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THE CRYSTAL FALLS IRON-BEARING DISTRICT OF MICHIGAN

BY
J. MORGAN CLEMENTS and HENRY LLOYD SMYTH
WITH
A CHAPTER ON THE STURGEON RIVER TONGUE
BY
WILLIAM SHIRLEY BAYLEY
AND
AN INTRODUCTION
BY
CHARLES RICHARD VAN HISE

WASHINGTON
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Part I.—THE WESTERN PART OF THE DISTRICT

By J. MORGAN CLEMENS

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., April 23, 1898.

SIR: I transmit herewith the manuscript and illustrations of a monograph upon the Crystal Falls Iron-bearing District of Michigan, by J. Morgan Clements and H. L. Smyth. The district is thus called from its principal mining town. The area reported upon connects the Marquette district on the north and the Menominee district on the south.

This monograph is one of the series which is to treat of the iron-bearing districts of the Lake Superior region. The first of the series was that on the Penokee district (Monograph XIX); the second of the series was that on the Marquette district (Monograph XXVIII). The present report is the third of the series, and the report upon the Menominee district, now being prepared by W. S. Bayley, will be the fourth.

No previous detailed report has been issued upon the Crystal Falls district, although the area has been touched upon by Messrs. T. B. Brooks and Carl Rominger. The present report is the first which contains geological maps and sections of the district.

The field work upon which the present report is based began about five years ago. The work of the first season was a topographical survey and a reconnaissance geological survey. The work of the second season was detail geological work by H. L. Smyth, W. N. Merriam, and their assistants. The work of these two seasons was done for private parties. These parties turned over to me the original specimens, notes, and maps to assist in the preparation of this report. The detail geological mapping of the second year had covered only a part of the area included within the present report, and in the remainder of the area in the following years detail surveys were made by J. Morgan Clements and W. S. Bayley.

In the vicinity of the mines and the iron-bearing formations the examination of the district has been of the most detailed character, practically all of the ledges having been visited and advantage having been taken of underground workings and borings. Moreover, in order to determine the succession, for large areas, it was necessary to make a close magnetic survey with the dial compass and dip needle. In the areas more remote from the mines the work was of a less detailed character.

The western half of the district is treated by J. Morgan Clements in Part I of this monograph. The eastern half of the district, with the exception of the Sturgeon River tongue, is treated by H. L. Smyth in Part II. The chapter upon the Sturgeon River tongue was prepared by W. S. Bayley. My own part of the work has been a general supervision of the entire survey, with frequent trips into the region to assist in solving the general structural problems.

To the gentlemen who furnished the complete results of their surveys for the first two seasons, we are deeply indebted. The drawing for the maps was done by E. C. Bebb. The colored plates were prepared by J. L. Ridgway.

Very respectfully, your obedient servant,

C. R. VAN HISE,

Geologist in Charge.

HON. CHARLES D. WALCOTT,

Director United States Geological Survey.

INTRODUCTION.

By C. R Van Hise

This report is a full account of the Crystal Falls iron-bearing district of Michigan.

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes both the Lower Huronian and the Upper Huronian series, and these are also separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geological province as the Huronian rocks of the north shore of Lake Huron, and to be equivalent to the Lower Huronian and Upper Huronian series which there occur. The reasons for this belief are fully given in Bulletin 86.[1]

The Archean is believed to be wholly an igneous group, and therefore no estimate of its thickness can be given. It covers a broad area in the eastern part of the district, and from this several arms project west. West of the main area there are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 feet to more than 1,000 feet thick; the Randville dolomite, from 500 feet to 1,500 feet thick; the Mansfield slate, from 100 feet to 1,900 feet thick; the Hemlock volcanic formation, from 1,000 feet to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. We thus have a minimum thickness for the series of about 2,200 feet, and a possible maximum thickness of more than 16,000 feet. However, a large part of the latter is composed of volcanic material. It is not likely that the sediments at any one place are as much as 5,000 feet thick.

[1]Correlation papers, Archean and Algonkian, by C. R. Van Hise: Bull. U. S. Geol. Survey No. 86, 1892, pp, 156-199.

The Upper Huronian is a great slate and schist series, which it is not possible to separate on the maps into individual formations, and it is impossible to give even an approximate estimate of the thickness of this series.

Various igneous rocks intrude in an intricate manner both the Upper Huronian and the Lower Huronian series.

The aim of the following paragraphs is to sketch very briefly the history of the district.

THE ARCHEAN.

The Archean consists mainly of massive and schistose granites and of gneisses. Nowhere in the Archean have any rocks of sedimentary origin been discovered. The Archean has been cut by various igneous rocks, both basic and acid, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but more ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The Archean granites and gneisses and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

THE LOWER HURONIAN SERIES.

The Sturgeon quartzite, the first deposit of the advancing sea, when formed consisted mainly of sandstone, but in places at the base of coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great schistose conglomerate, which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies from probably more than 1,000 feet in thickness in the Sturgeon River tongue to less than 100 feet in thickness at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

In the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it can not be represented on the maps as a separate formation. In the northeastern part of the district a quartzite resting on the Archean, but occupying a higher position stratigraphically than the Randville dolomite, is overlain by an iron-bearing formation. It appears, therefore, that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the area, the Archean was not yet submerged in the central and northeastern parts of the district. However, since the quartzite resting on the Archean in the latter area can not be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents a transgression deposit of the same general lithological character, rather than a formation, all parts of which have exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment, and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper waters for much of the district. Since the Randville dolomite has its full thickness on the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land arose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1,500 feet, it probably represents a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation, (2) the Hemlock volcanic formation, and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Hemlock formation is mainly a great volcanic mass, including both basic and acid rocks, lavas, and tuffs, but it contains also subordinate interbedded sedimentary rocks. This formation occupies a larger area than any other of the Lower Huronian formations and is perhaps the most characteristic feature of the Crystal Falls district. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material, there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate and possibly glauconite, from which its other characteristic rocks were derived.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreaks in the western part of the district. In the southern and southeastern parts of the area the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district and the Randville formation in the central part of the district is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near the top of the Mansfield formation intercalated with the slates. The Groveland formation can not be certainly traced farther north than the northeastern portion of the western Archean oval. It is apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics of the same part of the geological column as the Hemlock volcanics east of the western Archean oval, the Mansfield slate, and the Groveland formation, is explained by the fact that in the western part of the district the volcanoes first broke out and there continued their activity longest. While north of Crystal Falls the volcanic rocks were being laid down, the Mansfield formation was being deposited in the southeastern part of the district. This activity continued there through the time that the Groveland formation was being deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent:

(1) East of the western Archean oval, to the Hemlock volcanics found there and the overlying Groveland formation;

(2) At Michigamme Mountain, to the Mansfield slates and the Groveland formation;

(3) In the Mansfield area, to the Mansfield slates and the Hemlock volcanics occurring there; and

(4) In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks of the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.[1]

Following the deposition of the Lower Huronian series the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the only formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless when the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been little variation in the elevation of the upper surface of the series, but very great difference in its thickness.

[1]The Penokee iron-bearing district of Michigan and Wisconsin, by E. D. Irving and C. R. Van Hise: Mon. U. S. Geol. Survey, Vol. XIX, 1892, pp. 428-433.

THE UPPER HURONIAN.

After the Lower Huronian series was deposited the district was raised above the sea, may have been gently folded, and was eroded to different depths in different parts of the district.

Following the earth movements and erosion the waters for some reason advanced over the district and the Upper Huronian series was deposited. The basal horizon was a conglomerate, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has subsequently been changed into a ferruginous quartzite. The typical occurrence of this quartzite is at the east end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartzite, they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface are the great Hemlock formation, and here the basal horizon of the Upper Huronian is a slate or slate conglomerate, the fragments of which are derived mainly from the underlying Hemlock formation. The sandstones and conglomerates varied upward into shales and grits, which have been subsequently altered into mica-slates and mica-schists. After a considerable thickness of mudstone and grit was deposited, there followed a layer of combined clastic and nonclastic sediments, the latter including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks, and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferruginous rocks there was deposited a great thickness of shales and grits, which have been transformed into mica-slates and mica-schists.

FOLDING OF THE ARCHEAN AND HURONIAN SERIES.

The Crystal Falls district had now been an area of deposition for a very long time, and a great thickness of sediments had accumulated. A profound physical revolution next occurred, the greatest since Archean time. The region was raised above the sea and was folded in a most complex manner. As a consequence, the more conspicuous folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds, however, have steep pitches. It therefore follows that the region was subjected to great compressive stresses in all directions tangential to the surface of the earth, and that the yielding was mainly in one direction here and in another there, although on every fold there is evidence of yielding in two directions at right angles to each other. Some of the folds are very close, as in the case of the Huronian area between the two Archean ovals in the northeastern part of the district, and in the Felch Mountain range. In other areas—as, for instance, in the Crystal Falls syncline— the major fold is somewhat open. However, upon the open folds are superimposed folds of a higher order, so that the detail structure is very complicated. So far as known, the district has nowhere been faulted.

Subsequent to or during the late stage of this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and the Upper Huronian rocks vast bosses and numerous dikes. The intrusives vary from those of an ultrabasic character, such as peridotites, through those of a basic character, such as gabbros and dolerites, to those of an acid character, such as granites. These intrusives, while altered by metasomatic changes, do not show marked evidence of dynamic metamorphism—therefore the conclusion that they were introduced later than the period of intense folding, already described.

A few illustrations are mentioned. The Archean and other great massifs are less profoundly altered than are the softer and weaker deposits of the Huronian. In these more rigid formations, such as the granites and quartzites, all phases of alteration by granulation and recrystallization are beautifully exhibited. The Sturgeon River area affords one of the best-known illustrations of a schistose conglomerate the matrix of which has completely recrystallized and, therefore, can not be

discriminated from a gneiss of igneous origin, but contains numerous pebbles and bowlders flattened in the plane of schistosity.

The great Hemlock volcanic formation varies from rocks which are altered chiefly by metasomatic change to those which have become complete crystalline schists containing no vestige, either macroscopically or microscopically, of a texture or structure which may be interpreted as igneous.

SUBSEQUENT HISTORY.

After the introduction of the intrusives the region was subjected to vast denudation, which reduced it approximately to its present configuration. This period of erosion continued until late Cambrian time, when the sea again overrode the district and deposited upon the older rocks Upper Cambrian sediments. Long after the deposition of the Cambrian, and perhaps later Paleozoic rocks, the district was again raised above the sea, and the major part of the Cambrian deposits have been removed, although they are found in patches throughout much of the district, and occur as a continuous sheet just east of the area discussed.

The district may have again been submerged in Cretaceous time; but if so, the deposits formed were removed after the area finally emerged from the sea. Since Cretaceous time the region seems to have been one of erosion. During the Pleistocene period a thick mantle of glacial deposits was spread over the entire district. Since Pleistocene time erosion has advanced far enough to uncover the rocks here and there.

METAMORPHISM.

The folding varied in its closeness in different parts of the district. Moreover, the formations are of very variable character, including a great variety of sediments and of igneous rocks. The formations, therefore, vary greatly in their capacity to resist stresses. It thus follows that during the folding process certain formations yielded to a much greater degree than others. The amount of contained water and other conditions were also variable. As a result of these many variable factors, it is one of the most characteristic features of the district that there are to be found nearly all varieties of metamorphism in various stages of advancement. The working out of the details of the transformations of the different kinds of rocks during their processes of metamorphism is one of the chief scientific results which has come from a study of the district.

CORRELATION.

In order to compare the succession in the Crystal Falls district with that in the adjacent Marquette and Menominee districts, the descending pre-Cambrian succession in each of the three districts is here given in parallel columns, the formations which are thought to be equivalent being placed opposite one another:

Descending succession of formations in the Marquette, Crystal Falls, and Menominee districts.

MARQUETTE DISTRICT.	CRYSTAL FALLS DISTRICT.	MENOMINEE DISTRICT.
Upper Marquette.	*Upper Huronian.*	*Upper Menominee.*
(1) Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the districtby the Clarksburg volcanic formation.	(1) Michigamme formation, bearing a short distance above its base an iron-bearing horizon.	(1) Great Slate formation
(2) Ishpeming formation, being composed of the Goodrich quartzite in the eastern part of the district and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	(2) Quartzite in eastern part of district.	
Unconformity.	*Unconformity.*	*Unconformity.*
Lower Marquette.	*Lower Huronian.*	*Lower Menominee.*
(1) Negaunee iron formation, 1,000 to 1,500 feet.	(1) The Groveland formation, about 500 feet thick.	(1) Vulcan iron formation containing slates.
(2) Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick.	(2) Hemlock volcanic formation, 1,000 to 10,000 feet thick. In western part of district also occupies the place of (1) and (3).	
(3) Ajibik quartzite, 700 to 900 feet.		
(4) Wewe slate, 550 to 1,050 feet.	(3) Mansfield formation, 100 to 1,900 feet thick.	
(5) Kona dolomite, 550 to 1,375 feet.	(4) Randville dolomite, 500 to 1,500 feet thick.	(2) Antoine dolomite.
(6) Mesnard quartzite, 100 to 670 feet.	(5) Sturgeon quartzite, 100 to 1,000 feet thick.	(3) Sturgeon quartzite.
Unconformity.	*Unconformity.*	*Unconformity.*
Archean.	*Archean.*	*Archean.*

From the three columns it appears that the equivalents in the different districts can be made out with a considerable degree of certainty. There are, however, various differences, due to several causes.

For Upper Huronian time, omitting the Clarksburg formation, the succession in the Marquette, Crystal Falls, and Menominee districts is substantially the same. The Clarsksburg formation in the Marquette district may be omitted from consideration, because it is volcanic and replaces in part the Michigamme and Ishpeming formations. The Upper Huronian was a great period of slate and grit deposition. The chief difference which appears between the Menominee district and the other two districts is that in the former no iron ores have been found in the Upper Huronian within the district proper, although such rocks occur a short distance to the west, at Commonwealth and Florence, in Wisconsin.

The succession for the Lower Huronian in the three districts can be paralleled with a high degree of probability. The chief differences are due to the disturbance of the great volcanic outburst in the western part of the Crystal Falls district and to the uneven surface of the Archean land at the beginning of Lower Huronian time. As a consequence of the latter, the waters did not reach the western part of the Marquette district and the northeastern part of the Crystal Falls district as early as the eastern part of the Marquette district, the central part of the Crystal Falls district, and the Menominee district. The transgression of the Lower Huronian sea for the region covered in these three districts was therefore from the southeast toward the northwest.

The Negaunee iron formation of the Marquette district is equivalent to the Groveland iron formation of the Crystal Falls district and the Vulcan iron formation of the Menominee district.

The Siamo slate and the Ajibik quartzite of the Marquette district are approximately equivalent to the Hemlock volcanic formation in much of the Crystal Falls district, but in places where the latter formation displaces the

Mansfield formation they are equivalent to only a part of the Hemlock volcanic formation. The Wewe slate of the Marquette district is equivalent in the western part of the Crystal Falls district to a part of the Hemlock volcanic formation, and in the southeastern part of the district is probably equivalent to a part of the Randville dolomite. It appears that the Siamo slate, Ajibik quartzite, and Wewe slate of the Marquette district, and the Mansfield and Hemlock formation of the Crystal Falls district, are equivalent to a part of the Antoine dolomite of the Menominee district.

The great dolomite formation occurring in all of the districts is supposed to be equivalent, except that, as just explained, the deposition of limestone continued longer in the southeastern part of the Crystal Falls district and in the Menominee district than in the remainder of the region. The absence of the limestone and lower formations in the western two-thirds of the Marquette district and the northeastern part of the Crystal Falls district is explained by the fact that during early Algonkian time this part of the region was not submerged. The Mesnard quartzite of the Marquette district and the Sturgeon quartzite of the Crystal Falls and Menominee districts stand opposite each other.

From the foregoing it is apparent that the three districts together present a most interesting and complex structural problem. While there is sufficient similarity in the formations for one to feel considerable assurance of their general equivalence in the different districts, it is certain that the formations of similar kind did not begin and end at the same time. Moreover, there are remarkable lateral transitions in sedimentation, as a result of the uneven surface of the Archean at the beginning of Algonkian time and because of volcanic outbursts. As a result of the first of these conditions, it is necessary to equate fragmental formations which occur in the central and western parts of the Marquette district and the northeastern part of the Crystal Falls district, with nonfragmental limestones in the area to the east and south. Consequent upon the Upper Huronian volcanic outbursts in the Marquette district, the Michigamme and Ishpeming formations are largely replaced by the Clarksburg volcanics. Similar outbursts in the western part of the Crystal Falls district in Lower Huronian time placed volcanic rocks for this part of the district opposite the Mansfield slate and the Groveland iron formation.

The foregoing relations, combined with the great variety and complexity of the sediments of the district, the presence of many forms of contemporaneous volcanic deposits, the intrusion of the widest variety of igneous rocks of various ages from Archean to later Algonkian time, and the complicated folding and metamorphism to which the district has been subjected, will readily convince one that the working out of the detail structure of the district by Messrs. Clements, Smyth, Bayley, Merriam, and others has not been accomplished without most painstaking and laborious work, especially as the region is covered by timber or brush and is overspread by a mantle of glacial deposits.

OUTLINE OF THIS MONOGRAPH.

PART I.

CHAPTER I. The Crystal Falls district is situated on the Upper Peninsula of Michigan, and forms a connecting link between the Marquette and Menominee districts of Michigan. A history of the previous work in the district, accompanied by a summary of the literature, is given, and there is reproduced a series of maps which indicate the development of knowledge concerning the distribution of the rocks and their structural relations. As explanatory of the locations given, the mode of work is described and the object and method of taking magnetic observations is briefly outlined.

CHAPTER II treats of the geographical limits, structure, stratigraphy, and physiography. The portion of the district here described includes approximately 540 square miles. Structurally it is closely related to the Marquette district; the essential features being a northwest-southeast set of folds, with a superimposed series trending northeast-southwest. The oldest rocks belong to the Archean. They cover an oval area which is surrounded by the Algonkian rocks represented by the Lower and Upper Huronian series. The Archean and Algonkian are overlain with strong unconformity by rocks of the Cambrian division of the Paleozoic. The drift deposits of the Quaternary are everywhere present. Only the pre-Paleozoic rocks, however, are discussed. The most noticeable topography is that of the drift, which in places is seen to be superimposed upon pre-Pleistocene topography. The maximum elevation is 1,900 feet above sea level, and the minimum 1,250 feet. The conclusion is reached that this portion of Michigan before Glacial times had been reduced to the condition of an approximate peneplain. The drainage is chiefly by a few large streams which flow into Green Bay of Lake Michigan. A small part is drained by streams flowing into Lake Superior. In portions of the area the drainage has reached an advanced stage, in other portions it is very youthful. The development of the drainage is illustrated in the case of the Deer River. The timber and soil vary much in character.

CHAPTER III treats of the Archean. The rocks of this age form an elliptical core, following the axis of a northwest-southeast trending anticline. Exposures are few because of the superimposed drift. The Archean is overlain unconformably by Algonkian sediments derived from the granite, and there is absence of contact action. These facts indicate that it was the floor upon which the overlying sediments were deposited. Petrographically it consists chiefly of biotite-granite. On the periphery of the area a biotite gneissoid granite is very well developed. Some of this at least is of dynamic origin. The Archean is cut by acid and basic dikes which are now both schistose and massive.

CHAPTER IV treats of the Lower Huronian series. This series is subdivided into the following formations, from the base upward: The Randville dolomite, the Mansfield slate, and the Hemlock volcanics.

Section I. The Randville dolomite is poorly exposed. It consists of quartzose dolomite, grading down into quartz-schist and recomposed granite. It has evidently been derived partly from the granite, and is considerably younger than that. Its relations to the overlying formations were not observed. The thickness could not here be determined, but, in the area studied by Smyth, its maximum is about 1,500 feet.

Section II. The Mansfield slate is best exposed in the vicinity of the town of the same name. It here occupies a valley, through which flows the Michigamme River. Petrographically this formation includes graywackes, clay slate, phyllite, siderite-slate, chert, ferruginous chert, and iron ores, with various metamorphic products derived from them. The slate predominates. The Mansfield slates are intruded by basic igneous rocks, which underlie them. They are overlain by volcanics, which contain fragments of the slates, and are hence younger than they. The Mansfield slates strike north and south and dip on an average 80° to the west. They represent the limb of a westward-dipping monocline. The maximum thickness of the belt is 1,900 feet. Followed south away from the point of maximum thickness it rapidly

thins out and disappears. In the slate but a single ore body of commercial importance has been found. This is exploited by the one Bessemer ore-producing mine of the district. The ore body is presumed to have resulted from the alteration of a siderite, and the concentration in a favorable position of the iron from the portions of the ferruginous beds removed by erosion. A possible continuation of the Mansfield slate is suggested by the occurrence of small outcrops of somewhat similar slates about 5 miles slightly to the west of north.

Section III. The Hemlock formation consists almost exclusively of volcanic rocks, both basic and acid, with crystalline schists derived from them. Sedimentary rocks play a very unimportant role. Exposures are numerous west of the belts of previously described rocks, and where erosion has removed the drift the formation has a marked influence on the topography. The thickness is estimated from the dip to reach 23,000 feet, but this is probably illusory because of reduplication due to folding. In the northern portion of the district the formation overlies the Kona dolomite. In the southern portion it overlies conformably the Mansfield slate. It is probable that volcanic activity began in the north and moved south, and that some of the volcanics to the north are contemporaneous with the Mansfield slates. The volcanics are cut by a few acid dikes. Basic dikes forming enormous bosses of basic rock are of frequent occurrence. The volcanic origin of the major portion of this formation is perfectly clear. Some of the volcanics are submarine. The greater proportion, however, were derived from volcanic vents, which could not be located, but were probably situated near the Huronian shore line. The Hemlock volcanics are divided into igneous and sedimentary rocks. Under the igneous rocks there are described both acid and basic lavas and pyroclastics. Under the sedimentary rocks there are described volcanic sediments, both of eolian and water-deposited character. By extreme metamorphism crystalline schists have been produced from both igneous and sedimentary rocks. The acid volcanics include rhyolite-porphyries and aporhyolite-porphyry. The rhyolite-porphyry shows interesting micropoikilitic textural characters. Some of the porphyries have been rendered schistose by pressure. Acid pyroclastics are scarce and were derived from the aporhyolite. The basic lavas correspond to the modern basalts. They are much altered. To indicate these facts and at the same time show their correspondence to the Tertiary and recent basalts, they are called "metabasalts." The basic lavas include nonporphyritic, porphyritic, and variolitic types. A columnar structure was not observed, but an ellipsoidal structure is very common. This structure is described in detail and the conclusion reached that basalts possessing this structure were originally very viscous and correspond to the modern *aa* lavas. The amygdaloidal structure, which is almost universally present in the volcanics, is described and illustrated. The alteration of the basalts is discussed and special cases described. As result of this alteration the textural as well as the mineralogical characters may be completely changed, and the volcanic origin of the resulting rocks could not be determined but for their association. In the zone of weathering, calcification is the controlling alteration process. In rocks more deeply buried, silicification is the process which predominates. The pyroclastics comprise eruptive breccia, including thereunder friction breccias and flow breccias, and volcanic sedimentary rocks. The eolian deposits, which are described as tuffs, grade from fine dust deposits up into those in which the fragments are bowlders. The water-deposited volcanic fragmentals are known as volcanic conglomerates, and likewise grade from those of which the particles are of minute size into those of which the fragments are of very large size. At various places clastic rocks occur which are now schistose, and whose exact mode of origin—that is, whether eolian or water deposited—could not be determined. Normal sediments consisting of slate with limestone lenses form a lenticular deposit in the volcanics near the top of the formation. They are insignificant in quantity.

Under the Bone Lake crystalline schists there are included rocks of completely crystalline character, hut which by field and microscopical study have been connected with the volcanics and are considered to have been derived from rocks similar in nature to them.

The rocks composing the Hemlock formation are little likely, owing to their somber color, to be much used for building or ornamental purposes. They offer, however, an inexhaustible supply of the best quality of road-building material.

CHAPTER V treats of the Upper Huronian series. This series is connected in the northern part of the area described with the Upper Marquette series of the adjoining Marquette district, and is considered to correspond stratigraphically to the Upper Marquette. Owing to lack of exposures and to the intricacy of folding, the series could not be subdivided. It covers a great area surrounding the Hemlock formation, and extends beyond the limits of the map. The exposures are scanty. It influences the topography only in a very general way, being for the most part heavily drift covered. Its thickness could not be estimated. The rocks of this series wrap around the subjacent Lower Huronian series. The line between them is undulatory. The indentations in the Lower Huronian represent minor cross synclines, and the protuberances represent minor cross anticlines. The most prominent fold of the series is known as the Crystal Falls syncline. The strike of the axis of this syncline is in general to the south of west, and pitches in the same direction. The syncline is not simple, but has minor rolls, as shown in various exposures. This folding has been productive of extensive reibungsbreccias. The folding occurred immediately preceding the deposit of the Keweenawan series in other parts of the Lake Superior region. The Upper Huronian is penetrated by intrusive rocks of acid, intermediate, and basic composition. The rocks constituting the series may be divided into those of sedimentary and those of igneous origin. The sedimentary rocks are graywackes, ferruginous graywackes, micaceous, carbonaceous, and ferruginous clay slates and their crystalline derivatives, and thinly laminated cherty siderite-slate, ferruginous chert, and iron ores. In two places rocks of conglomeratic nature occur. The extensive folding which the series has undergone, coupled with the intrusions of the igneous rocks, has produced crystalline schists from the muds and grits. These are extensively developed in the southern portion of the district in the vicinity of the Paint and Michigamme rivers. The igneous rocks which have penetrated the Upper Huronian subsequent to the folding which affected it are not described under the series. Interlaminated with the crystalline schists there are, however, certain rocks, now perfectly crystalline hornblende-gneisses, which are presumed to have resulted from the metamorphism of either basic intrusive sheets or interbedded flows.

The economic development of the district followed that of the adjoining Menominee district. The exploited ore deposits occur near Amasa, and in the vicinity of Crystal Falls. The ore is hematite and limonite. The grade is non-Bessemer. The ore is associated with white and reddish chert, and this formation lies between carbonaceous slates. The ore bodies in general pitch to the west at varying angles, which correspond to the pitch of the axes of the synclines in which they occur. These minor folds in turn correspond to the western pitch of the main Crystal Falls synclinorium. The ore bodies are concentrates in synclinal troughs, as described by Van Hise for other Huronian districts. The mining is now for the most part undergound, and is carried on in open stopes. The greatest shipment of ore from the area, including the Lower Huronian Mansfield mine, was 586,970 tons in 1892. The total shipment for 1898 reached 325,814 long tons.

CHAPTER VI treats of the intrusives. There is here included a varied assortment of rocks, exhibiting in common intrusive relations to the sedimentary and igneous rocks. The term "intrusive" is not to be interpreted as synonymous with the "dike rocks" of some authors. These rocks are never found to penetrate the Cambrian rocks, and have not been affected by the folding which metamorphosed the Upper Huronian sediments. They are presumed to be of Keweenawan age. The intrusives have in some cases been injected along the axes of the folds, these representing the lines of greatest shattering, and hence least resistance.

In Section I there are described a number of intrusive rocks which can not be connected genetically with one another. These comprise ordinary biotite-granites, with micropegmatitie varieties muscovite-biotite-granite, metadolerite, metabasalt, and picrite-porphyry. Where the granites have intruded the Upper Huronian series they have contorted the strata, and include and metamorphose the rocks, producing muscovite-biotite-gneiss, and staurolitiferous and garnetiferous mica-schists. The metadolerites possess no special points of interest in themselves, but where they have intruded the Mansfield slates they have caused interesting exomorphism. The slates are converted into adinoles, spilosites,and desmosites. Chemical analyses indicate the chief change which has taken place in the production of these rocks from the clay slate to have been in the increase of silica and soda as the contact is approached. There seems thus to have been a direct transference of sodium and silicon

from the igneous rock to the sedimentary. The metabasalt dikes are of little interest. The ultrabasic picrite-porphyries are extremely altered. This alteration has produced in one case chiefly tremolite and in another serpentine. One of these serpentine picrite-porphyries is polar-magnetic. The picrite-porphyries are presumed to have contained a vitreous base, and correspond to the modern Tertiary limburgite.

In Section II there is given a study of a series of rocks varying from those of intermediate acidity through those of basic composition to ultrabasic kinds. The exposures of these rocks are found in an area underlain by the Upper Huronian series, extending from Crystal Falls southeast to and a short distance beyond the Michigamme River. The prevailing rocks are, on the one hand, diorites of intermediate acidity, ranging to more acid rocks, tonalites, quartz-mica diorites, and granite. On the other hand, we have hornblende-gabbros, gabbros, norites, and, lastly, peridotites of varying mineralogical character. Only those kinds of rocks of which analyses have been obtained— mica-diorite, hornblende-gabbro, norite, and wehrlite—are discussed. The diorites are holocrystalline rocks of medium to coarse grain. In texture they show some variation from those which are hypidiomorphic granular to those in which the texture is imperfectly ophitic. As facies of the dioritic magma there are described diorite, mica-diorite, quartz-mica-diorite, tonalite, and plagioclase-bearing granite. A quartz-mica-diorite-porphyry occurs in narrow dikes cutting the mica-diorite. Analysis of the mica-diorite shows it to stand upon the border between the lime-soda feldspar rocks and the orthoclase rocks. The gabbros and norites are noncrystalline rocks of moderately fine to coarse grain. They show considerable variation in texture. The hypidiomorphic granular texture predominates, but some few show a good parallel texture. Others are noticeably porphyritic, a few have poikilitic textures, and less commonly there is an approach to the ophitic texture. Hornblende and labradorite is the most common mineral association, giving typical hornblende-gabbro. A monoclinic pyroxene at times becomes abundant, giving a transition to the normal gabbro. Bronzite at times is the prominent bisilicate constituent of these rocks, giving bronzite-norite. A bronzite-norite-porphyry also occurs. Locally the hornblende-gabbro has been crushed, and there is produced therefrom a schistose rock which represents a transition to a hornblende-gneiss. Of these rocks the hornblende-gabbro was first formed. It was intruded by normal gabbro, and both of these types were then cut by dikes of bronzite-norite and bronzite-norite-porphyry. The rocks included under the peridotites show considerable mineralogical variation. There is produced an amphibole-peridotite, which, when augite becomes predominant, grades to wehrlite. This in its turn becomes feldspathic, and indicates a transition to olivine-gabbro. The amphibole-peridotite also becomes feldspathic and quartzitic, indicating a transition toward diorite. When the order of crystallization of the minerals composing the granular rocks of the entire series described above is considered, it is seen to have been as follows: Bronzite is apparently the oldest. The olivine and monoclinic pyroxene come next and are of essentially the same age. Mica and hornblende follow, and are contemporaneous. Then comes plagioclase, orthoclase, and quartz. A consideration of the chemical analyses of the rocks above described shows them to belong to a series ranging from a diorite, on the one hand, to hornblende-gabbro and norite and to peridotite on the other. On the acid side of the series variations are shown microscopically, but of these rocks chemical analyses have not been obtained. It is not possible to state which of these rocks most nearly resembles in its composition the original magma of which the different types represent the differentiation products. The hornblende-gabbro is that type which apparently first reached its present geological position. It was followed in the acid part of the series by the diorite, which in its turn was succeeded by the diorite-porphyry. Along the basic series hornblende-gabbro was succeeded by gabbro, followed by the bronzite-norite and the peridotite. In general the forces of differentiation have been toward increasing acidity and increasing basicity.

PART II.

CHAPTER I treats of geographical limits and physiography. The geographical limits of the area described are given and a brief statement made concerning the conditions under which the work was done. In the preliminary sketch of the geology the rocks represented are stated to range in age from Archean to early Paleozoic. In that part of the district north and west of the Michigamme River the Arckean is exposed in several regularly outlined oval areas from 10 to 12 miles long and from 2 to 6 miles wide. The intervals between these ovals are occupied by highly tilted metamorphosed sedimentary and igneous rocks of Algonkian age. In the southern and eastern portions of the district the edges of the tilted rocks are covered by the gently dipping Cambrian sandstone. Nevertheless, field work shows that the distribution of the Archean in ovals, which is so characteristic for the areas north, also holds here. The chief surface feature is a rolling plain, which slopes gently to the southeast, and upon which is superimposed the glacial drift with its characteristic topographical features, multitudinous in variety and detail, but insignificant in relief. While the details of the topography are mainly glacial, the broader features have often clearly been determined by the presence of the more resistant Archean and Algonkian rocks. The drainage is to the southeast, mainly into Lake Michigan, through the Michigamme and the Sturgeon rivers. Details of the drainage have been determined by the distribution of the rocks. It is interesting to note that the Michigamme flows along the eastern edge of its drainage basin, having no eastern tributaries.

CHAPTER II treats of magnetic observations in geological mapping. Certain of the rocks occurring in the Crystal Falls district contain magnetite in such quantity that they have a marked influence on the magnetic needle. Advantage is taken of this fact in the mapping of the rocks where exposures are wanting. The instruments and methods of work used in making magnetic observations are described. Facts of observation are mentioned, and general principles are laid down. Application of these principles to special cases is then considered, and finally a description of the method used in the interpretation of complex structures follows.

CHAPTER III. In Section I the position, extent, and previous work done in the Felch Mountain range is described. An abstract of the literature covering the area is given.

Section II contains a general sketch of the geology of this range. The rocks range from Archean to early Paleozoic. These last are not considered for the present. The Archean is distributed in areas which represent the cores of large arches formed over the whole region by mountain building energy, and subsequently truncated by deep Cambrian denudation. The rocks, chiefly of sedimentary origin intermediate between the Archean and Paleozoic, to which the name Algonkian is applied, occupy a narrow strip ranging from a mile and a half to less than a mile in width, and extending east and west for a distance of over 13 miles. This strip constitutes the Felch Mountain range. It is bordered on the north and south by the Archean. The lowest part of the Algonkian occupies parallel zones next to the Archean both on the north and on the south, and is succeeded toward the interior of the strip by the younger members. The general structure therefore is synclinal, but is not simple. The strip contains two or more synclines separated by anticlines. They have likewise been affected by cross folds, which give a different pitch to the axes of the east and west folds. The structure is also complicated by faulting. The Algonkian is divided into two series separated by an unconformity. In the first occur, from the base upward, the Sturgeon quartzite, the Randville dolomite, the Mansfield schist, and the Groveland iron formations. Above these follows a younger series which is undivided.

Section III treats of the Archean. This limits the Algonkian rocks on the north and south, and is very well exposed. The topography is very rough. Usually, but not always, a topographical depression, occupied by a swamp or by a stream, exists along the contact between the Archean and the Algonkian. Petrographically the Archean consists of (1) granites or granitic gneisses, (2) gneisses, (3) mica-schists, (4) hornblende-gneisses, or amphibolites. The granites possess the usual characters of such rocks. The gneissoid members of this division are merely crushed granites and are connected with the massive rocks by indistinguishable gradations. The gneisses are banded laminated rocks, the minerals of which have crystallized in parallel elongated forms. Subsequent to crystallization they have been acted on by great stresses. The mica-schists are even, medium-grained rocks, with generally well-developed schistosity. The original character of these schists is wholly indeterminable. Their relationship with the granites and gneisses is perhaps a reason for regarding them as derived from originally massive granites by dynamic metamorphism. The hornblende-gneisses, or amphibolites, are black or dark-green rocks, which are universally foliated. They occur in narrow bands in the

granites and gneisses. Their boundaries are sharp and frequently cut the foliation of the amphibolites and of the gneisses. The field relation as well as the composition of the amphibolites leads to the conclusion that they are old dikes of basic rocks which have been metamorphosed and recrystallized.

Section IV treats of the Sturgeon quartzite. The Sturgeon formation is the most widespread ; member of the Algonkian series in the Felch Mountain range. It occurs in two parallel zones of varying width, immediately adjoining the Archean to the north and to the south, except when displaced from this position by faults. It is fairly well exposed. It frequently forms distinct lineal ridges, which, with but few exceptions, seldom rise to the mean altitude of the adjoining Archean. Owing to the completeness of recrystallization, the original sedimentary features have almost been obliterated, so that it is difficult to find places suitable for dip observations. Sufficient dips have been found to show that subordinate folds occur within the quartzite. The average thickness is probably not less than 450 feet, and may be more. Petrographically the formation includes massive quartzites and mashed quartzites or micaceous quartz-schists, in some of which the relations of the quartz present unusual features.

Section V. The Randville dolomite, consisting of crystalline dolomitic rocks, overlies the Sturgeon quartzite. The Randville dolomite covers a larger share of the surface in the Felch Mountain range than any other member of the Algonkian. Natural exposures are fairly numerous and very evenly distributed. Moreover, test pits and diamond-drill borings have shown the presence of the formation in the covered areas. Relatively the dolomite is a weak rock, and occupies relatively low ground. An average thickness of 700 feet is estimated for the Randville dolomite within the Felch Mountain range. Petrographically the formation consists of a rather coarse-grained, thoroughly crystalline dolomite, with more or less abundant crystals of tremolite and a number of other minerals of minor importance.

Section VI. The Mansfield schist is only exposed in certain test pits. Its presence has also been determined by diamond-drill borings. The thickness is so small—not more than 200 feet—that, though it weathers readily, it produces no noticeable effects on the general topography. Petrographically it consists of fine-grained mica-muscovite or mica-biotite-schists, probably derived from the metamorphism of a clastic. It shows nothing of especial interest.

Section VII. The Groveland formation is magnetic and has been traced, by means of compass and dip needle. Excellent natural as well as numerous artificial exposures render the data concerning the distribution of the formation very satisfactory. The most prominent hills in the Algonkian belt owe their relief to the fact that they are underlain by the Groveland formation. Petrographically we may recognize two main kinds of rock. The usual kind consists of quartz and the anhydrous oxides of iron, while the other and much rarer consists essentially of an iron amphibole with quartz and the iron oxides as associates. Both of these kinds are clearly of detrital origin. The conclusion is reached, based on certain microscopical structures, that iron and silica were originally present largely in the form of glauconite.

Section VIII. Mica-schist and ferruginous quartzites of the Upper Huronian series occur in the eastern part of the Felch Mountain range. The rocks constituting the series are soft iron-stained mica-schists, with thin, interbanded beds of ferruginous and micaceous quartzite. Neither kind shows traces of clastic origin. From their structures and general relations they are believed to have been derived from sedimentary rocks by metamorphism.

Section IX. The Algonkian rocks are cut by intrusives, among which both acid and basic rocks are represented. The acid rocks are granites occurring in narrow dikes. No dikes of granite are known to cut the Randville or Mansfield formations.

Chapter IV treats of the Michigamme Mountain and Fence River areas. These areas occur in the central part of the district. In the Fence River area the structure is very simple. In the Michigamme Mountain area the structure is complex.

Section I treats of the Archean. The prevalent rock is granite, cut by acid and basic dikes.

Section II treats of the Sturgeon formation. This is scarcely known as a distinct Algonkian member in this area apart from the Randville formation. In one section purely clastic sediments were observed, for which it is convenient to retain the name. These exposures consist of slates and graywackes, with some layers of a coarser texture.

Section III treats of the Randville dolomite. In the Fence River area the dolomite lies on the east side of the Archean and occupies a belt about one-half mile in width, and extending from the mouth of the Fence River about 10 miles to the north and west, where it leaves the portion of the district studied. In the Michigamme Mountain area the dolomite tops the low arch in a broad crumpled sheet. The formation in the Fence River area occurs in an eastward-dipping monocline with a number of minor plications. An average thickness of about 1,500 feet is estimated for the formation in this area. In the scattered outcrops of the Michigamme Mountain area the dolomite strikes and dips toward all points of the compass, caused by the gentle arching from the general northwest-southeast axis, combined with sharp local folds which run nearly east and west. Petrographically the formation ranges from coarse saccharoidal marbles, sometimes very pure but usually filled with secondary silicates, to fine-grained, little-altered limestones, which are occasionally so impure as to be calcareous or dolomitic sandstones and shales. The prevalent colors are white, but various shades of pink, light and deep blue, and pale green occur. Some of the varieties are oolitic. This structure does not seem to have been noted previous to this in limestones of pre-Cambrian age.

Section IV treats of the Mansfield formation. The typical locality of this formation is in the vicinity of the Mansfield mine, which lies to the west of the district studied. Where it occurs in the Michigamme Mountain area, the formation consists of phyllites or mica-slates of various colors. The structure of this area is so complex and the outcrops so few as to forbid any but an approximate outlining of the general boundaries of the formation. The geological position of the formation is free from doubt. It overlies and passes downward into the Randville dolomite. The formation does not seem to influence the topography. Like the preceding one, it has been extensively folded. The average thickness is probably not less than 400 feet. The mica-slates or phyllites possess no especial petrographical interest.

Section V treats of the Hemlock formation. The Mansfield formation of the Michigamme Mountain area changes along the strike into rocks of a different character, to which the above name is given. In the Fence River area it occupies a belt between 2,000 and 3,000 feet in width, between the Randville dolomite on the west and the Groveland formation on the east. The best exposures occur on the sections made by the Fence River. No folds have been observed within this formation. The thickness probably varies from 0 to 2,300 feet as a maximum. The rocks of the formation are chiefly chloritic and ophitic schists, with which are associated schists bearing biotite, ilmenite, and ottrelite; greenstone, conglomerates or agglomerates, and amygdaloids. The general characters of the schists are (1) a groundmass composed of chlorite, quartz, magnetite, epidote, and in some cases plagioclase microlites, and (2) the presence in this groundmass of much larger porphyritic individuals of several secondary minerals. As evidence of the origin of these schists, first, there is the absence of rocks possessing any sedimentary characters; next, lavas and also greenstone-conglomerates or agglomerates are undoubtedly present in the series; furthermore, the minerals which compose the schist are those which would result from the alteration in connection with dynamic metamorphism of igneous rocks of basic or intermediate chemical composition; and finally, the grain and character of the groundmass, and in some slides the presence of plagioclase microlites disposed in oval lines point directly to an igneous origin and to consolidation at the surface. The conclusion is readied that the Hemlock formation of the Fence River area is composed of a series of old lava flows varying in composition from acid to basic.

Section VI treats of the Groveland formation. This is of wide extent throughout this part of the Crystal Falls district, but its outcrops are limited to three localities. Its distribution has been determined by means of its magnetic properties. It is not topographically prominent, except in the Michigamme Mountain area, where it forms part of Michigamme Mountain. In the Fence River area it is probably not folded. It there dips to the east. At Michigamme Mountain it is found in several well-marked folds. The thickness of the formation is estimated to be approximately 500 feet. The rocks are interbanded ferruginous quartzite and actinolite and grünerite schists, which still contain evidence of detrital origin.

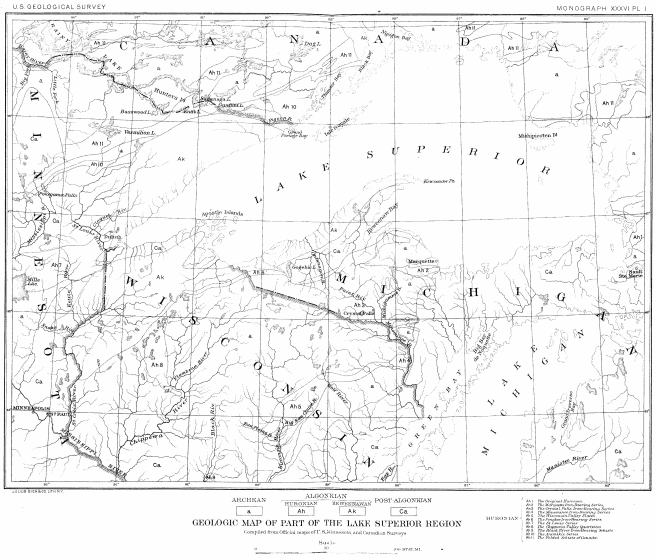
Chapter V treats of the Northeastern area and the relations between the Lower Marquette and the Lower Menominee. The territory included in the Northeastern area extends from the northernmost outcrops of the Fence River area to the northern end of the Republic trough, a distance of about 11 miles. Outcrops are scarce throughout this area, and the main conclusions are drawn from the magnetic work. Through the structural and lithological results of the magnetic work the gap between the Marquette and the Crystal Falls district is bridged, and it is shown with a high degree of probability that the Negaunee iron formation of the Marquette range is identical with the Groveland iron formation of the Felch Mountain range.

Chapter VI treats of the Sturgeon River tongue. In the southeastern part of the Crystal Falls district and just north of the Felch Mountain range a tongue of fragmental rocks extending eastward has been studied. The extreme length is 12 or 13 miles. Its width at its eastern end is 1½ miles; to the west it widens rapidly. It is bounded both to the north and to the south by Archean granites and schists; to the east it is overlain by Paleozoic sandstones and limestones; and at its west end it is covered by glacial deposits. Within the tongue two small granite islands occur. The Archean or Basement Complex rocks comprise gneissoid granites, hornblende-schists, and biotite-schists, which are cut by dikes of greenstone and granite, and veins of quartz. The sedimentary rocks comprise conglomerates, arkoses, quartzites, sericite-schists, clay slates, rocks that are probably tufaceous, dolomitic limestones, and calcareous sandstones and slates. They may be divided into a conglomerate series and a dolomite series. From the distribution of the exposures of the two series it is concluded that the conglomerate series is the older, and that conformably above it follows the dolomite series. The two form a westward-pitching syncline. The conglomerate series and the dolomite series are correlated respectively with the Sturgeon quartzite and the Randville dolomite of the adjoining Felch Mountain range.

THE CRYSTAL FALLS IRON-BEARING DISTRICT OF MICHIGAN

Part I.—THE WESTERN PART OF THE DISTRICT

By J. MORGAN CLEMENS



[Plate I. Colored map showing the distribution of pre-Cambrian and other rocks in the Lake Superior region, and the geographical relations of the Crystal Falls district of Michigan to the adjoining Marquette and Menominee districts of Michigan]

CHAPTER I. INTRODUCTION.

The present report is an account of a portion of the Crystal Falls district of Michigan, so called from the most important town, Crystal Falls, the county seat of Iron County. The iron-bearing district along the Paint River, near the site of the town of Crystal Falls, was first called in literature the Paint River district by Brooks.[1] As soon as the town was begun, about 1880, the name of the town was applied to the district.[2] It is situated on the Upper Peninsula of Michigan, adjoining the northeastern border of Wisconsin, and serves as a link connecting the two well-known iron-ore-producing districts of Michigan, the Marquette, and the Menominee. The Crystal Falls district is of itself of considerable economic importance, as will be seen, though not deserving to be ranked with either of the two above-mentioned iron districts. Since the geological relations of the rocks

[1]The iron-bearing rocks (economic), by T. B. Brooks: Geol. Survey of Michigan, Vol. I, Part I, 1873, p. 182.

[2]Rept. Com. Min. Statistics Mich. for 1881, p. 222.

of the Marquette district have now been ascertained,[1] it is hoped, by means of the determination of the succession in the intermediate Crystal Falls district, that the Menominee rocks may be closely correlated with those of the Marquette district.

The accurate, delimitation of the iron-bearing or coal-bearing formations, or any other formations containing valuable mineral products, is of inestimable value to miners and investors. In the iron districts of Michigan alone innumerable test pits have been sunk in areas of solid granite, and at great distances outside of the possible iron formations, thus wasting large sums of money. Although the investigations carried on in the Crystal Falls district, the results of which are here recorded, do not enable us to point out definitely the places where the prospector will find iron deposits, they have enabled us to delimit in a broad way the various formations, and warrant the statement that iron deposits may occur in certain areas and that the prospector will assuredly not find iron deposits in certain others.

The opportunity of studying the Crystal Falls district was given me through Prof. C. R. Van Hise. In the prosecution of the field studies and in the preparation of the report I have availed myself of his advice and suggestions, which have been generously offered and which have been found of greatest value. To him I am most deeply indebted.

The report is based not only on my own field work, but also on the field work done by a number of other geologists, whose notebooks have been placed at my disposal. The names of these geologists may be found on page 22. Among them, the notes of Mr. W. N. Merriam and Dr. W. S. Bayley have been found especially valuable. Mr. Merriam, assisted by Dr. Bayley, spent a season in doing very detailed work on the area shown on the sketch map at the bottom of Pl.

III, between Crystal Falls and Mansfield, and from this point northwest to some distance beyond Amasa. The magnetic lines represented in this part were traced by Mr. Merriam, and the geology in general is the same that he outlined on his final field map

I wish to thank Mr. C. K. Leith, who has been of the greatest clerical assistance, and Mr. E. C. Bebb, by whom the maps were drawn; also Mr. J. L. Ridgway, by whom the colored plates of natural size specimens were prepared.

[1]The Marquette iron-bearing district of Michigan (preliminary), by C. R. Van Hise and W. S. Bayley; with a chapter on the Republic Trough, by H. L. Smyth: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 477-650. Ibid, (final), Mon. U. S. Geol. Survey, Vol. XXVIII, 1897.

PREVIOUS WORK IN THE DISTRICT.

On account of its comparatively slight economic importance, and also on account of its isolation, very little work of which the results have been published was done in this district prior to that on which this monograph is based. As a rule, the earlier observers began the season's work either in the Marquette or in the Menominee range, and working westward the Crystal Falls district was reached only as the season neared its close, or as the appropriation was nearly exhausted. The published work upon this district is given below in chronological order.

1850.

BURT, WM. A. Report of linear surveys with reference to mines and minerals, in the Northern Peninsula of Michigan in the years 1845 and 1846. Dated March 20, 1817. Thirty-first Congress, first session, 1850; Senate documents, Vol. Ill, No. 1, pp. 842-882, with map.

During the year 1846 a linear survey was made of that part of the Upper Peninsula of Michigan described as being bounded on the north by the fifth correction line, on the south by the fourth correction line and the Brule River, on the east by ranges 23 and 26 W., and on the west by range 37 W. This includes in its limits the district under discussion. In the course of the survey, geological observations were made by William A. Burt, the deputy surveyor in charge of the work. The report and accompanying geological map embodying the results of these observations are concealed among the Senate documents of the Thirty-first Congress. The following quotations from this report give all the observations on the part of the territory surveyed in which we are at present interested:

Topography.—West of range 31 west, and north of the Brule River to the fifth correction line, is a tract of about 43 townships in which the rock is mostly greenstone and hornblende slates. This part of the surveyed district is less broken than that above described, and a large proportion of it may be denominated rolling lands. There are, however, many ridges and conical hills of various heights upon this part of the survey, and also deep valleys of streams, many of which have ledges upon their sides. These general characteristics are often changed for cedar, spruce, or tamarack swamps, which are most numerous in townships 46, 47, and 48 N. [This includes the part of the district supposed to be the continuation of the northern Wisconsin peneplain (p. 31).]

Granite (and syenite).—These rocks occupy an area of about 22 townships on the northeast part of the survey, between the fifth correction line and the south boundary of township 45 N., and east of range 32 W., in a series of irregular uplifts, frequently forming- high cliffs and sloping ledges on the most elevated portion of this district. [This covers a part of the Archean granite oval of the Crystal Falls district, as well as the large Archean areas northeast of it.]

Argillaceous slates.—The argillaceous slates alluded to in townships 42 and 43 N. are generally overlaid by deep drift; their boundaries, therefore, could not be satisfactorily defined. West of the Peshakumme River these slates appeared to have undergone considerable change by igneous action, and were often associated with an oxide of iron; but east of the Peshakumme no change by igneous action in the slates was observed, and on this part they have generally a reddish color. . . . .

They dip variously at a high angle, and are supposed to conform to the greenstone on the north and west, and to overlie or pass into the mica-slates on the south; and in their middle portion they dip about 90°, with strike nearly east and west. [These slates correspond to our least metamorphosed phases of the Upper Huronian.]

Greenstone and hornblende slate.—These rocks occupy a larger area in the district surveyed than any other class of rocks. They extend from the granitic and other rocks east of them westward beyond the survey. [See their outline on map, fig. 1.]

The greenstone and hornblende slates form a less broken surface than the granitic range; and next to it is the most elevated range in this district, having an estimated altitude, in many places, of from 1,000 to 1,100 feet above Lake Superior.

These rocks are frequently seen in the beds and banks of streams and in ridges and conical hills of various heights, often forming precipitous ledges upon their sides. . . .

The greenstone of this region is generally more or less granular and syenitic, with a dark green color when moist; its composition is hornblende, feldspar, and quartz—the former mineral greatly predominating. In some places the feldspar and quartz are nearly or quite wanting, leaving a granulated hornblende rock. Another variety of this rock was frequently seen which was composed of the same ingredients but very fine grained and compact and having frequently a laminated or slaty structure, the cleavages of which generally dip from the granitic rocks at a very high angle. . . . .

Some of these hornblende slates have in their seams and cleavages a silky luster, from the presence of mica or talc in very fine grains. . . . .

All of these rocks are traversed by many quartz veins, from a line to 4 feet or more in width, and with still larger veins and dikes of more recent trap rock. This range is supposed to have become blended with the trap range of Keweenaw point as it passes under the red sandstone lying between them, and probably farther west the two are united in one range. [These are the altered and more or less schistose basalts and accompanying fragmentals which are comprised in the Hemlock formation.]

Mica-slates.—These slates stretch along the southerly side of the argillaceous slates on the south part of the survey. They extend from the Brule River on a course east- northeast for

about 22 miles, in townships 41 and 42 N., ranges 29, 31, and 32 W., and have an average breadth of about 4 miles. . . . .

The mica-slates are supposed to dip northerly under the argillaceous slates at a high angle, varying at the surface from 45° to 80°. . . . .

This rock is composed of mica, quartz, and feldspar. Its laminæ are undulating or waved, but its cleavages, on a large scale, are even and regular. . . . .

These mica-slates are best developed on the south boundary of township 42 N., ranges 31 and 32 W., in the beds and banks of the Peshakumme and Mesqua-cum-a- cum-sepe, and at the falls near the junction of the latter stream with the Brula River. [These, according to our observations, are the most altered phases of the Upper Huronian.]

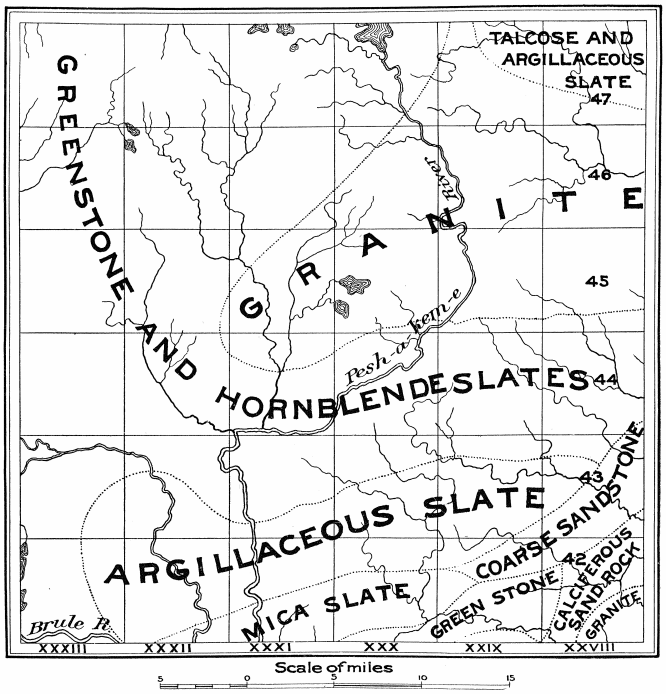


FIG. 1.—Reproduction of a portion of the geological map of the Upper Peninsula of Michigan by Wm. A. Burt, 1846.

That part of the geological map accompanying the above report which corresponds to the Crystal Falls district is reproduced in fig. 1.

1851.

FOSTER, J. W., AND WHITNEY, J. D. Report on the geology of the Lake Superior land district. Part II. The iron region, together with the general geology. Thirty-second Congress, special session, 1851; Senate documents, Vol. III, No. 4, pp. 406, with maps and section.

In 1851 there was published a report by Foster and Whitney on the iron regions of the Lake Superior land district, together with the general geology. This gives the first connected account of the results obtained by the various surveyors who had been engaged on the Government survey of the Upper Peninsula of Michigan. Accompanying this report there are two colored maps and a section. The subdivisions of the rocks as made by Burt in the Crystal Falls district are not retained in this report by Foster and Whitney. The map is generalized, and the hornblende-slates, etc., of Burt are included under the general term "crystalline schists," and are placed by the authors in the Azoic system. There are represented here and there throughout this Azoic area a trappean knob and bed of marble.

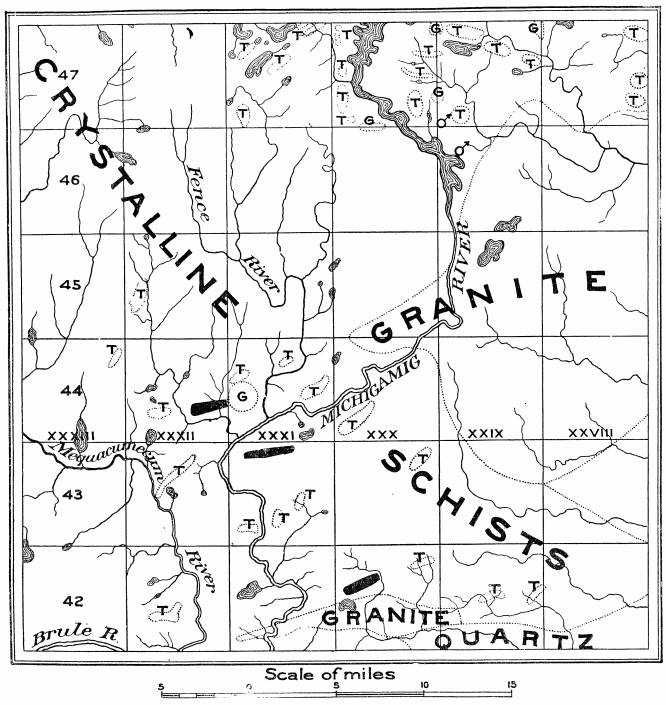
The granite area shown on Burt's map is very much reduced in size, and no longer connected with the large granite areas to the east. The granite on the lower reaches of the Michigamme, in T. 42 N., R. 31 W., is here indicated for the first time. In these respects only does this portion of the map show a decided advance in knowledge of the distribution of the rocks. A copy of the map, showing the distribution of the rocks by symbols instead of colors, is reproduced as fig. 2.

1873.

Brooks, T. B. The iron-bearing rocks (economic). Geol. Survey of Michigan, Vol. I, Part I, 1873, pp. 319. With Atlas Plate IV and general map, by Rominger, Brooks, and Pumpelly.

The next mention of the district that I have been able to find was made in 1873 by Maj. T. B. Brooks, in his report on the iron-bearing rocks of Michigan.

However, this report seems to show a decided decrease in knowledge from that possessed by Burt concerning the geology of this district. It is true that indications of iron had been seen, but the observations made were so meager that nothing could be done toward determining the relations of the rocks or unraveling the structure of the area.



[FIG. 2. Enlarged reproduction of a portion of a map of the Lake Superior land district, by Foster and Whitney]

Upon the map accompanying the report (Geol. Survey of Michigan, 1873), a portion of which is reproduced in fig. 3, Brooks has failed to outline the granitic areas known to the previous explorers. Except in a few places, which have been left uncolored, the district is covered with the color representing the Huronian.

Brooks refers the ore-bearing rocks to the Huronian in the following words:

Too little is known about the remote Paint River district, in townships 42 and 43, ranges 32 and 33, to enable me to give anything of interest regarding its geological structure. The Huronian rocks are extensively developed there, and contain deposits of hard hematite ore. I had the opportunity to examine only two localities at the Paint River Falls, sec. 20, T. 43, R. 32, and sec. 13, T. 42, R. 33, (p. 182).

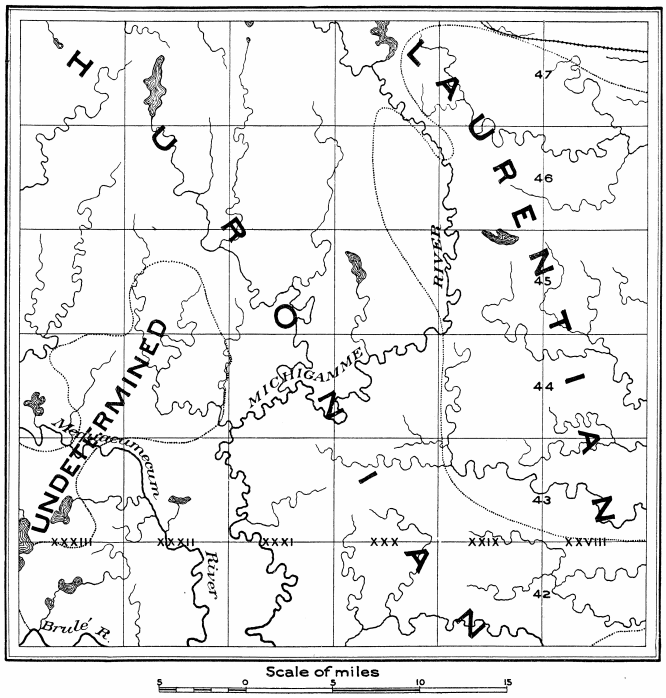
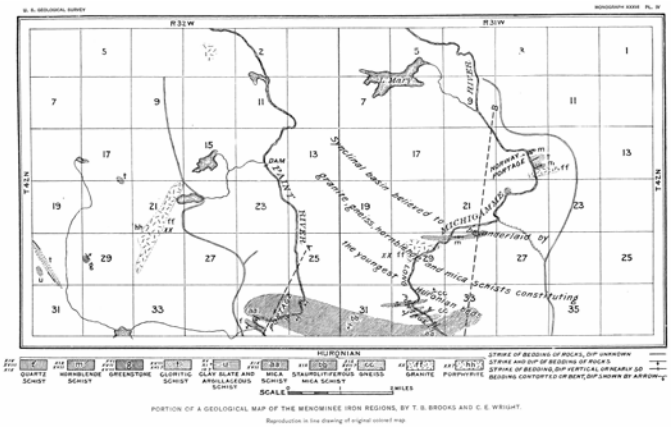


FIG. 3.—Enlarged reproduction of portion of a geological map of the Upper Peninsula of Michigan, by C. Rominger, T. B. Brooks, and R. Pumpelly, 1873.



[Plate IV. Portion of a geological map of the Menominee iron region, by T. B. Brooks and C. E. Wright]

He also gives his analysis (No. 68, p. 302 of Brooks's report) of an ore sample from the district, and calls attention to its abnormally high water content, freedom from silica, and richness in iron as compared to those of the more eastern mines in the Menominee region.

1880.

BROOKS, T. B. Geology of the Menominee region. Geol. Survey of Wisconsin, Vol. III, Part V, 1880, pp. 430-655. Atlas folio, Pls. XXVIII and XXIX, and Pl. XXX, by G. E. Wright.

In an article on the geology of the Menominee region, which was written for the geological survey of Wisconsin, the same author briefly touched on that part of the adjoining Michigan territory which is included in the district under consideration. His observations were thus confined to a few exposures in a limited portion of the area. He attempts to correlate certain beds by means of their lithological character with those with which he was familiar in the Marquette district and refers them uniformly to the higher members of the Huronian.

They are also so referred on the map which accompanies the report, though this is dated a year earlier than the date of publication of the report. That portion of the map covering a small part of the Crystal Falls region is reproduced on Pl. IV. The present survey enables us to add very little to this, and these additions are chiefly of a petrological character.

1881.

ROMINGER, CARL. Geology of the Menominee iron region. Geol. Survey of Michigan, Vol. IV, 1881.

In 1880 Dr. Carl Rominger, at that time State geologist of Michigan, spent a season in the Menominee district, and in his report gives detailed descriptions of a few occurrences in the Crystal Falls district, to which I shall refer later on. He considers the rocks in general to belong to the Huronian, and distributes the beds among his diorite group, iron-ore group, and arenaceous-slate group, as given and defined in the previous report on the Marquette district No attempt at more definite correlation was made.

1890.

VAN HISE, C. R. An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy. Am. Jour. of Sci., 3d series, vol. 41, 1891, p. 133.

On December 30, 1890, Prof. C. R. Van Hise read a paper on Lake Superior stratigraphy before the Wisconsin Academy of Sciences, Arts, and Letters, the same article being published the following year in the American Journal. The iron-bearing series of this district was in this article referred to the Upper Marquette (Upper Huronian).

1893.

WRIGHT, C. E. Report of State geologist from May 1, 1885, to June 1, 1888, in Rept. of the State Board of Geol. Survey of Michigan, 1893, pp. 33-44.

State geologist, Charles E. Wright, in a report for the seasons from 1885 to 1888, inclusive, merely mentions

the general strike of the rocks of the district, and makes no attempt to determine their age nor to unravel the structure.

WADSWORTH, M. E. Sketch of the geology of the iron, gold, and copper districts of Michigan. In Rept. of State Board of Geol. Survey for years 1891-92, 1893, pp. 75-186.

Dr. M. E. Wadsworth, who on Mr. Wright's death succeeded him as State geologist of Michigan, mentions the occurrence of carbonaceous slates, of granite and melaphyre, and of conglomerate near Crystal Falls, but does not enter into a discussion of the relations of any of these rocks. Dr. Wadsworth agrees with the correlation of Professor Van Hise, and places the Crystal Falls ore deposits in the Upper Marquette series (Wadsworth's Holyoke formation) (pp. 117, 132), but the evidence for so doing is not given in the report. He also is the first to recognize the volcanic nature of the rocks in the vicinity of Crystal Falls (p. 134).

1895.

ROMINGER, C. Geol. rept. on the Upper Peninsula of Michigan. Geol. Survey of Michigan, Vol. V, Part. 1, 1895, pp. 1-164.

In his report of work done on the Upper Peninsula of Michigan from 1881 to 1884, published in 1895, he follows the same plan, referring the various rocks exposed by mining operations to his different groups.[1]

CLEMENTS, J. MORGAN. The volcanics of the Michigamme district of Michigan. Jour, of Geol., Vol. Ill, 1895, pp. 801-822.[2]

In a preliminary article on this district, by the writer, published in 1895, the volcanic character of the rocks which cover a large area of the Crystal Falls district was emphasized, and in a sketch map in the same article was given an outline of the distribution of the various rocks for a portion of the district, with their stratigraphical succession (p. 803), the discussion of the structure and correlation being left for the present report.

[1]Geol. Survey of Michigan, Vol. IV, 1881, p. 8.

[2]After the publication of this article, the name Michigamme having been applied to a formation, it was deemed advisable, in order to avoid confusion, to change the name of the district to the Crystal Falls district.

The above-mentioned sketch map, with the maps by Burt, Foster and Whitney, Brooks, Brooks and Wright, the section by Foster and Whitney, and the section by Brooks, along the Paint and Michigamme rivers, are the only maps or sections which, so far as can be learned, have been published of that part of the Crystal Falls district under discussion.

MISCELLANEOUS REFERENCES.

JULIEN, ALEXIS A. Appendix A. Lithology. Geol. of Michigan, Vol. II, 1873, pp. 1-185.

WICHMANN, ARTHUR. Microscopical observations on the iron-bearing rocks from the region south of Lake Superior. Brooks's Geol. of the Menominee Iron Region, 1880, Chap. V, pp. 600-655.

WRIGHT, CHARLES E. Geology of Menominee Iron Region. Geol. of Wisconsin, Vol. Ill, Part 8, 1880, pp. 665-741.

LANE, A. O. In sketch of the geology of the iron, gold, and copper deposits of Michigan. Rept. of State Board of Geol. Survey for 1891-92, 1893, p. 182.

PATTON, H. S. Microscopic study of some Michigan rocks. Rept, of State Board Geol. Survey for 1891-92, 1893, p. 186.

During the progress of the Michigan and Wisconsin State surveys specimens from outcrops were collected, and descriptions of these disconnected specimens are found in the State reports.

References to the pages on which the individual descriptions may be found will be given under the petrographical discussion of similar rocks here described.

UNPUBLISHED WORK.

In 1891 a survey was organized by a private corporation, and put in charge of Prof. C. R. Van Hise. He consented to take charge of this work on the conditions that all maps and notes should be available for this report and that no other compensation was to be made by the company. The object of this survey, known as the Lake Superior survey, was to study that part of Michigan of which Crystal Falls is the center, in order to determine the feasibility and advisability of opening up the mines of that district. This survey was vigorously prosecuted, and an excellent topographic map made of an area 32 miles north and south and 42 miles east and west, covering a large part of four 15-minute atlas sheets of the United States Geological Survey. At the same time, in connection with the topographic work, a reconnaissance geological survey was made.

The following is a list of those who took geological notes for this survey: Andrews Allen, A. H. Brooks, W. S. Bayley, J. P. Charming, E. T. Eriksen, J. R. Finlay, F. J. Harriman, F. T. Kelly, E. B. Matthews, E. R. Maurer, J. A. McKim, F. W. McNair, W. N. Merriam, and H. F. Phillips.

The following season was devoted to a detail study of the iron-bearing belts which had been outlined by the reconnaissance. This detail work in the western part of the district was prosecuted by parties in charge of W. N. Merriam, and in the eastern part of the district by parties in charge of H. L. Smyth. When they ceased work, the two areas mapped were separated in the north by about 12 miles, and a narrow belt separated the mapped areas to the south. During the season of 1894, under the direction of Professor Van Hise and assisted by Gr. E. Culver, and during part of the season by S. Weidman, I was engaged in completing this unfinished work for the United States Geological Survey, preparatory to connecting this district with the Menominee iron-bearing district to the southeast. This work was carried on in 1895 by Dr. W. S. Bayley, S. Weidman, and myself, and the mapping of the district extended as far as the Menominee district.

Mr. H. L. Smyth has written Part II of the present report, covering the portion of the district which was worked by his party. My description of the part of the district

worked by me is based largely on my own observations. Many of the facts of field occurrence, however, mentioned in the following paper were observed and recorded by the several men mentioned above, and were subsequently verified by my own observations in portions of the area surveyed by myself, and by visits to localities in other portions.

The topography of the greater portion of the district was taken by the members of the Lake Superior Survey. The remainder we owe to the topographical division of the United States Geological Survey. The areas covered by the respective organizations are shown on the sketch map below the topographical map (Pl. II).

MODE OF WORK.

As explanatory of the locations given in the paper, it is perhaps not out of place to give a brief description of the plan of work followed by the Lake Superior Division of the United States Geological Survey in this as well as in the other Lake Superior iron-bearing districts which have been previously surveyed.

The Upper Peninsula of Michigan affords an excellent example of the excellence which can be obtained in the rectangular land survey, when properly carried out by the Government. The section corner posts originally established are in many cases still to be seen, and of course the bearing trees are even more common. Since the original survey the timber value has increased so much that in certain forested areas the section lines have been resurveyed. Not uncommonly trails follow the section lines for long distances. Moreover, the roads are frequently laid out along the section lines, thus giving permanent land boundaries. The section corners consequently offer the most reliable points from which to make locations.

Traverses are made across each section, either from east to west or from north to south, and at varying intervals, according to the discretion of the geologist and the exigencies of the case. Each geologist is accompanied by a compassman, whose duty it is to determine the course of the traverses by means of a dial compass, and the distance traveled by pacing at the rate of 2,000 steps to the mile. Corrections are made at the corner and quarter posts. The compassmen employed are Michigan woodsmen, land lookers or cruisers as they are frequently called, and it is remarkable with what accuracy they will pace mile after mile through swamp and over rough hills, windfalls, etc.

The geologist explores the territory on both sides of the line followed by the compassman. Ledges are located by the geologist pacing to the compassman as he comes opposite him in a due east-west or north-south direction. With two coordinates thus determined, the ledges are located with reference to the starting point. For uniformity and to facilitate reference and cataloguing, it is customary to give the location with reference to the southeast corner of the section. Thus, 1,000 N., 1,000 W., SE. cor. sec. 5, T. 42 N., R. 33 W., gives the location of the outcrop at the center of the section, and affords a means of finding that ledge which could not be so accurately and concisely stated by the use of any ordinary landmarks. Moreover, easily recognized landmarks, such as houses, quarries, etc., are few, and exceedingly great changes may occur very rapidly, such, for instance, as those caused by widespread forest fires, so that such a method of location is practically valueless.

MAGNETIC OBSERVATIONS.

It has long been known that many rocks are possessed of decidedly magnetic properties, due to the presence in them of varying quantities of magnetic iron ore. By the mining engineers and prospectors this property has been turned to a practical use in aiding in the location of iron mines where the ore is of a magnetic kind. It is only in the past three decades that this property has been used to any extent by geologists as an aid in the interpretation of the structure of a region. So far as I can learn, the best published account of its use thus is in Brooks's report on the iron-bearing regions of Michigan.[1] Conclusive proof of its geological value was given in the mapping of the Penokee area, in 1876, by R. D. Irving of the Wisconsin survey.[2] That area extends for about 60 miles northeast-southwest, and is on the average about 4 miles wide. For the eastern part of the Wisconsin area the outcrops are few, and Irving located the iron formation by magnetic work. Along that belt have been sunk shafts belonging to various mines which have raised quantities of ore, and in no case has a shaft sunk outside of the limit indicated by Irving come upon paying ore.

By means of the dip needle and solar compass, observations were taken which enabled us to trace a curving magnetic formation and connect the outcrops, which were separated by about 16 miles. The same bed was further delimited, and the direction partly checked, by the occurrence, at varying distances along this course, of outcrops of rocks of the underlying formation.

Since the second part of this report contains an exhaustive article on the methods and use of the magnetic needle,[3] the subject is not further treated here. The lines of maximum magnetic disturbance—or briefly, the magnetic lines—are represented on the accompanying general map, PI. III, by blue lines marked with letters *D* and *E*.

[1]Magnetism of rocks and the use of the magnetic needle in exploring for ore, by T. B. Brooks. Geol. Survey of Michigan, Vol. I, Part I, 1873, pp. 205-243.

[2]Geol. of the eastern Lake Superior district, by R. D. Irving. Geol. of Wisconsin, Vol. III, 1880, pp. 53-238. Atlas sheets, XI-XXVI.

[3]See Part II, Chapter II, by H. L. Smyth, pp. 336-373.

CHAPTER II. GEOGRAPHICAL LIMITS, STRUCTURE AND STRATIGRAPHY, AND PHYSIOGRAPHY.

GEOGRAPHICAL LIMITS.

The portion of the district here described extends from the north line of T. 47 N. to the south line of T. 42 N., and from the center of R. 31 W. to the west line of R. 33 W., and contains approximately 540 square miles.

Upon the small sketch map at bottom of Pl. III is outlined the portions of the district which have been studied and described by the different authors.

The detail character of the formations is unknown for parts of the area under discussion. This is especially true of the north, west, and southwest parts, where, owing to the readily decomposable nature of the rocks, as determined by the few ledges observed, and to the drift mantle, very few outcrops are to be found.

STRUCTURE AND STRATIGRAPHY.

The Crystal Falls district is not sharply defined petrographically, but is continuous with the Marquette district on the northeast and the Menominee district on the southeast (Pl. I). It is, however, remarkable for the vast accumulation of volcanic rocks, which, while by no means absent from the adjoining districts, do not there play so conspicuous a role.

Structurally this district can hardly be better separated from the Menominee and Marquette districts than it can be petrographically. The important sedimentary troughs of the two adjacent districts are separated by an average width of 40 miles. The area between the districts on a direct course is occupied chiefly by Archean rocks, with narrow infolded troughs of Huronian rocks playing a very subordinate role. At the east the Archean is overlain by the sedimentaries of the Paleozoic, the Cambrian, and the Silurian. The connecting Crystal Falls rocks are west of this Archean dome.

In the Marquette district the essential structural features have been shown[1] to be a great east-west synelinorium, upon which more open north-south folds are superimposed. At the western end[2] of the district the superimposed north-south folds become close, and the Republic trough is a close fold with an axis in an intermediate position. In the adjoining Crystal Falls district there are also two sets of folds with their axes approximately at right angles to each other. The closer folds are represented by the great anticline in the central part of the district. This anticline has its axial plane trending west of north and south of east, and the axis plunges down both at the north and south ends.

The more open set of folds at right angles to the above set, is represented by the Crystal Falls syncline, with its axis striking to the south of west, and plunging west. Farther south the axes of the folds become much closer and more nearly east and west, thus nearly according in direction with the close folds of the Menominee district. Thus the structural features of the Crystal Falls district merge into those of the Menominee district, which joins the Crystal Falls district on the southeast, where the great structural feature is a synclinorium similar to that of the Marquette, but with its axis trending north of west and south of east.

A glance at Pl. III will show the presence in the eastern part of the northern half of the district of an oval-shaped mass of Archean, and, nearly surrounding this, a number of rock belts.

The Archean ellipse is 11 miles long and 3 miles wide on the average. The rocks are mainly granite and gneiss. They are cut by rather infrequent acid and basic dikes.

Immediately surrounding the Archean is a quartzose magnesian limestone formation, to which the name Randville dolomite has been given.[3] In the eastern half of the district described by Smyth, where more numerous exposures are found than occur in the western half, the formation has an estimated thickness of about 1,500 feet.[4] Not only are the exposures more numerous, but owing to the fact that the strata stand on edge, due to the closer folding of the rock series here, a more accurate estimate of their thickness can be made.

[1]Mon. XXVIII, cit., p. 566 et seq.

[2]Loc. cit., p. 570.

[3]See Part II, Chapter IV, by H. L. Smyth, p. 431.

[4]See Part II, Chapter IV, Sec. III, p. 433.

According to Smyth, this limestone formation, in the southeastern end of the ellipse, at its upper horizon becomes mixed with slates, and these increase in quantity until the formation passes above into a slate formation, called the Mansfield slate.[1] This slate formation is found overlying the limestone to the west of the central ellipse likewise, but as few outcrops have been found, it is not positively known to exist as a continuous zone encircling the northwestern end. In a direct line with its probable continuation to the north, a graywacke was found at one place, sec. 19, T. 46, R. 32. This single outcrop is insufficient evidence to warrant the introduction of a graywacke formation as the northern equivalent of a part of the Mansfield slates, and it is probably but a phase of that formation. The only mine of this district producing Bessemer ore is in a deposit in the Mansfield slate.

The close of the Mansfield Slate time was marked by the extrusion of a great series of volcanics, which constitute the next formation in the succession. This volcanic formation has its best and most typical development west of the western Archean ellipse. Because the Hemlock River and its tributaries have exposed good sections in the volcanics, and because this river drains a great portion of the volcanic area, the name “Hemlock formation” is applied to the volcanics. The dip of the flows and of the tuff beds wherever observed is about

75° west. The maximum breadth is about 5 miles. Deducting 15° for initial dip, this would give the enormous maximum thickness of 23,000 feet to the volcanics, upon the supposition that no minor folds occur.

These volcanic rocks have associated with them rocks of unquestionably sedimentary origin, as is shown by their well-bedded condition and the rounding of the fragments. The subaqueous rocks are, however, composed of little-altered volcanic materials, and evidently point to oscillations of the crust during the time of volcanic activity—such oscillations as have long been known to be common in volcanic regions.

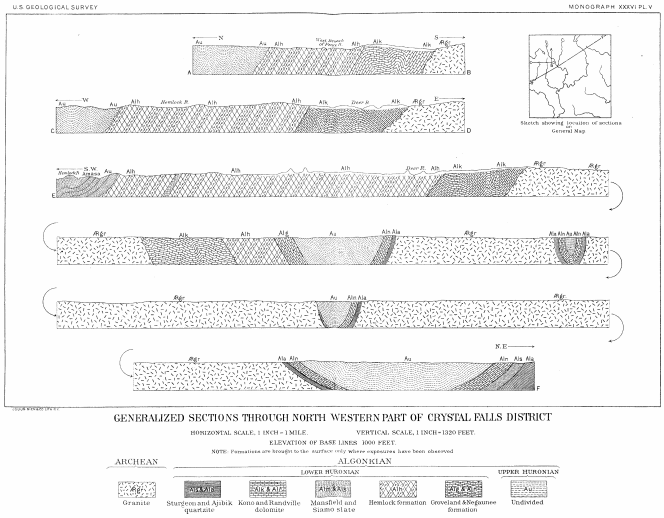
Following the volcanics, and overlying them, probably unconformably, comes a series of sedimentary rocks, believed to belong to the Upper Huronian. These comprise chloritic, ferruginous, and carbonaceous slates, associated with quartzites, graywackes, and small amounts of carbonate beds. The general character of the series is what one would expect in rocks the detritus of which was from the Hemlock volcanics. It is in this slate series that, with the exception of the Mansfield mine, the ore deposits of the Crystal Falls district are found. The sedimentaries extend west from the Hemlock volcanics to the limits of the district, underlying thus a very broad expanse of country. Where exposed, they show frequent changes of character. This prevents the identification of individual beds for any considerable distance. Owing to the imperfect exposures of the beds and their close folding, it has been found impossible to subdivide this series of rocks into distinct formations.

[1]See Part II, Chapter IV, Sec. IV.

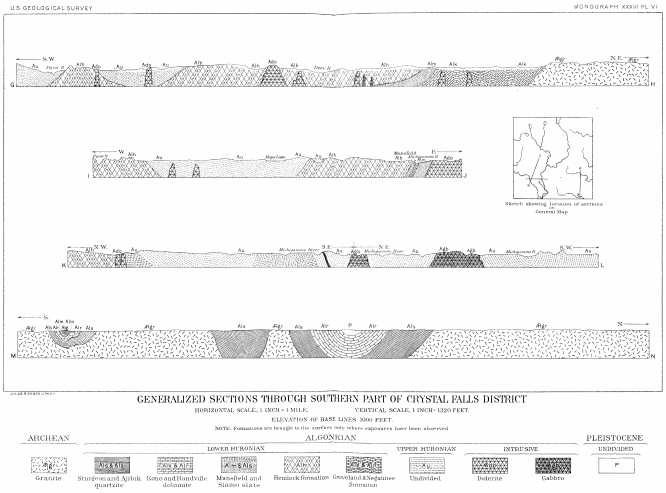
The series has in places been highly metamorphosed, resulting in the production of gneisses and mica-schists, in places garnetiferous and staurolitic. The series corresponds in a broad way stratigraphically and lithologically to the Michigamme formation of the Marquette district.[1] Since, however, it has been found impossible to subdivide this series, and because it may possibly include more than the Michigamme formation of the Marquette district, it is considered advisable to speak of it simply as the Upper Huronian series. The generalized sections through the western half of the Crystal Falls district, which are given on Pls. V and VI, will aid in the comprehension of the structural and stratigraphical features thus briefly outlined.

Here and there in the Crystal Falls district isolated patches of Upper Cambrian Lake Superior (Potsdam) sandstone are found. This occurs in beds which are either horizontal or only a few degrees inclined from the horizontal. They overlie unconformably the steeply inclined Huronian strata. The great lapse of time represented by this unconformity is indicated by the deposits of the Keweenawan and Lower and Middle Cambrian time, found elsewhere. The Lake Superior sandstone grades from the very coarse basal conglomerate below into a moderately coarse sandstone above. The sandstone is of a reddish brown to gray color, and is not well indurated as a rule, but is loosely cemented with ferruginous and in places calcareous material. As a result of this imperfect induration, the sandstone is not very resistent to the agents of disintegration. Hence it is that only remnants have been found, but enough is present to indicate that the greater part, and probably the entire Crystal Falls district, was covered by Cambrian deposits. The thickness of the Cambrian deposits can not be determined.

[1]Fifteenth Annual, cit., p. 598, and Mon. XXVIII, cit., p. 444.



[Plate V. Generalized sections to illustrate the stratigraphy and structure of the northwestern part of the Crystal Falls district of Michigan]



[Plate VI. Generalized sections to illustrate the stratigraphy and structure of the southern part of the Crystal Falls district of Michigan]

The next higher portion of the geological time scale represented in the district is that part of the Pleistocene period which in this part of the United States is characterized by the past existence of great ice-sheets. The evidences of the existence of the ice are everywhere present, either in the rounding and polishing and scoring on the surfaces of the rocks exposed or in the character of the drift deposits. The direction of the

ice movement was clearly from the northeast to the southwest, as is shown by the trend of the striæ, which were observed upon the rounded rock outcrops in various places. The thickness of the drift deposit varies very materially. In places it has been almost entirely removed by denudation, if in such places it ever formed anything more than a thin veneer upon the surface. In other places it reaches a very considerable thickness, as is shown by the glacial topography characteristically developed in T. 45 N., R. 32 W.

As the present report is confined to the pre-Paleozoic rocks, no detail description will be given of these Cambrian and Glacial deposits, nor are they represented on the map, except in those places where it has been found impossible to map the underlying rocks. The generalized columnar section on Pl. VII gives in condensed form our knowledge concerning the formations mentioned.

PHYSIOGRAPHY.

TOPOGRAPHY.

The topography in its large features is pre-Glacial, and in some cases this older topography is rather distinct. For instance, in the case of the Deer River Valley, drift covers the gentle slopes and bottom, but is not sufficiently deep to completely hide the pre-Glacial Deer River Valley.

In the southwestern part of the district west of Crystal Falls, or, more generally, west of the Paint River, pre-Glacial topography is seen in places. Here we find the drift as a veneer and only partly hiding the bed-rock topography, which depends mainly on the strikes, dips, and varying characters of the rocks.

It is so well known that this part of the country was at one time covered by ice, that it is useless to cite such proof as the rounding and scoring of the rocks and the character of the drift material, a good portion of which can be readily seen to have been brought from some other region, no such rocks as those forming it existing where the bowlders now lie. The ice-sheet left a deposit of drift, and we find the pre-Glacial topography essentially modified by it. As a result of this, the prevailing and most noticeable topography of the western half of the Crystal Falls district is that of the drift, and is characterized by short ridges and broken chains of hills, usually oval, though at times of very irregular outline, between which are lakes and swamps. The swamps are even occasionally found on rather steep slopes, where a thick spongy carpet of moss (sphagnum) retains sufficient moisture for cedars and other trees and shrubs characteristic of the Michigan swamps to grow. The swamps follow the carpet of moss up the hills to the spring line.

The Glacial drift topography is especially marked where the drift was of considerable depth. These conditions are well exhibited in parts of T. 45 N., Rs. 31, 32 W., shown on the large-scale map, Pl. VIII. Here, even though the ground is very heavily timbered, one may easily trace out the sinuous course of the eskers. When traversing the country, one is constantly descending into pot-holes or is climbing ridges, some of them 75 to 100 feet high, often with a crest only a few feet, in some places not more than 4 feet, wide.

Where the drift mantle has been removed, the rounded character of the rock exposures is usually shown. This holds good especially for the more resistant rocks, such as the granites and massive greenstones. Slates and tuffs, weathering more readily, have in numerous cases had time since the ice retreated to be weathered into rough broken ledges, some of which show perpendicular cliffs.

The elevations range usually from 1,400 to 1,600 feet above sea-level. The hills rarely rise more than 200 feet above the low ground at their bases. The extremes of height noted in the district are from 1,250 to 1,900 feet above sea-level, corresponding, respectively, to the valley of the Michigamme on the south and the watershed between Lake Superior and Lake Michigan on the north. Between these two extremes there is a strip of territory, 25 miles across from north to south, in which the variations in height are within the limits of 200 feet.

A consideration of the slight difference of level which prevails over the greater part of the Crystal Falls district has led Smyth to the conclusion that this portion of Michigan had before Glacial times been reduced to the condition of an approximate peneplain. (See Part II, Chapter I.) This peneplain is a continuation of the peneplain of northern Wisconsin, and lies between the northern Michigan base-level on the north and the central Wisconsin baselevel on the south, to both of which attention has recently been called by Van Hise.[1]

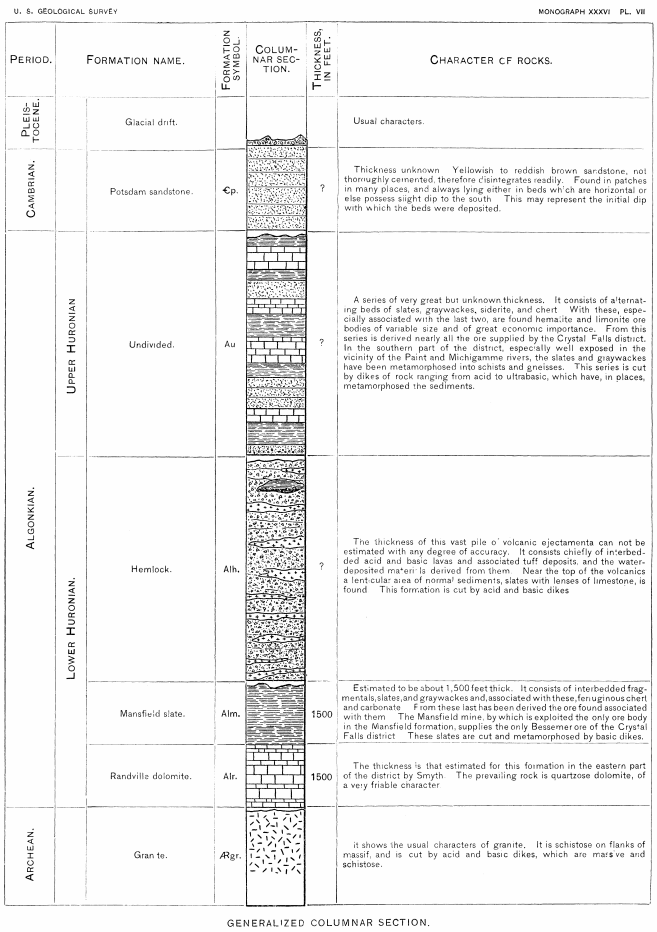
DRAINAGE.

The greater heights in the Michigamme district are in the northern part, where some few of the hills rise to a height of 1,800 feet, and one to a maximum of 1,900 feet above sea-level; but the majority do not rise above 1,600 feet. The belt including these higher elevations extends about NE-SW. This belt represents the crest of the watershed, from which all streams on the northern side flow to Lake Superior, and on the southeastern side all flow to Green Bay of Lake Michigan. A part of this watershed is undivided, and it is not uncommon to find extensive swamps in which streams flowing to opposite sides of the watershed take their origin. The portion of the Crystal Falls district which is tributary to Lake Superior is so small that it will be totally neglected in the further discussion of the drainage. The topographical map, Pl. II shows the general slope and drainage of the district to be SSE. The eastern part of the district is drained by the Michigamme[2] River with its tributaries, the Fence (Mitchigan), and the Deer, while the Paint (Mequacumecum) River, with its main tributaries, the Hemlock and the Net, drains the west and northwestern portions. The Brule (Wesacota) flows along the

southern part of the district, being for the most part just below the southern limits of the present map. It forms throughout its course the boundary line between Michigan and Wisconsin. The Paint flows into the Brule in sec. 12, T. 41 N., R. 32 W., and the Brule and the Michigamme unite in sec. 16, T. 41 N., R. 31 W., to form the Menominee River. This last flows southeast through the adjoining Menominee district, and is the boundary line between Michigan and Wisconsin from its source to its mouth.

[1]A central Wisconsin base-level, by C. R. Van Hise: Science, new ser., Vol. IV, 1896, pp. 57-59, 219. A northern Michigan base-level: ibid., pp. 217-220.

[2]The Indian names which the streams and lakes of this district formerly bore have either been dropped or else, in a few eases, have been replaced by translations, though most commonly they have been replaced by English names, which are altogether new. Those names which have been retained receive various spellings at the hands of different authors, and even at the hands of the same writer. The Michigamme River, for example, is frequently spelled by Burt in the same article *Peshakumme* and *Pesh-a-hem-e*. The name Michigamme is also spelled on various maps *Machigamig* and *Michigamig*. Whereas the Paint we find spelled *Mequacumecum*, as above most commonly, though Burt spells it *Mesquacumecun* and also *Mesqua-cum-a-cum.*



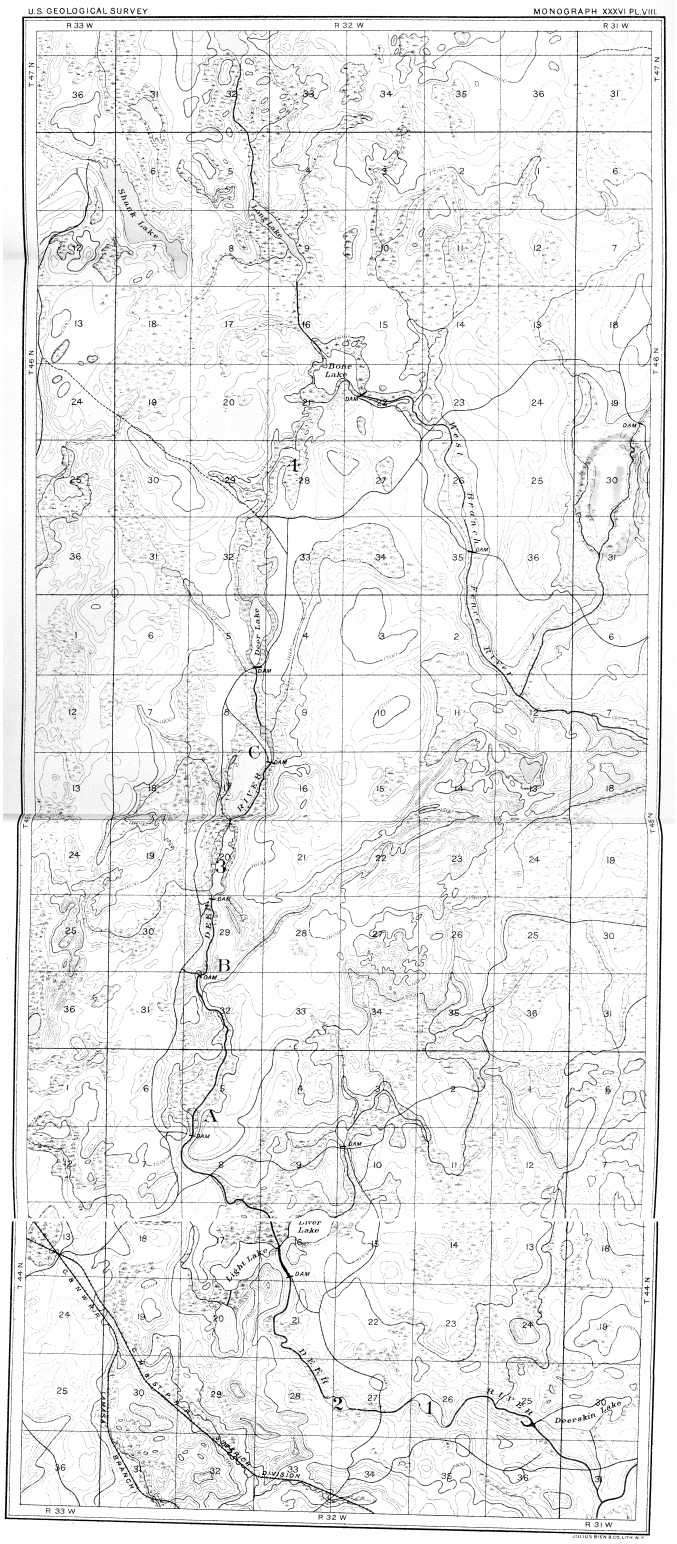
[Plate VII. Generalized columnar section]

A glance at the map, Pl. II, will show the presence, especially in the northern half of the district, of a great number of lakes of varying sizes. These lakes of clear water, with bottoms of gravel, or most commonly of a thick deposit of decayed vegetable matter, are a very characteristic feature of the landscape. Many are in the midst of swamps, surrounded on all sides by a quaking bog, which prevents one from approaching very closely; others are surrounded by steep but low drift hills. The lakes may or may not have a visible inlet and outlet. In all cases the present water levels are considerably below the original water levels. In many cases the lakes are but remnants of much larger bodies of water. They are gradually filling up with silt and vegetable growth. These lakes, covered with floating lily pads and surrounded by more or less extensive hay marshes, are favorite places for the deer, which in many parts of the district are still fairly numerous. The numerous lakes indicate the youthful character of the drainage. Many of the streams head in the lakes. In other cases they flow through them, connecting them in chains. This indicates the mode of origin of the most of the streams of the area. The youthful character of the drainage is still further shown by the fact that with but few exceptions the rivers have not reached rock. They are still cutting in drift.

In the case of the Deer River this gradual development from the original condition of a chain of lakes to the present condition of a river in which the lakes play very subordinate parts is well shown. Moreover, its development illustrates very well several of the stages passed through by rivers in general, and for these reasons it may be well to describe it in detail.

The life history of the Deer River,[1] as it is to-day, began with the deposit of the drift, which destroyed the former streams of the district and concealed their records. It appears probable from the topography that the river occupies the same, or approximately the same, bed in which its pre-Glacial forerunner moved. The noticeable valley occupied by the stream is at a maximum about 3 miles broad, though its drainage area is a strip averaging 5 or 6 miles in breadth. The hills between which the stream flows are not very high above the river bed, the maximum elevation being 175 feet. The few rock outcrops are in all cases found on the tops and flanks of these hills, where they have been exposed by denudation. At one point only has rock been found in situ near the river bed, and that is toward the mouth of the river. The conclusion is natural, since the river is 175 feet below these exposed rocks and has not reached rock, that it must be flowing through a preexisting depression or valley partly filled by the drift of the Glacial epoch.

[1]The substance of the following was presented to the Wisconsin Academy of Sciences, Arts, and Letters at the annual meeting, September 27, 1895, in a paper entitled “Some stages in the development of rivers, as illustrated by the Deer River of Michigan.” An abstract of the paper was published in Amer. Geol., Vol. XVII, 1896, p. 126.



[Plate VIII. Map of a portion of the Crystal Falls district, showing in detail the glacial topography and illustrating the development of the Deer River]

The partial filling of this valley at the time of the retreat of the ice to the northeast was accompanied by the filling of the depressions in the drift by the water flowing from the front of the melting glacier. After the depressions were filled, the overflowing water naturally followed the general southeastern slope, which exists throughout the area and is shown by the topographical maps and by the flow of the rivers. The immediate course of the water was determined by the former valley, which was not completely obliterated by the drift deposit. Drift barriers across the valley separating the ponded water, or lakes, from one another were cut through, the material eroded being spread over the bottoms of the lakes below. Thus was formed a chain of lakes, connected usually by narrow streams; the processes by which the channels were cut out and the lakes drained and filled up with the debris were going on at the same time. The result has been to obliterate the lakes to a great extent and to accentuate the character of the stream.

The final effect of the processes, briefly outlined, would be to destroy the lakes entirely and produce a stream.

By following on Pl. VIII the Deer River from its mouth to its source, we may see the several stages in its development, which are also typical for other streams of the glaciated portions of the world. The river is about 20 miles long and has a width near where it enters into the Michigamrne of 20 to 30 yards. Near its mouth it is a slow-flowing, sluggish stream, which has nearly reached its base-level of erosion, and like many of the older streams of the Coastal Plain region of the United States is gradually filling portions of its channel with the silt and vegetable matter brought down from above.

A short distance from its mouth it resembles such streams also in the meandering character of its channel. This resemblance is still further enhanced by the presence of a remnant of a crescent-shaped cut-off, so characteristic of the old age of rivers. Just opposite this cut-off is a lake, which is of interest on account of its possessing two outlets, both leading into the river. Unfortunately this fact was observed on the topographical sheet too late to permit of a return to the field for the purpose of determining the cause of the presence of the two outlets.

Passing up the stream we soon reach the lakes, which farther on become more numerous. The life history of these, lakes is inseparably connected with that of the river. They reached maturity during or at the close of the Glacial epoch, and since that time their history is that of decline. This part of the history of these lakes may be briefly stated as follows: As the erosion continues, the areas of water are reduced and the surrounding swamp areas are correspondingly increased. If a lake were large and considerable inequalities existed in its bottom, two or more small lakes connected by the stream flowing through them may be formed. The final stage is a swamp, traversed by the slow-flowing river.

The various stages in the history of the lakes are well illustrated on the accompanying map, Pl. VIII, by the following series of lakes. In Nos. 1 and 2 the general character of such bodies of water, which may be considered essentially as mere expansions of streams,

is seen. No. 3, and Deer Lake, have long since reached maturity and are advancing rapidly to the point where they will each be separated into two bodies of water. No. 4 has already reached this stage, and in the swamp marked A we have the last stage, the swamp, with the stream flowing between peaty banks.

On Light and Liver lakes, in the lower part of the Deer River, we may see all but the last of these stages illustrated. The lakes are attached to the main river by very short streams. The main river after leaving the rapids above, where it accumulates considerable detritus, enters a flat portion of its course partly occupied by the two lakes in question. Here, its rapidity being diminished, the stream deposits the detritus. Thus it has gradually built a delta, now for the most part covered by swamp growth. This tends to advance the shore line, and thus diminish the water area. The rapid cutting down of the barrier immediately below the lakes by the swiftly-flowing stream tends to lower the lakes and thus diminish their surface area still more.

The combined effect of the draining and filling has been to separate what was formerly a long narrow lake trending NE-SW. into three rounded bodies of water, two of which are connected with each other, the larger of these two and the third lake being connected with the main stream by very short necks. An artificial dam has been built across the narrow channel below the lakes, and the effect has been to flood the delta and unite the lakes into one large body of water, occupying, approximately, the area covered by the glacial lake, thus restoring the conditions which existed before the natural barrier had been trenched.

In the remainder of the course of the Deer River the tendency of other artificial dams to restore the river to its original condition, that of a series of connecting lakes, is well shown. These dams were built by lumbermen at the foot of the lakes or swamps when it was desired to retain a large body of water at these places. When, on the other hand, the desire was to enable the logs to pass rapids, a dam (marked B on the map) was built near the head of the rapids. The back water would bring the logs to the dam, and on opening the gates the flood would carry them over the rapids into the deeper water beyond. The Deer River thus, after having reached a somewhat advanced stage, has been rejuvenated by the Michigan lumbermen.

A study of the small tributaries shows the same condition of things, although not on so large a scale nor so perfectly as in the main stream.

The source of the Deer River is in the copious springs which rise out of a spongy, marshy piece of ground less than 125 yards distant from Rone Lake, and about 20 feet below the usual water level of Rone Lake, and are really fed by the lake water percolating through the drift and appearing at this point. From the springs there is a depression which leads up to the lake. The highest point of this depression was about 3 feet above the normal water level of the lake.

The outlet of Rone Lake is the Fence River. The river leaves the lake at a point three-quarters of a mile distant from the head of the Deer River Valley. In order to obtain a supply of water for driving the Fence River, Rone Lake has been converted into a reservoir. A dam was built at the outlet which raised the water about 4 feet, and the result was to turn some of the water of the lake into the Deer River, necessitating also a dam across this small valley near the lake shore. At present only a few strokes of the shovel would be necessary in order to turn the water of the flooded lake from the Fence into the Deer River, thus gaining for it a drainage area extending 7 miles farther north and including three large lakes, the main sources of the water supply of the western branch of the Fence.

I have no data which would enable me to show that the valley at the head of Deer River was ever a channel for the waters of Bone Lake. I am inclined to believe that such was not the case. For had it existed with the present slope, 20 feet in 375 feet, or even a much lower one, the water would have had a marked erosive power, and it would have cut back its channel much more rapidly than the Fence, which for a mile below the lake is a comparatively sluggish stream, and would have eventually captured Bone Lake and its feeders.

The Deer River is still continuing the process of lengthening its channel, and the springs which give it birth are gradually undermining the barrier at its head, so that it is possible that it will, unless artificially restrained, obtain much more water from Bone Lake than it does at present. A change in atmospheric and other conditions, which would insure a state of equilibrium between the incoming and outgoing waters, thus preserving the waters of Bone Lake at their present level, would be favorable for the final successful robbery of the upper Fence River system by the Deer River. This favorable condition, as may be readily seen, would be greatly increased in proportion as the increase of inflowing over outflowing water raised the level of the lake.

TIMBER AND SOIL.

The district was at one time very heavily timbered, with hard wood and pine, the former predominating on the whole. Along the flood plains of the large streams one finds sandy pine barrens where once there were heavy pine forests. On the headwaters the pine are found scattered through the hard wood. Individually these trees are very much larger and better than the thick and therefore smaller growth of the plains. Lumbering, which had been confined for years to the main drainage channels of the district, has of late been rapidly extended, following all the ramifications of the tributary streams, until at present there remains in this district only a few years' cut of pine at the very headwaters of the rivers. Following the lumbermen comes the forest fire, which finds its most nourishing food in the dry resinous pine tops left by them. The fires, once started, are not confined, however, to the cut pine, but spread to the adjacent standing pine and even into the hard-wood forests, carrying destruction with them, and leaving but

the gaunt, bare, and blackened trunks to mark the sites of what were formerly thick forests.

The pine-covered areas have a thin soil and are poorly adapted to agriculture. The areas covered with hard wood have, on the contrary, soil well adapted to the crops of the latitude.

The advance of the lumberman has necessitated the damming and clearing of streams and the blasting of channels to permit the floating of the logs, and this has driven the fish, especially the speckled trout, which formerly crowded all the streams, into the smallest and most inaccessible ones. Ruffed grouse, *Bonasa umbellus*, and deer are still rather plentiful in certain portions of the area, although the pot-hunter with set guns, spring nooses, and pitfalls is rapidly exterminating them. The deadly character of such appliances is brought vividly to mind, when, as happened in my own case, one is suddenly arrested, while following a deer trail through the underbrush, by a hay wire noose around his neck, and he may be thankful if the bent sapling, having been bent so long as to lose its elasticity, fails to spring up and render the device effective.

CHAPTER III.
THE ARCHEAN.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The granite described in this chapter belongs to the oldest system in the district, and forms the western elliptical core designated on Pl. III as Archean. It is surrounded by sedimentary strata, which have a quaquaversal dip away from the granite as a center. The portion of the Crystal Falls district, in which the granite outcrops, is about 13 miles long by 3 miles wide, its longest axis extending in a NW. and SE. direction and covering parts of Ts. 44, 45, and 46 N., Rs. 31 and 32 W.

The exposures of granite are especially numerous in the southeast part of the oval area, where, owing to the proximity of large streams, the Fence and Deer rivers, and the consequent increased erosion, the drift has to some extent been removed. In the northwest part of the area, with rare exceptions, all the rocks are deeply covered with drift.

In general the topography of the area is that of the drift, but in the southern part it is seen to have been considerably influenced by the character of the underlying rocks. The granite usually outcrops in small, rounded, and isolated knobs, whose relations to one another can only be conjectured. Where an occasional knob is composed of massive granite and more or less gneissoid granite, the exposed surface is so small as to prevent the observer from determining the relations between the two. Cutting the massive and schistose granite are certain long narrow masses of dark-colored rocks of rather fine grain, and, with few exceptions, very schistose. From their geological occurrence it was concluded, in spite of their appearance, that they are dike rocks cutting the granite. The following paragraph, quoted from the manuscript notes of G. O. Smith, describes very clearly their field occurrence:

> The gaps in this granite ridge seem to indicate greenstone dikes, as here the granite usually has a facing of the greenstone more or less extensive, and often in the center of the gap there are several small areas of greenstone. In all cases the greenstone is markedly more affected by weathering than is the granite. A study of the relations at the few points of contact did not yield much more than negative results, but these pointed to the intrusive character of the greenstones.

RELATIONS TO OVERLYING FORMATIONS.

The relations of the granite to the sedimentary rocks might be explained in two ways; the former may serve as the base of the latter rocks, or it may penetrate them. The occurrence of the granite in an elliptical shape, with sediments surrounding it showing quaquaversal dips, might be regarded as evidence of its intrusion in the Huronian sediments, and on this theory it would follow that the granite is of Huronian or post-Huronian age. If intrusive, it should be found to penetrate and metamorphose those sediments. Against the intrusive character of the granite, and in favor of its pre-Huronian age, are the following facts: (1) There is a total absence in the surrounding sedimentary strata of any dikes which are related to the granite. (2) There is a total absence of any metamorphic action, so far as observed, in the sedimentaries. (3) On the east flank of the granite core, on the west bank of the west branch of the Fence River in the SW. corner sec. 1, T. 45 N., R. 32 W., is a recomposed granite, which passes up into a fine sericitic quartzite, with false bedding. These rocks evidently derived their material from the granite, and hence mark the beginning of sedimentation in this area.

Thus the positive evidence confirms the negative, and since the granite underlies the oldest sedimentary rocks, whose age has been determined to be Huronian, the former is classified as Archean, that term being used here to designate those rocks of undoubted igneous character which form the foundation upon which rest the oldest determinable sedimentary rocks. It is not the province of this paper to enter into a speculative discussion of the origin of the Archean rocks of the district. For such a discussion the reader is referred to Professor Van Hise's exhaustive disquisition on the Principles of North American pre-Cambrian Geology,[1] where the conclusion is reached that "the Archean is igneous and represents a part of the original crust of the earth, or its downward crystallization."[2] The Archean has gradually reached the surface by the removal by erosion of the superjacent rocks.

[1] Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, pp. 571-874.

[2] Loc. cit., p. 752.

PETROGRAPHICAI CHARACTERS.

The rocks of the Archean comprise biotite-granite, gneissoid biotite-granite, and acid and basic dikes.

BIOTITE-GRANITE (GRANITITE).

The rock occupying the main and central part of the Archean area is a biotite-granite. This rock is also found to some extent on the border of the area. The rocks of this kind vary in color from light-gray rocks to those having various tints of red, depending usually upon the degree of alteration. They vary also from medium to coarse grain. Some varieties show a decided porphyritic texture, and in some cases also an approach to a laminated structure. The porphyritic character is due to the presence of large crystals of feldspar, which stand out from the surrounding granitic groundmass, thus producing a typical granite-porphyry. The feldspar phenocrysts lie with their longer axes parallel, and thus help to produce an imperfect laminated structure. This parallel structure in the granite-porphyry is apparently analogous to the flow structure of the volcanic rocks, and probably was produced by movements in the magma before it had reached even a viscous state, as we find that the phenocrysts 'give no evidence of having undergone excessive mashing or torsion. The different textural varieties grade into one another in such a way as to indicate that they are merely modifications of the same magma. In addition to these textural varieties, which are original, we find in certain places a passage from massive to schistose rocks, in which the schistosity is of dynamic origin, i. e., of secondary nature.

In the thin sections these rocks show the normal granitic texture and the usual mineral constituents which characterize biotite-granites. The chief minerals are orthoclase, microcline, plagioclase, quartz, and biotite. Zircon and apatite are the accessory minerals present, and the secondary minerals include epidote-zoisite, chlorite, muscovite, rutile, and iron pyrites.

Quartz occurs in grains forming the cement and molding around the other minerals. In one of the granites it has a peculiar saccharoidal character macroscopically, and under the microscope such portions are resolved into very fine aggregates of quartz grains.

The quartz is also frequently found in round blebs of varying size included in the best crystallized feldspar crystals. Thus the crystallization of the quartz, unless such quartz represents the "quartz de corrosion" of the French authors, continued through the entire time occupied by the crystallization of the feldspars, since it is included in the oldest feldspar of the rocks, and also forms the matrix in which lie the youngest feldspars. Undulatory extinction, so general in the quartzes, shows that the rocks have been subjected to pressure, and in some cases it has been sufficient to produce the extreme cataclastic structure of very greatly mashed rocks.

The quartz includes numerous gas and fluid inclusions, the latter frequently with dancing bubbles and forming negative crystals, by means of which it is easy to orient the irregular grains. The quartz of one of the specimens was found to contain liquid inclusions, each of which, besides the usual bubble, held a small rectangular crystal. These crystals are transparent, with a light greenish tinge. A crystal similar in appearance found in the same quartz individual is partly inclosed by a large U-shaped bubble, and gave inclined extinction, though no further optical tests could be made upon it.

Three kinds of feldspar are present: (1) A finely striated plagioclase ; (2) a feldspar, unstriated, or at most showing Carlsbad twins, and presumed to be orthoclase; and (3) microcline, these last two being frequently intergrown after the manner of perthite. The plagioclase was the first feldspar to crystallize. It is invariably so altered that the twinning laminæ are nearly obliterated, thus preventing accurate measurements. It is probably oligoclase; and if so, it is highly probable that much of the white mica produced by its alteration is paragonite instead of muscovite, a fact not determinable microscopically. The phenocrysts are orthoclase, usually in Carlsbad twins, and thus at first sight appear to have been the first feldspar to crystallize; but I find that these phenocrysts not uncommonly inclose small rectangular, more or less automorphic,[1] crystals of plagioclase, which is in reality the oldest feldspar. Hence these orthoclases, notwithstanding their porphyritic character, are later than a part of the plagioclases. One phenocryst with Carlsbad twinning was observed in which one part of the individual shows microclinic striations. The other part was untwinned, and near the center of the phenoeryst, bisected by the Carlsbad twinning plane, was found a rectangular plagioclase crystal.

[1]Automorph, Xenomorph; Über die Eruptivgesteine im Gebiete der Schlesisch-Maehrischen Kreideforination, by Carl E. M. Rohrbach: Tsch. Mm. Pet. Mit., Vol. VII, 1886, p. 18.

Idiomorph, Allotriomorph; Rosenbuscb: Mik. Phys., Vol. II, 1887, 2d ed., p. 11.

L. V. Pirsson bas recently proposed in a paper, read before the Geological Society of America, on A Needed Term in Petrology, the term anhedra for minerals which do not possess crystallographic outlines and are xenomorphic, in contradistinction to those which we properly call crystals and which are automorphic: Geol. Soc. Am., Vol. VII, 1896, p. 492, and Am. Jour. Sci., 4th series, Vol. II, 1896, p. 150.

The microcline is usually the best crystallized feldspar in the ground-mass, and also by far the freshest. In the few cases in which it was observed in contact with plagioclase, the latter molded it, and is therefore older than the microcline, which in its turn is older than the orthoclase. In one case a microcline individual showing the lattice structure over a portion of its surface possesses no twinning lamellæ in another portion, the twinning lamellæ fading until they totally disappear. Thus no sharp delimitation is apparent between the twinned and untwinned portions of the individual.

In most slides all the feldspars are much altered, but even in those in which the microcline is fresh the plagioclase and orthoclase always show alterations, the plagioclase altering most easily and usually being so

changed that it is with difficulty that one can recognize the twinning lamellæ. Hence some of them may have been taken for the nonstriated orthoclase. In an early stage of the alteration of the feldspars minute dark ferrite particles which impregnate them are hydrated, and this gives the feldspars a more or less distinctly red tinge. In a more advanced stage of alteration, muscovite and a little epidote-zoisite are produced. Another alteration of the feldspar is always associated with marked pressure phenomena, and hence is presumed to be the result, partially at least, of dynamic action. This is the partial or complete granulation of the feldspar and the production from that mineral, with the addition from other sources of the iron and magnesia necessary, of secondary white mica and quartz, and some biotite. It is highly possible that some of the small limpid grains considered to be secondary quartz are really an acid feldspar. Orogenic movements are also indicated by the bending of twinning lamellæ, and were probably the partial cause of the twinning.

Biotite occurs in plates, and as a rule shows better-developed crystals than does the feldspar, though it frequently occurs in decidedly ragged flakes. It is strongly pleochroic, showing absorption in the following colors: Pale straw yellow to yellowish brown, for rays vibrating perpendicular to cleavage, to very dark chocolate brown and greenish brown for those parallel to cleavage. In the case of the biotite showing a greenish color this seems to be the result of incipient alteration, since the edges of the flakes are ragged, and in many cases almost the entire biotite of the section is altered to a chlorite, which shows ordinary white to light greenish pleochroism, with the simultaneous production of epidote and bundles of needles with high single and double refraction, having yellowish or brownish color. These needles are taken for rutile. The biotite is found usually lying between the feldspar and quartz grains almost as though it had been the last product of crystallization. It has suffered crushing with the other minerals. Apatite and zircon were observed in a few crystals. No original iron ore was seen. As intimated above, by the use of the term “epidote-zoisite,” the exact character of this secondary material is not always determinable. In some instances parts of an epidote crystal show the deep blue interference color of zoisite, apparently indicating a mixture of the zoisite and epidote molecules, the latter predominating in the crystals.[1] The remaining secondary minerals mentioned as occurring in the granite show their usual characters.

GNEISSOID BIOTITE-GRANITE, BORDER FACIES OF GRANITE.

About the central area of biotite-granite just described, and in part forming the border of the Archean area, are rocks having a gneissic structure. With these are associated the biotite-granites. The gneissoid rocks in general are markedly darker in color than the granites, showing normally a rather dark gray. They vary little from one another in texture and are much finer grained than the granites. The fine-grained condition of these schistose and banded rocks has perhaps a great deal to do with their dark color, though this is primarily owing to the amount of biotite present.

In some of the specimens the bands can be readily distinguished under the microscope, and are seen to contain a white mica and a much smaller amount of biotite. These two minerals are present in fine films between the crushed quartz and feldspar grains, giving to the rocks a very decided schistose character. These mica folia are much more numerous in certain areas than in others, thus producing a more or less perfect banding. The mica plates are not all regularly parallel, although ordinarily having a tendency to this arrangement, and are usually parallel to the banding. The most perfect schistosity is thus developed parallel to the micaceous bands. The banding and the schistose structure are plainly of secondary origin, the result of dynamic action.

[1] On some granites from British Columbia and the adjacent parts of Alaska and the Yukon district, by F. D. Adams: Canadian Record Sci., Sept., 1891, p. 346.

Others of the gnessoid granites, however, when examined under the microscope, are decidedly massive, and it is only on a large scale that the banding shows distinctly. In such cases the cause of the banding could not be determined, and might by some be ascribed to differentiation, though, from the association of these gneissoid granites with those just described, it is assumed that the banded stricture is due to dynamic action. If this be the case, however, a complete recrystallization has taken place, and slight dynamic effects are now shown. The strike of the banding, wherever it was taken, was uniform, varying from N.-S. to nearly N. 45° W., agreeing, on the whole, with the trend of the Archean oval area.

The microscope shows that the constituent minerals of the gneissoid granites are the same as those which compose the granites just described. These show also the same relations to one another and the same general characters as in the granites, except where mashing has completely obliterated the original texture, and hence no further description of them is necessary.

The crushing to which the gneissoid granites have been subjected is very clearly shown in the present cataclastic condition of the quartz and feldspars.

As stated above, both the gneissoid granite and the granite proper are found in the border area of the Archean. In those rocks in which the contact shows a gradual transition from the banded rock to the unbanded, the micaceous bands are clearly secondary, and are the result of the crushing of the original granite, these lines representing macroscopic and microscopic shearing planes along which the feldspar and quartz have been thoroughly granulated, and sericite and some biotite produced, as was found to be the case also in some of the granites. These rocks thus agree in their dynamic origin with a similar but apparently more extensive and better developed gneissoid border facies in the Morbihan

(Brittany) granites, which have been described, and whose origin has been so clearly demonstrated by Barrois.[1] Numerous other similar cases have been described recently from the Canadian granite massifs and from Sweden and other districts.

[1]Ann. Soc. Geol. du Nord., 1887, p. 40.

ACID DIKES IN ARCHEAN.

Observations upon dikes of acid rocks cutting- the Archean granite are very few, and we may suppose tins to be partly due to their occurrence in isolated knobs, which prevented the determination of the relations of adjacent exposures of rocks of slightly different character. Some few dikes were, nevertheless, observed, and are granites varying from medium to coarse grained, granolitic[1] to porphyritic rocks. The porphyritic facies is the most common. The dikes do not show differences from the main mass of the Archean granite sufficient to warrant detailed petrographical description. The following description of one mass of granite-porphyry is given, as it offers good proof of its relation to the schistose border facies of the granite. In this case the gneissoid rock is found as inclusions in the granite-porphyry, as is illustrated in the accompanying diagrammatical sketch; fig. 4, taken from a ledge in the field. In this sketch the sharply outlined angular and lenticular areas represent the gneiss included in the granite-porphyry. The phenocrysts of this granite-porphyry have a parallel arrangement, the long direction of the phenocrysts agreeing also with the trend of the longer axes of the inclusions. The banding and foliation in the inclusions strike at a right angle to the flow-age structure of the granite. The lines of separation between the areas of gneiss and the granite, as shown in this outcrop, are sharp, and point to their nature as inclusions, and such is accepted as the true explanation of their angular character and sharp outlines. As this porphyritic granite was intruded through the border facies of the Archean granite, these fragments were taken up, and were so arranged as to agree with the direction of movement in the intruding mass. This occurrence shows this granite-porphyry to be younger than the great mass of Archean granite, whether we consider the inclusions to be a border facies of the Archean granite, derived from it by dynamic action, and thus of secondary origin, or to have resulted from differentiation of the molten magma.

[1]This term has been proposed by a committee on nomenclature for the geologic folios of the United States Geological Survey, for use in place of "granitic."

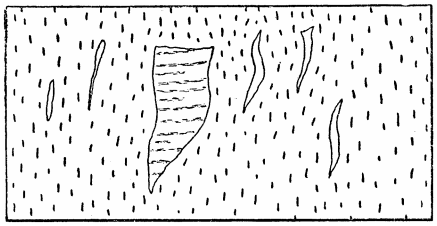


FIG. 4.—Granite-porphyry with inclusions of gneissoid granite.

BASIC DIKES IN THE ARCHEAN.

The influence of the dikes on the character of the topography has already been mentioned. They occur in long narrow bands of varying widths, and with one exception are markedly schistose. Considering the granite on a large scale as an approximately homogeneous mass, we would expect to find lines of weakness, which might be indicated by the arrangement of the dikes. No such definite arrangement can be seen, however, as the dikes are found to extend in all directions. A good example of their mode of occurrence may be seen in fig. 5, which also illustrates very clearly their influence on the topography. A small valley, in sec. 1, T. 44, R. 32, through which a brook flows, is occupied by the main dike, from which diverge the smaller ones, penetrating the granite on both sides. These, not having been much more deeply eroded than the granite, do not form channels deep enough to be shown on a map with a 10-foot contour interval. It is without doubt owing to the fact that the dikes weather so much more readily than does the granite that we may partly explain the comparative scarcity of exposures. The depressions separating the granite knobs are believed to indicate in many cases the position of dikes, but being now filled with glacial deposits, the underlying dike rocks, if such are present, are covered. Thus we find them exposed only where erosion has cleared this debris away, or where portions of the dike still border the steep sides of the granite on the sides of depressions.

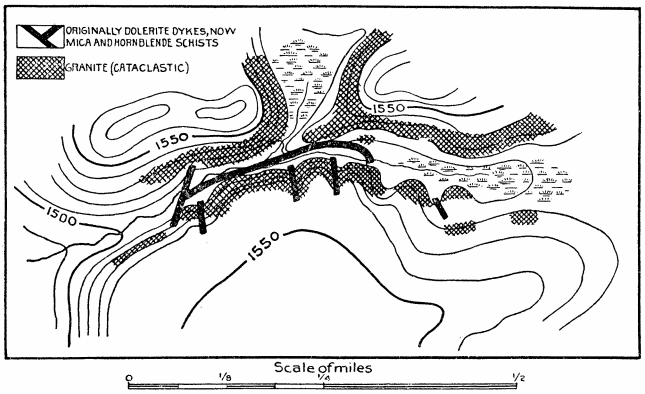


FIG. 5.—Illustration of the effect on the topography of the differential erosion of basic dikes and granite.

The dikes may be classified as (1) earlier dikes, showing a schistose structure, and with no trace of igneous textures, and (2) later massive dikes, showing original igneous textures.

(1) SCHISTOSE DIKES.

The general character of these rocks occurring as dikes may be briefly mentioned. They are schistose, for the most part fine grained, and black in color. The constituents of the schistose eruptives, arranged according to their relative importance, are biotite, hornblende, chlorite, quartz, feldspar (?), calcite, epidote, iron oxide, sphene, and muscovite.

The clear limpid grains which form the groundmass are undoubtedly for the most part quartz. No satisfactory results were obtained in the tests for feldspar, but it is highly probable that some is associated with the quartz. Dark chocolate-brown to light-brown biotite is almost an invariable constituent. In some cases it is accompanied by a little chlorite, which appears not to have been derived from the biotite. In a few rare instances biotite is absent altogether, chlorite taking its place. The biotite and chlorite are usually found between the quartz grains. They have a parallel arrangement, and this gives the rock its schistosity. Biotite and epidote are found included in the grains of quartz of the groundmass. Muscovite is rarely present, but when found is in medium-sized automorphic plates. Ragged pieces of ore, either ilmenite or titaniferous magnetite, and sphene, secondary to these, are found in almost all specimens, and in a few instances iron pyrites was observed. Calcite is invariably present in irregular, fairly large grains, almost equaling the quartz in quantity. Epidote is found in large quantity, both in crystals and in irregular grains, the crystals occurring among the bunches of biotite and included in the grains of quartz. The large amount of epidote in association with the calcite seems to point to the very basic character of the feldspar of the original rock.

A bluish-green hornblende is rather frequently associated with the mica. In rocks in which the hornblende predominates mica is always present, but the reverse is not true, the most micaceous rocks being entirely free from the hornblendic component.

The hornblende is found in large prismatic individuals without terminal faces. This mineral contains some of the other constituents of the rock in which it is found, such as quartz, epidote, and more rarely iron oxides. The interspaces between the hornblende crystals are filled with irregular biotite flakes and with grains of quartz, epidote, and iron oxide. This hornblende is apparently one of the last, if not the last, mineral to develop. The hornblendic rocks are not nearly so schistose as the micaceous ones.

The secondary origin of the hornblende is clearly shown in one of the sections which is traversed by a fissure; the hornblende can be seen extending into, and in places crossing, this fissure. The other minerals are presumed to be secondary, but this can not be proved for them. The schistose character of the rocks is evidence of dynamic action. The presence of undulatory extinction was noticed in the quartz of some specimens, but its absence is the rule. However, from the absence of great pressure phenomena, and the remarkably fresh condition of the minerals composing the basic rocks, which contrasts strongly with the generally altered condition of the minerals of the more refractory acid rocks including them, it would appear that complete recrystallization has occurred.[1]

The schistose structure can undoubtedly be referred to the dynamic action which resulted in the upturning of the sedimentaries and caused the development of schistosity in certain portions of the border of the granite. This dynamic action was in all probability also the chief force in the production of the secondary minerals.

The schistosity of the dikes does not agree in direction with the general strike of the schistosity throughout the entire district, but is always nearly parallel to the long extension of the dikes. These dikes represent belts of weakness, and it is therefore natural that the movements should occur along these belts rather than across them.

This schistosity of the dikes also furnishes a slight clue as to their age. Younger than the granites they cut, they must have occupied their present position at the time the dynamic revolution took place which resulted in the development of schistosity in the granite, as well as in the sedimentaries. It is impossible to bring the date of their intrusion within narrow limits. It seems very probable, however, that they were formed at the time of the extrusion of the basic Hemlock volcanics, though it is impossible to prove their connection with them.

[1]Principles of North American pre-Cambrian Geology, cit., pp. 706-707.

(2) MASSIVE DIKES.

The only dike rock which retains to some extent its original texture is a much-altered medium-grained dolerite (diabase). The alterations it has undergone are those usual for such basic types of rock, and this one exhibits nothings peculiar or of special interest. An ophitic texture, while still recognizable, is more or less obscured by the uralite which has developed out of the pyroxene. The remnants of the original plagioclase feldspar present show exceedingly slight pressure effects. The alteration processes would therefore seem to have been due to the action of percolating water, without special mechanical influence. Hence we may date the intrusion of this particular dike after the orogenic movements which affected the granite core, rendering portions of it schistose, and crushing all of it to a greater or less extent. These movements are presumed to have taken place just prior to or during Keweenawan time; and therefore the age of this dike Is Keweenawan or post-Keweenawan.[1]

RÉSUMÉ.

In the above-described granite massif we have a rock of pre-Huronian age, as shown by its relations to the overlying sedimentaries. It possesses in general a coarse granular, and in places porphyritic texture. Along its border it contains portions which are much finer grained, darker than the rest of the mass, and very well banded. The boundaries between the banded rock and the granite at times are sharp, but frequently are very indefinite. This banded schistose portion is found to be due to pressure, causing the gradual passage from the granular granite to the gneissoid, schistose granite.

One instance of undoubted inclusion of gneissoid granite by a true granite was observed. If the gneissoid granite was derived by pressure from the Archean granite, then the particular granite dike which includes the fragments