen 10580, slide 5189. From the Gunflint beds; Animikie series. In ordinary light, × 60. The section illustrates a phase of the iron formation in which all of the minerals, quartz, siderite, magetite, and actinolite are together. The colorless part is the cherty background, which is completely, although finely crystallized. The siderite is represented by the vague rhombohedral areas, which include numerous minute particles of gray and black material, presumably oxides of iron. This mineral is the most abundant one in the section. The magnetite occurs as usual with its characteristic crystal outlines, and in places is included in such a manner in the siderite as to suggest its formation from that mineral. The actinolite is scattered here and there in minute blades and needles, being particularly abundant upon one side of the figure. (See p. 265.)

Fig. 4. Cherty iron carbonate. Specimen 9814, slide 3880. From Lawrence county, Ohio. In ordinary light, × 25. The photographic Figs. 1 and 2, Pl. xxi, are from this section. The beginning of the alteration of siderite to limonite and hematite, and also the beginning of the formation of concretions, are here better seen. The background is finely crystalline and amorphous silica, the nature of which is better shown by the figures referred to. This cherty iron carbonate from Ohio is remarkably like that from the Penokee series shown in Pl. xxvii, Figs. 1 and 3, the only difference being that the alteration of the siderite is of a different character, in one case black oxide of iron being produced, and in the other red and brown oxides. (See p. 217.)

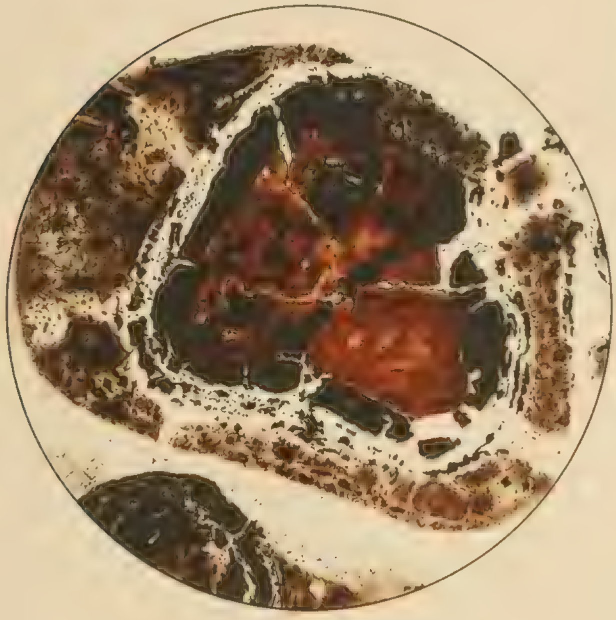


Fig. 1

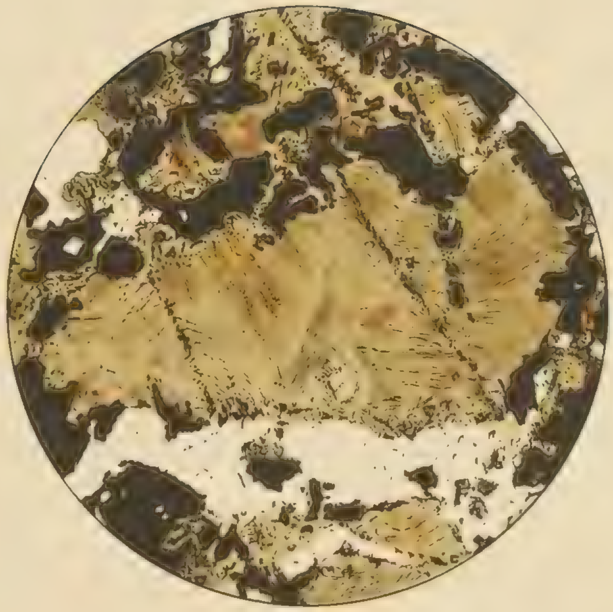


Fig. 2.

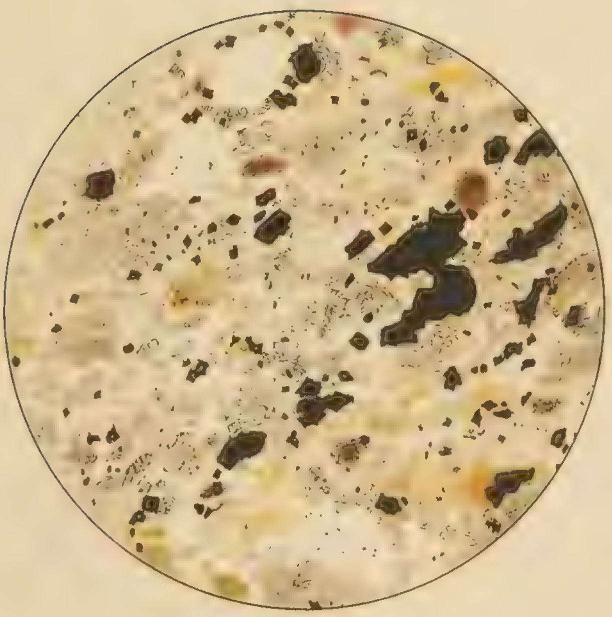


Fig. 3.

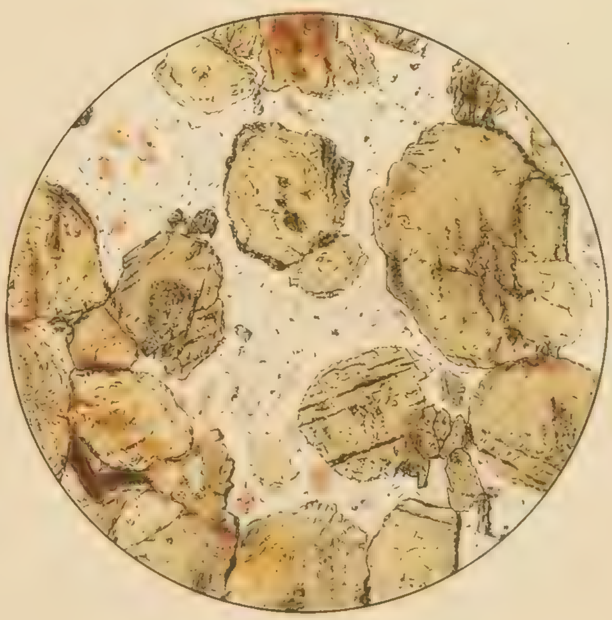


Fig. 4.

THIN SECTIONS FROM THE IRON FORMATION OF THE ANIMIKIE SERIES, AND FROM LAWRENCE COUNTY, OHIO.

# PLATE XXX.

## Plate XXX.—Ore Deposits.

Fig. 1. Longitudinal section of south deposit, Montreal mine. Above the main dike rock rich ore is found, while between this and some smaller dikes is mixed ore.

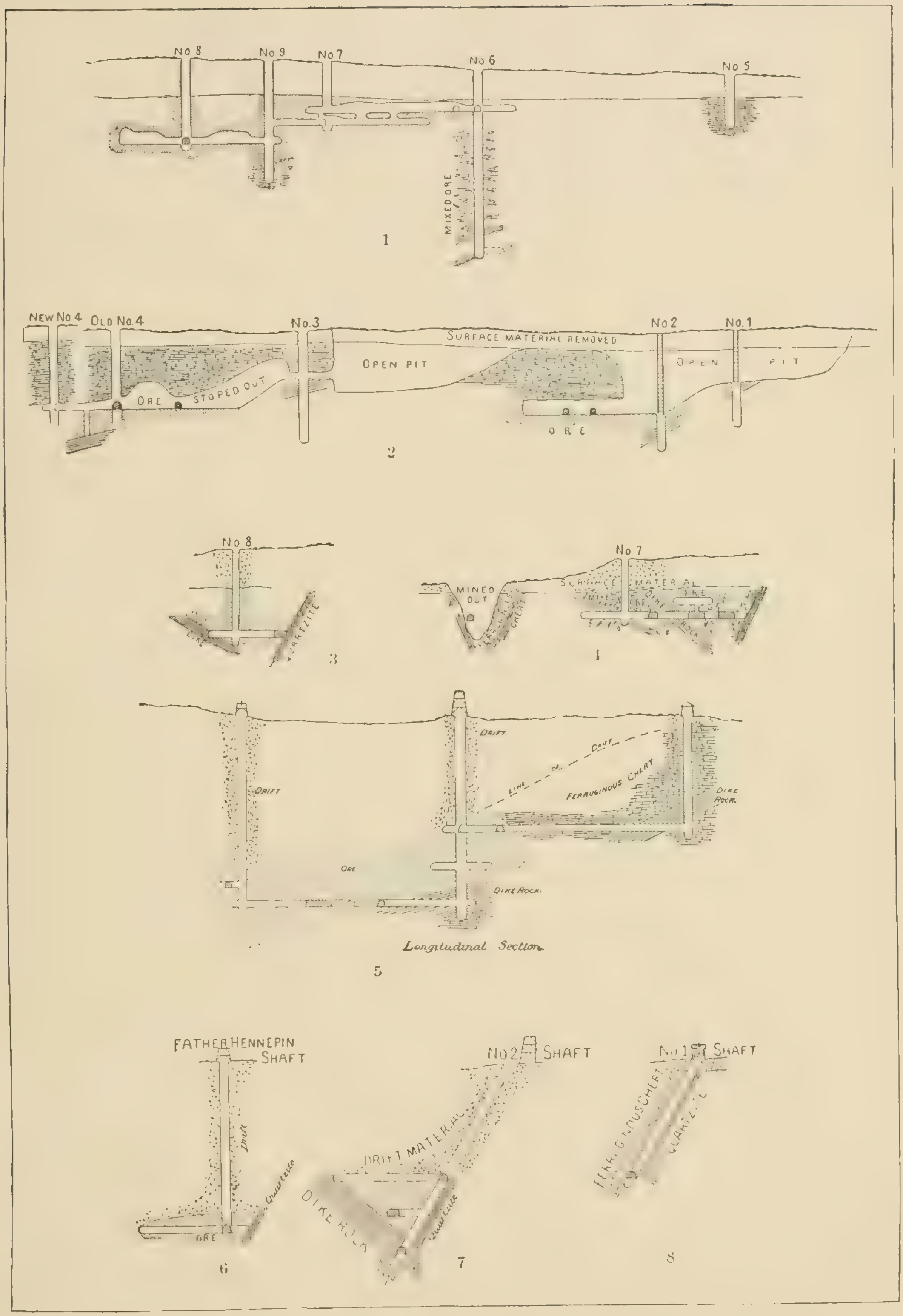
Fig. 2. Longitudinal section of north deposit, Montreal mine. Ore is seen above each of two dikes at different depths. The fact is noted that ore which was originally found at the surface and mined in an open pit has in both cases been carried under the rock surface. In this case two parallel dikes, very close to each other, have, in both cases, above them a moderate sized ore deposit.

Fig. 3. Cross section of south deposit, Montreal mine, at No. 8. shaft. The relations of the foot wall quartzite, dike rock, ore and drift, are well illustrated.

Fig. 4. Cross section of south and north deposits, Montreal mine, on line of No. 7 shaft of south deposit. The quartzite, both dike rocks of the south deposit, and the dike rock of the north deposit are all seen.

Fig. 5. Longitudinal section of Pence mine. A strong dike carries above it a heavy deposit of ore, which was reached by two shafts immediately upon passing through the drift. Just above this same dike, a little farther to the west, no ore is found.

Figs. 6, 7, and 8. Cross sections of Pence mine, at Nos. 1, 2, and Father Hennepin shafts. The relations of the dike rock, quartzite, ore deposits, drift material, and ferruginous cherts in this mine are by these sections clearly shown.




ORE DEPOSITS.

Fig. 1.—Longitudinal section of south deposit, Montreal mine.
Fig. 2.—Longitudinal section of north deposit, Montreal mine.
Fig. 3.—Cross section of south deposit, Montreal mine.
Fig. 4.—Cross section of south and north deposits, Montreal mine.
Fig. 5.—Longitudinal section of Pence mine.
Figs. 6, 7, 8.—Cross sections of Pence mine.

PLATE XXXI.

## Plate XXXI.—Ore Deposits.

Fig. 1. Longitudinal section of south deposit, Colby mine. This figure shows a very large deposit of ore, which was found at the surface, but which, in following eastward, was found to pass under the ferruginous chert. So far as this figure goes, no indication of a dike is seen, but a drill hole put down from one of its deeper levels has passed through a thick dike rock.

Fig. 2. Longitudinal section of north deposit, Colby mine. This deposit, before it had been developed to such a depth as the south deposit, reached a dike, and a little farther north this same dike reaches the surface of the ground.

Fig. 3. Cross section of north and south deposits, Colby mine. The perpendicular line running through the figure is drawn because the two parts of the section are not exactly upon the same plane. They differ from this so slightly, however, that the true relations of the ore bodies to the surrounding rocks are shown by the combined figure.

Fig. 4. Longitudinal section of Trimble mine. This is a case in which the main deposit of ore is above three parallel dikes very close to one another. This deposit, like many others, is found at the surface, but when traced eastward, passes below the ferruginous chert. Above the lower dike, a little farther west, is a considerable ore deposit.

Fig. 5. Cross section of Trimble mine, showing quartzites, ferruginous chert, and dike rocks.

Fig. 6. Cross section of Minnewawa mine, showing the same relations of quartzite, dike rock, and ore bodies; and also a faulting of the foot wall quartzite where cut by the dike rock.

Fig. 7. Section designed to show variation from unaltered carbonate to ferruginous chert and ore bodies in passing from higher to lower horizons, and to illustrate the manner of ore concentration. S. Upper slate; Q. Quartzite; F. Q. Feldspathic Quartzite.

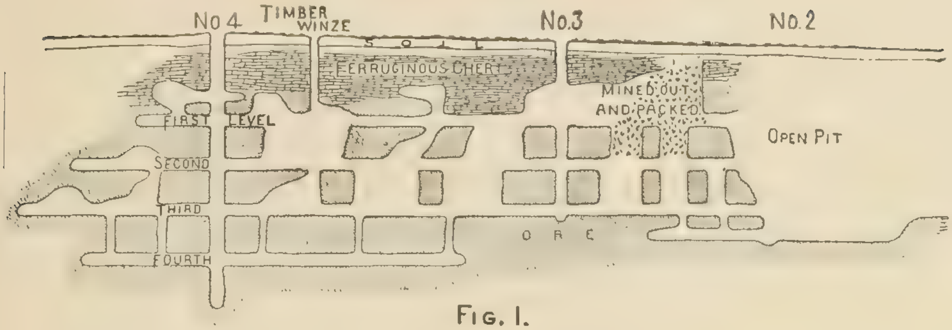



FIG. I.

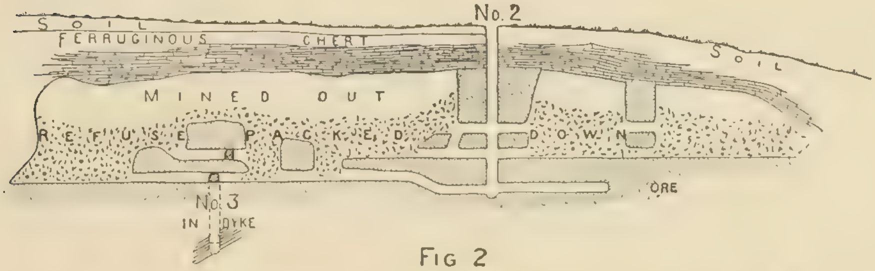



FIG 2

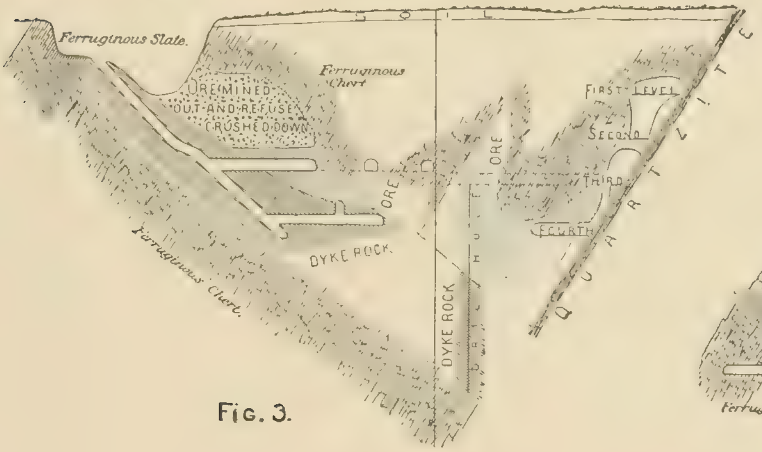



FIG. 3.

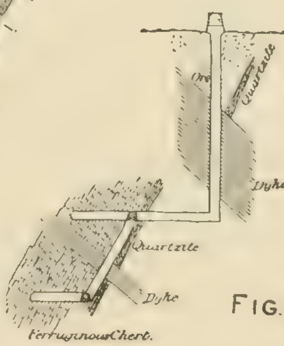



FIG.6.

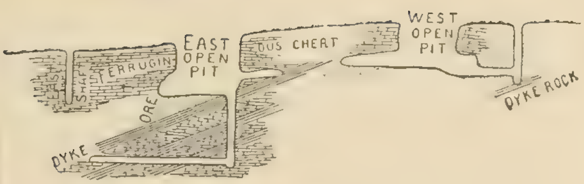



FIG.4.


FIG.5.

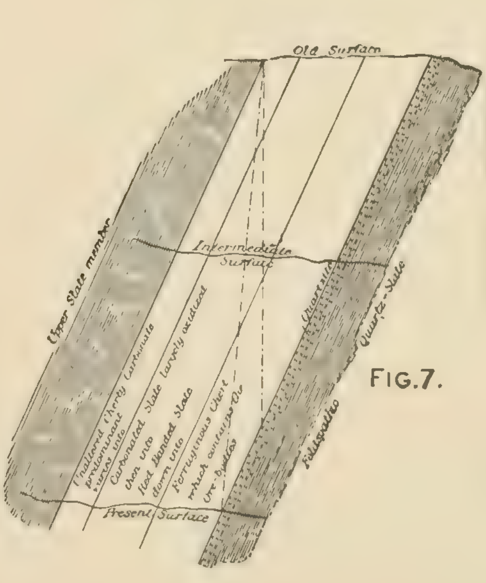



FIG.7.

ORE DEPOSITS.

Fig. 1.—Longitudinal section of south deposit, Colby mine.
Fig. 2.—Longitudinal section of north deposit, Colby mine.
Fig. 3.—Cross section of north and south deposits, Colby mine.
Fig. 4.—Longitudinal section of Trimble mine.
Fig. 5.—Cross section of Trimble mine.
Fig. 6.—Cross section of Minnewawa mine.
Fig. 7.—Theoretical section to show variation from unaltered carbonate.

# PLATE XXXII.

## Plate XXXII.—Graywackes from the Upper Slate Member.

Fig. 1. Micaceous graywacke. Specimen 9118, slide 2906. From the SE. ¼ of Sec. 11, T. 45 N., R. 1 W., Wisconsin. In polarized light, × 25. The section shows the general rounded character of the quartz grains, some of which are now minutely angular by enlargement. The complex, minutely crystalline areas represent single fragments of feldspar, which are now largely altered to mica and quartz and thus appear more like finely crystalline interstitial material than simple fragmental grains. (See p. 326.)

Fig. 2. Biotitic and muscovitic graywacke. Specimen 9541, slide 3092. From NW. ¼ of Sec. 11, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 60. The figure illustrates a more quartzose part of the section. It shows nicely the alteration of feldspar. In the center of the figure was a simple fragment of feldspar, which has largely altered into mica and quartz, as a result of which the rounded area is now a completely crystalline mass of mica, quartz, and feldspar. Its true nature is, however, shown by its rounded appearance and by the fact that the many detached, small, irregular areas of feldspar extinguish together. (See p. 316.)

Fig. 3. Biotitic graywacke. Specimen 9598, slide 3331. From SE. ¼ of Sec. 15, T. 45 N., R. 1 W., Wisconsin. In polarized light, × 60. The figure illustrates the same thing as Fig. 2. The large roundish area in the center of the figure was once a single fragmental feldspar, but it has almost wholly decomposed, and thus forms an interlocking mass of mica and quartz. In this case detached areas of quartz thus formed are seen to be a unit over a considerable area. This figure and the previous one illustrate the crystalline character which can result from the alteration of fragmental feldspar. Many individuals of mica and quartz have been produced from a single feldspar, and, as they form simultaneously by the alteration, they interlock as completely as if they were original crystallizations, and also with the residual feldspar in case there is any. (See pp. 324–325.)

Fig. 4. Biotitic and chloritic graywacke. Specimen 9109, slide 4418. From the NE. ¼ of Sec. 12, T. 45 N., R. 1 W., Wisconsin. In polarized light, × 25. A typical fine grained biotitic and chloritic graywacke. The fragmental character of the quartz is plain, although many of the smaller particles are quite angular. The fragmental feldspar was originally as abundant as the quartz, but the figure does not well show this, as most of the grains of this mineral are extensively altered to biotite and chlorite. (See p. 325.)

Fig. 1.—Micaceous graywacke.

Fig. 2.—Biotitic and muscovitic graywacke.

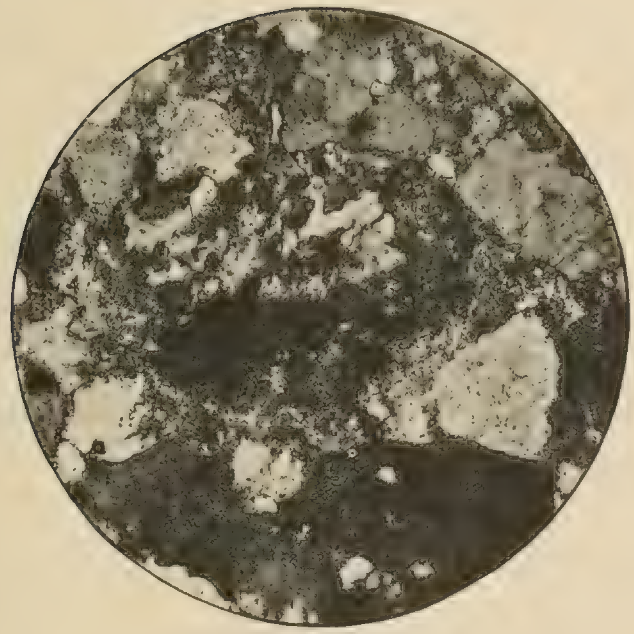


Fig. 3.—Biotitic graywacke.

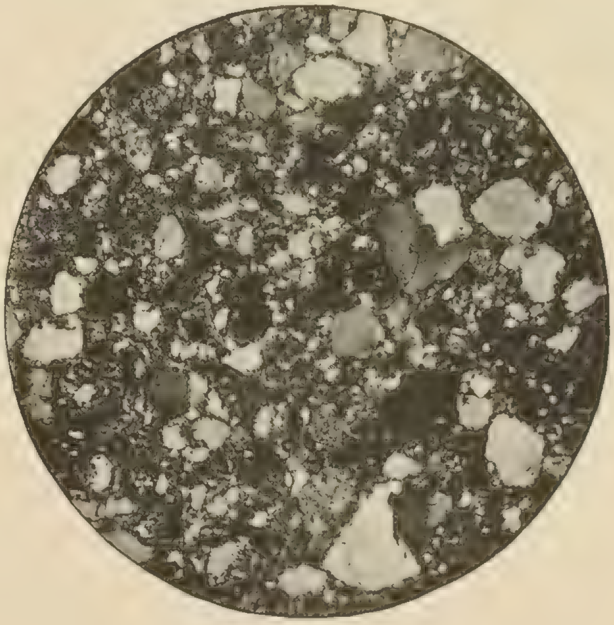


Fig. 4.—Biotitic and chloritic graywacke.

THIN SECTIONS OF GRAYWACKES FROM THE UPPER SLATE MEMBER

# PLATE XXXIII.

## Plate XXXIII.—The Development of Mica-Slates.

Fig. 1. Biotitic and muscovitic graywacke. Specimen 9514, slide 3092. From the NW. ¼ of Sec. 11, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 60. The section is one of the least altered feldspathic fragmental rocks. Large rounded areas of feldspar make up most of the section, although smaller particles of fragmental feldspar and quartz are contained. The incipient alteration of the feldspars to the micas is observed, and the smooth outlines of the fragmental grains have already been lost by alteration. This is the original phase of rock, the alterations of which carried to the extreme have produced the crystalline mica-schists. (See p. 316.)

Fig. 2. Biotite-slate. Specimen 126, Wright. From the NE. ¼ of Sec. 9, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 25. The section is from a rock which was originally like Fig. 1. The alterations of the feldspar to the micas and quartz have been carried to a greater degree. The regular outlines of the original areas are wholly lost, so that while they have a general roundish or oval form their exteriors are minutely angular. The micas are much more abundant at and near the exteriors of the grains of feldspars than in the interiors, although the alterations have extended quite to the centers. (See p. 310.)

Fig. 3. Biotite-slate. Specimen 128, Wright. From the NW. ¼ of Sec. 9, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 25. The original condition of this rock was precisely like that of Figs. 1 and 2. The series of alterations there shown have, however, gone much farther. The fragmental character of the feldspars is quite lost. They have been penetrated by secondary muscovite and biotite until they are most irregular in form, only a single grain approximately retaining its oval outline. As a further result of this process a considerable proportion of interstitial crystalline quartz and mica, as compared with the two previous figures, is found, which has come directly from the decomposition of the feldspar. (See p. 310.)

Fig. 4. Biotite-slate. In polarized light, × 25. This figure is taken from part of the same section as the last, in which the alterations just described have gone still farther. The crystalline character of the developing rock is better shown. There remain, however, areas of feldspar which act as a unit, although they are cut in every direction by the alteration products, quartz and mica. (See p. 310)

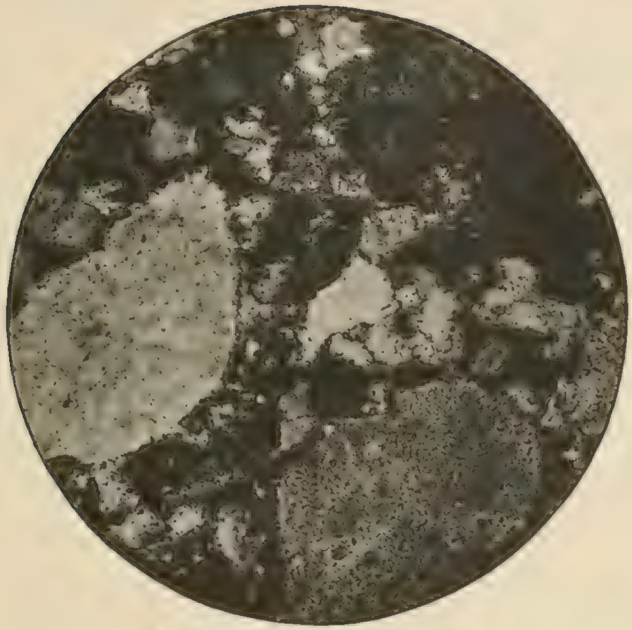


Fig. 1.—[illegible]

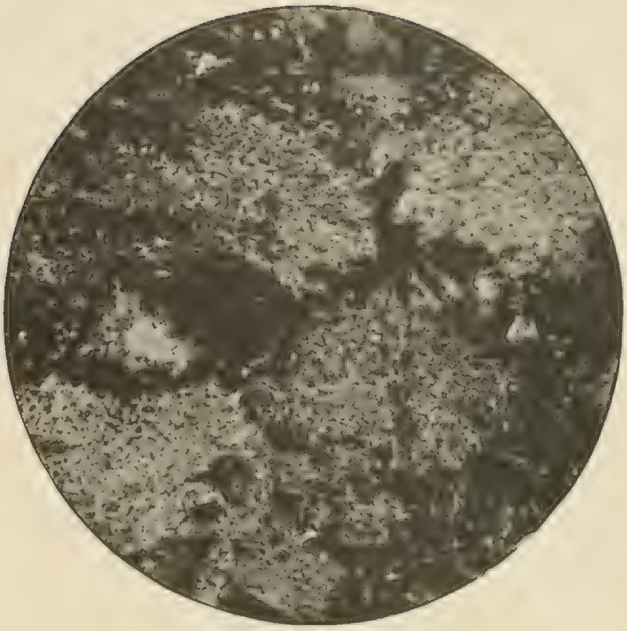


Fig. 2.—[illegible]

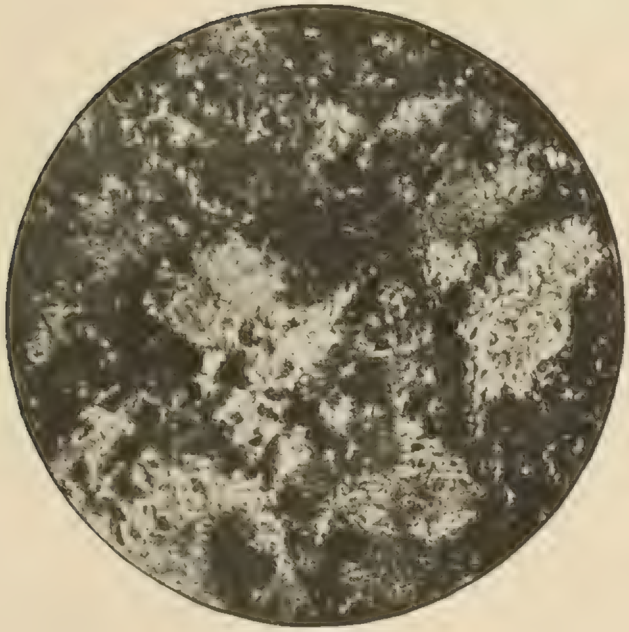


Fig. 3.—Biotite slate.

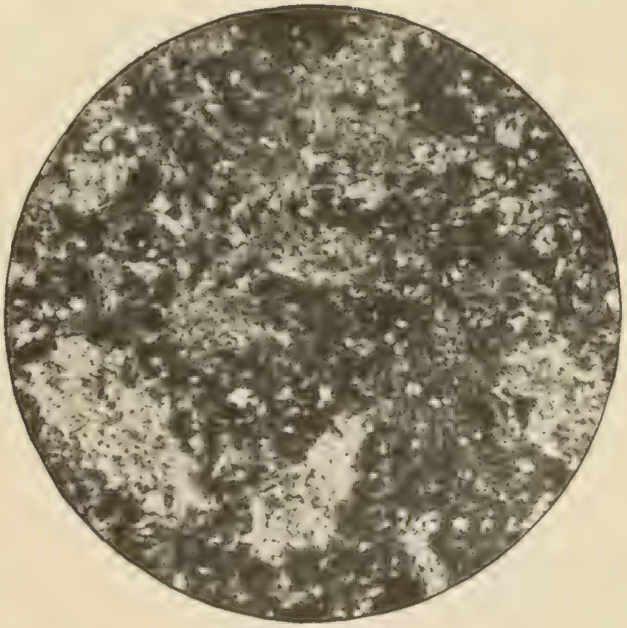


Fig. 4.—Biotite slate.

THIN SECTIONS SHOWING DEVELOPMENT OF MICA-SLATES

# PLATE XXXIV.

## Plate XXXIV.—The Development of Mica-Schists and Mica-Slates.

Fig. 1. Muscovitic biotite-schist. Specimen 2039, Wisconsin. From the NE. ¼ of Sec. 6, T. 44 N., R. 2 W., Wisconsin. In polarized light, × 60. The processes of alteration described in the previous plate has here gone so far as to leave but little trace of original fragmental feldspar. Areas of feldspar, however, remain in the section, which, while cut by quartz and mica, so as to give all of the minerals a most crystalline material, yet polarize as a unit. (See pp. 320–321.)

Fig. 2. Biotite-schist. Specimen 153, Wright. From the NE. ¼ of Sec. 4, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 60. The section is a typical biotite-schist from the Upper slate member. The examination of the thin section shows no evidence of fragmental origin. It is composed almost wholly of mica and quartz, the two minerals interlocking in the most intricate fashion. Taken alone it could not be shown that this rock and the preceding were derived from fragmental feldspathic sediments, but taken in connection with the previous figures and the formation in which they are found, it is certain that they have been produced by the alteration of such a rock. The figures of the previous plate and 1 and 2 of this plate constitute a graded series which illustrates well the series of alterations by which there has been produced from a completely fragmental rock, composed chiefly of feldspar, a rock which is a typical crystalline schist. (See p. 311.)

Fig. 3. Biotite-slate. Specimen 130, Wright. From SE. ¼ of Sec. 10, T. 44 N., R. 3 W., Wisconsin. In polarized light, × 60. The section is one of the exceedingly finely crystalline black biotite-slates. That it has been derived from a fragmental feldspathic rock like the mica-schists is shown by the vaguely outlined fragmental feldspars, the alteration of which here produces the finely crystalline biotite and quartz. (See p. 315.)

Fig. 4. Biotite-slate. Specimen 9113, slide 2903. From the SE. ¼ of Sec. 12, T. 45 N., R. 1 W., Wisconsin. In polarized light, × 60. The section is one of the typical finely crystalline biotite-slates. It was doubtless produced from a fragmental feldspar rock, as in the previous figure, although it shows no remaining fragmental feldspar. However, in other parts of the thin section and in the hand specimen the vague outlines of rounded feldspars are seen. (See p. 326.)

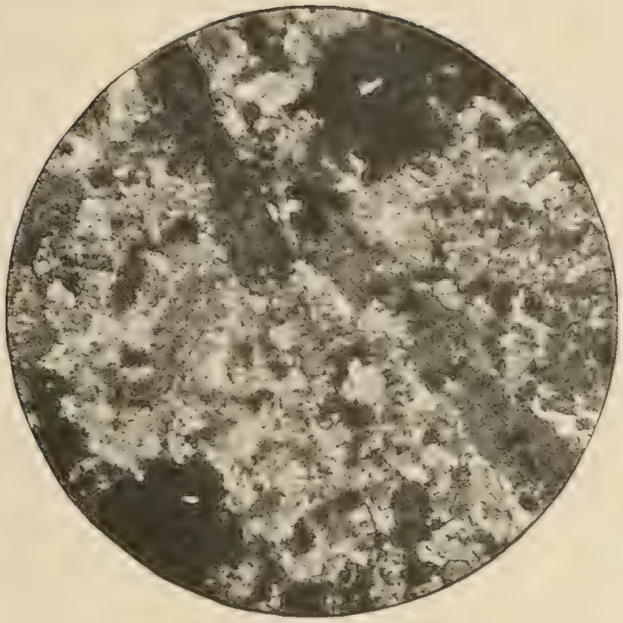


Fig. 1.—Muscovitic biotite schist.

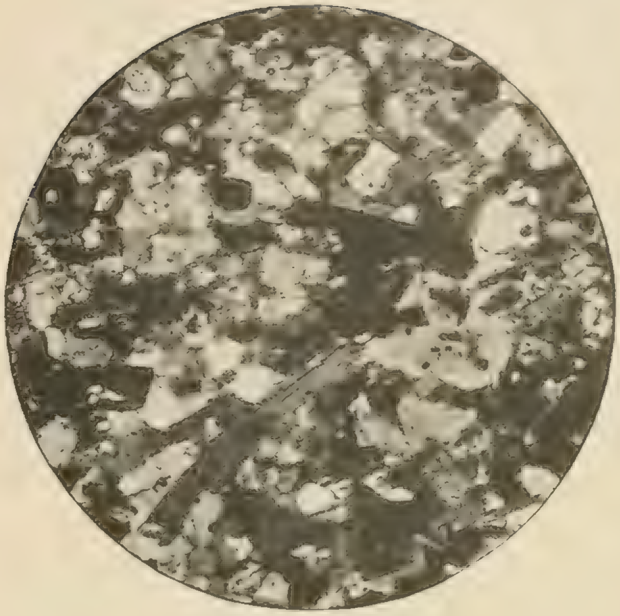


Fig. 2.—Biotite schist.

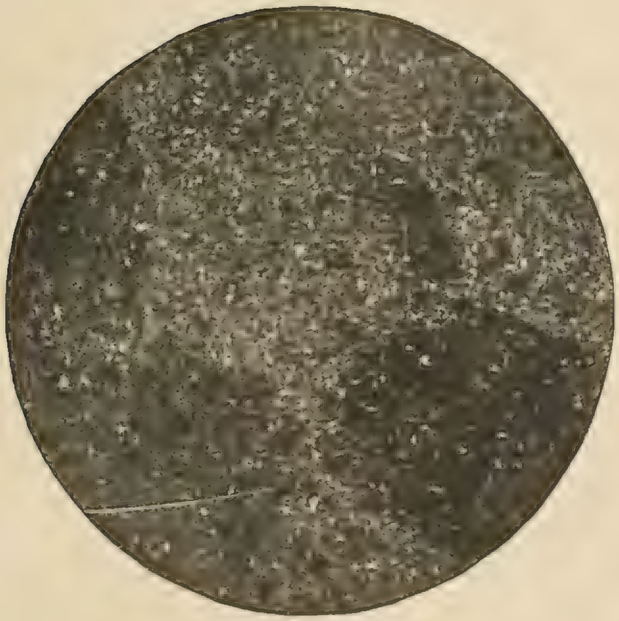


Fig. 3.—Biotite slate.

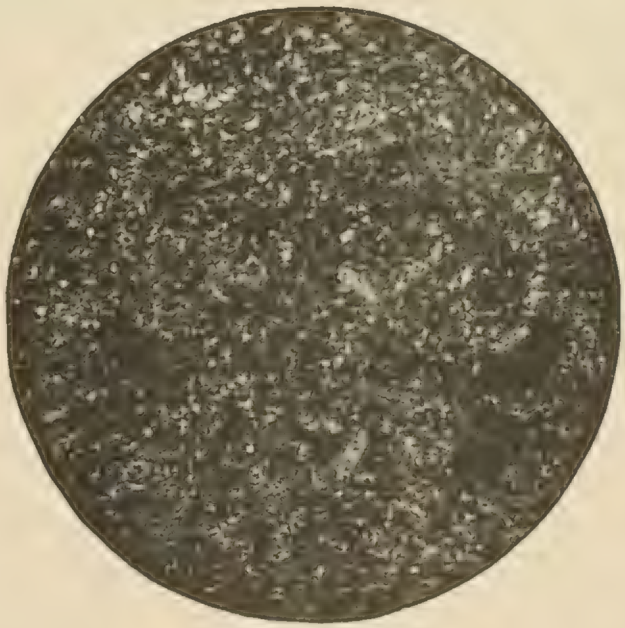


Fig. 4.—Biotite slate.

THIN SECTIONS SHOWING DEVELOPMENT OF MICA-SCHISTS AND MICA-SLATES.

PLATE XXXV.

## Plate XXXV.—From the Eastern Area.

Fig. 1. Ferruginous chert and quartzite. Specimen 12937, slide 6547. From near the center of Sec. 23, T. 47 N., R. 44 W., Michigan. In polarized light, × 60. The section shows the sharp transition which frequently occurs between nonfragmental and fragmental sediments in the iron-bearing belt of the Eastern area. Upon one side of the figure is seen a small part of a band of pure nonfragmental chert. This abruptly changes into fragmental quartz set in a matrix consisting of nonfragmental chert and iron oxide. A portion of the fragments of quartz are simple and two grains are plainly enlarged. Other grains are of chert. In the change from nonfragmental to fragmental sedimentation the underlying nonfragmental material has been broken up to some extent and has yielded fragments which are associated with the simple grains of quartz. (See p. 363.)

Fig. 2. Greenstone-conglomerate. Specimen 9313, slide 4929. From the SE. ¼ of Sec. 14, T. 47 N., R. 44 W., Michigan. In ordinary light, × 25. The figure shows the extraordinary structure so constant in the greenstone-conglomerates. It is from one of the phases in which chlorite and quartz are the preponderating constituents. The anastomosing parts which contain the irregular areas are largely composed of quartz, while the irregular areas are chiefly made up of quartz, chlorite, and epidote. This represents a phase of rock in which the extreme of alteration has taken place. The products are minerals which, with the exception of chlorite, are ultimates in the series of transformations of rocks. (See pp. 384–385.)

Fig. 3. Greenstone-conglomerate. Specimen 9369, slide 3036. From the SW. ¼ of Sec. 15, T. 47 N., R. 44 W., Michigan. In ordinary light, × 25. The figure shows another phase of the remarkable structure characteristic of these rocks. It contains apparent fragments which are exceedingly angular and which are set in an anastomosing matrix, consisting largely of finely crystalline quartz. The fragments in this section are gray amorphous material, in which are numerous minute tabular crystals of plagioclase. (See pp. 381–382.)

Fig. 4. The same, in polarized light, × 25. This figure shows the reticulating quartzose background. The almost completely amorphous character of the major portion of the fragments is sharply brought out. Within them, as in the previous figure, the tabular crystals of plagioclase stand out. (See pp. 381–382.)

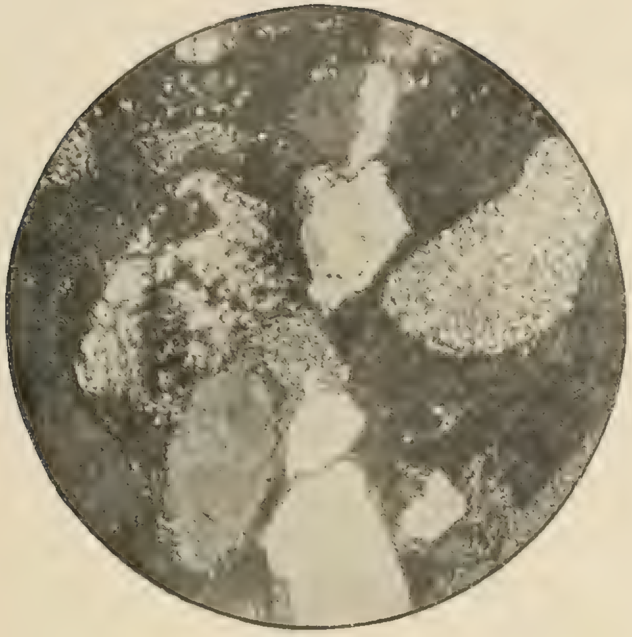


Fig. 1.—Ferruginous chert and quartzite.

Fig. 2.—Greenstone conglomerate.

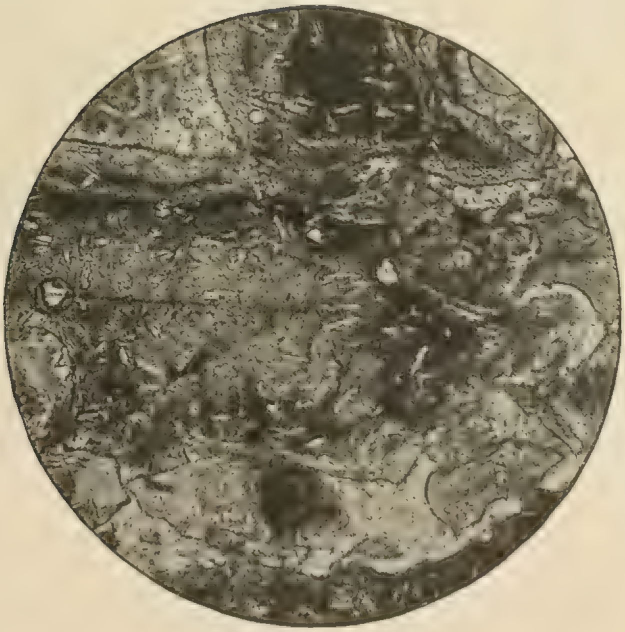


Fig. 3.—Greenstone conglomerate.

Fig. 4.—Greenstone conglomerate.

THIN SECTIONS FROM THE EASTERN AREA.

# PLATE XXXVI.


KEWEENAWAN

Ga. Gabbro.
South limit.

PENOKEE SERIES.

Upper Slate Member.

M S. Mica-slate
Bl. Sl Black slate
Q Quartzite
South limit.

Iron-bearing Member.

G Sch. Garnetiferous actinolite schist at summit of the member
Mg. Sch. Magnetic and actinolitic quartz-schist.
Limits of surface distribution

Quartz-Slate Member.

V. Q. Vitreous quartzite at summit of the member
Sl. Main body of the slate
B B. Basal breccia
South limit

Cherty Limes

W. Ch. Wh
L. Lime
South

Directions of colored lines show strike of layers

Scale of Map and Sections 1 inch=900 feet.

Contours 20 fe

MAP SHOWING THE DISTRIBUTION OF EXP


SOUTHERN COMPLEX.

one Member. Eruptives.

e chert
one
mrt

D Diabase

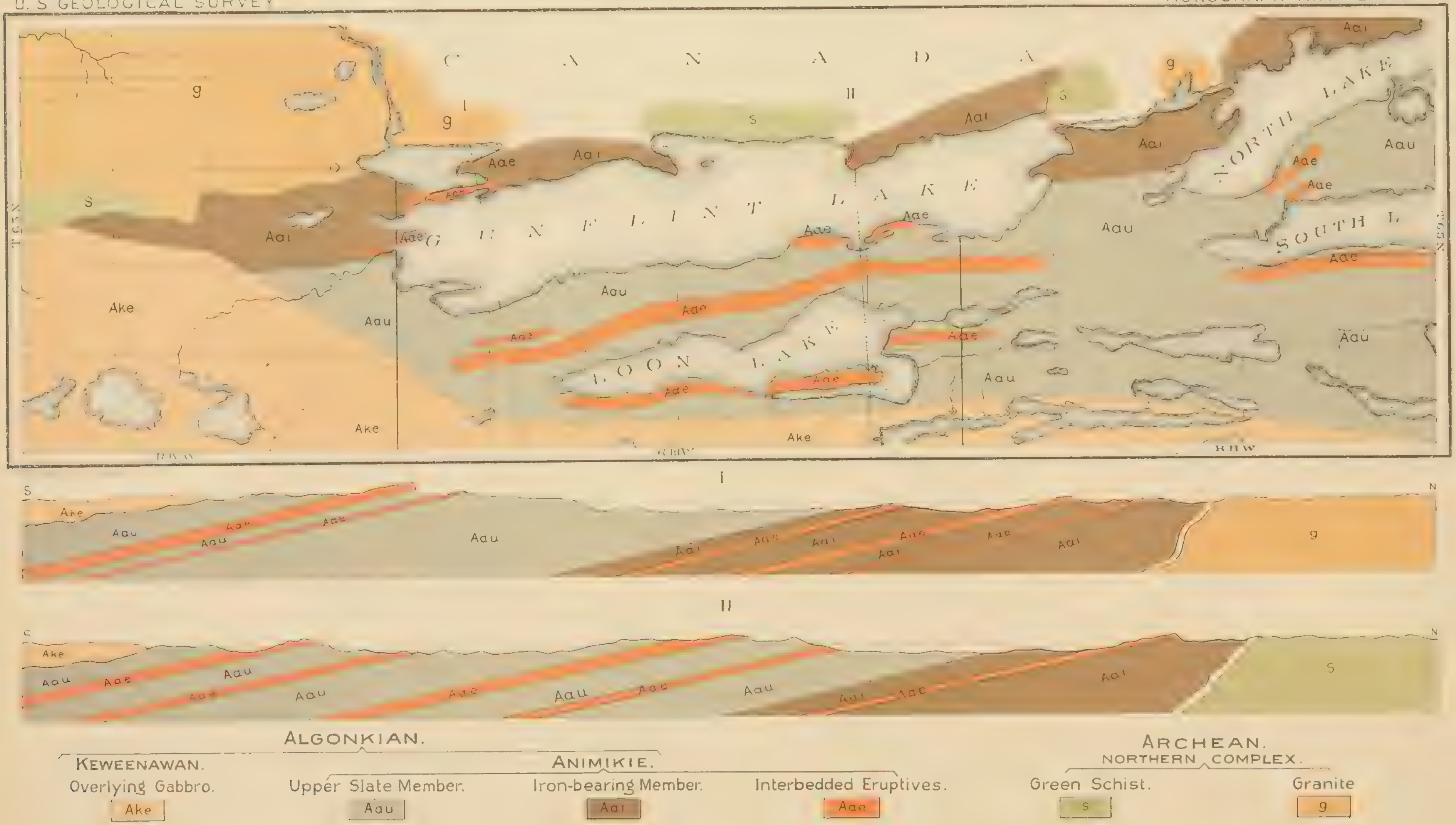
Gn. Schistose chloritic hornblende-gneiss
Gr Granite

et vertical distance

OSURES AT PENOKEE GAP, WISCONSIN.


MAP SHOWING THE DISTRIBUTION OF EXPOSURES AT PENOKEE GAP, WISCONSIN.

# PLATE XXXVII.




GEOLOGICAL MAP OF GUNFLINT LAKE AND VICINITY, MINN.

By. W. N. MERRIAM.

Scale of Map 1 inch 7920 feet. Scale of Sections 1 inch 1980 feet.

# INDEX.

## A.