ERRATA.

Page 13, line 31, read *are* instead of *is*.

Page 21, line 2, read *northeast toward the southwest* for *northwest toward the southeast*.

Page 89, line 14, read *40* instead of *400*.

Page 112, line 26, read *similar* instead of *familiar*.

Page 118, line 9, read *east* for *west*.

Page 138, fig. 16, read *Stambaugh Hill* for *Sheridan Hill*.

Page 139, line 23, read *transpiration* instead of *exhalation*.

MICHIGAN GEOLOGICAL AND BIOLOGICAL SURVEY

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THE IRON RIVER IRON-BEARING DISTRICT OF MICHIGAN

BY

R. C. ALLEN

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1910.

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LETTER OF TRANSMITTAL.

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

Governor Fred M. Warner, President.
Hon. D. M. Ferry, Jr., Vice President.
Hon. L. L. Wright, Secretary.

Gentlemen:—I beg to present herewith as a part of the report for 1910 of the Board of Geological and Biological Survey, Publication No. 3, a report on the geology of the Iron River Iron-Bearing District of Michigan.

Very respectfully,
R. C. ALLEN,
Director.

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THE IRON RIVER IRON BEARING DISTRICT OF MICHIGAN.

BY R. C. ALLEN.

CHAPTER I.

INTRODUCTION.

Field work in the Iron River district was begun by the writer in July and continued to October, 1909. During the spring and summer of 1910 frequent visits were made for the purpose of obtaining additional geological information which is constantly accumulating as new explorations are undertaken.

No earlier attempt had been made to map the geology of this district in any detail. The published literature is limited to brief mention here and there in reports of the Michigan and the United States Geological Surveys and to reports of geologists and mining engineers for commercial interests. Professor W. S. Bayley in 1901 made a cursory examination of the southern part of the area including the vicinity of Iron River and Stambaugh. The results of Prof. Bayley's examination were not published. Through the courtesy of the United States Geological Survey the writer was furnished a copy of Prof. Bayley's notes.

That published information regarding the geology of this district is so meagre is due to the deep cover of glacial drift through which the underlying formations project only in widely separated outcrops. Over wide areas there are no rock exposures. The meagre data afforded by rock exposures has in late years been supplemented by a large amount of underground exploratory work undertaken in search for iron ore.

As far as possible all geological facts are indicated by appropriate color or symbol on the general map of the district (Plate 1). The large scale of this map, 2 in. to the mile, and the subdivision of the sections into quarters and sixteenths are features which should appeal to land owners and explorers for iron ore. While the sheet is not too large for convenient use it is large enough to be used as a base on which to record new information which is rapidly accumulating as drilling progresses. The location of rock outcrops were ascertained in many cases by pacing to the nearest known section, quarter, or sixteenth corner while others, especially those in the producing area, were transferred from plats furnished by mining companies, as were also the location of shafts, pits, and drill holes. Where information warrants, formation boundaries have been indicated. It is regretted that information is as yet far from adequate for drawing the limits of the iron formation belts. In constructing the map, the writer has tried to delineate faithfully and accurately known facts of geology and has resisted the temptation to project extensions of iron formation belts very far beyond known occurrences on basis of inferred structure. However, such extensions are dealt with in the text of the report.

Much of the credit for any value which this report may have is due to the cooperation of the mining companies and land owners of the district. The writer was given free access to drill records, drill cores, mine plats, and underground workings of the mines, and in many cases the facilities of the mine offices were tendered him. But for the active assistance rendered by the mine operators and explorers this work could not have been done at all. The writer is indebted to practically every company, superintendent, engineer and mine captain in the district, not only for information freely given but for personal courtesy and kindnesses that have made the work a pleasure. Thanks are due to Messrs. I. N. Woodworth, O. R. Hamilton, Lowe Whiting, Zebina McColman, G. L. Bottsford, William Connibear and W. H. Selden for personal favors and assistance, and special indebtedness is acknowledged to Mr. Leigh Townsend and Parnell G. McKenna for assistance in preparation of the illustrations, to Mr. Ray Willoughby and I. D. Scott who acted as field assistants, Mr. Willoughby during July and August and Mr. Scott in September, 1909, and to Mr. O. W. Wheelwright who made detailed plats of special areas.

Lansing, Michigan, Nov. 15, 1910. R. C. ALLEN.

HISTORY AND DEVELOPMENT.

The first discovery of iron ore in the Iron River district is accredited to Mr. Harvey Mellen, a United States land surveyor. The field notes of Mr. Mellen's under date of August 8, 1851, describe the occurrence of an "outcrop of iron ore five feet high" on the west face of Stambaugh Hill, 52 chains north of the southwest corner of Section 36, T. 43 N., R. 35 W., and this outcrop was recorded on the original United States Land Survey plat of the township. While the occurrence of ore was thus early made known* mining did not begin until 31 years later, when Mr. Mellen's discovery became the site of the Iron River mine. The opening of the district dates from the fall of 1882 when the Chicago and Northwestern railroad reached Iron River with a spur from Iron River Junction, now Stager, and shipments began almost simultaneously from the Iron River and Nanaimo mines. In anticipation of the building of the railroad there came an influx of settlers, and the villages of Iron River and Stambaugh grew rapidly during the summers preceding the arrival of the railroad.

The history of the mining industry in this district is divided naturally into three periods; the first embraces the years 1882 to 1893, the second 1894 to 1898, and the third from 1899 to date.

During the years 1882 to 1893 inclusive the only important shippers were the Iron River and Nanaimo mines. The Beta was opened in 1886, the Sheridan in 1889 and the Hiawatha in 1893. The total shipments from these mines, including 2,092 tons from a prospect known as the Selden, was only 1,136,444 tons of which the Sheridan is credited with 56,813 tons and the Nanaimo 12,566 tons. The largest output for a single year was 180,340 tons in 1889.

In view of the rapid developments of recent years one is lead to inquire why the opening of the district was not followed by a more rapid expansion in the mining industry, such as characterized the earlier years of the Menominee, Penokee-Gogebic and Vermilion ranges which were opened about the same time, the Menominee in 1877, and Vermilion in 1883, and the Penokee-Gogebic in 1884. The explanation is not difficult to find but is involved in part in each of several factors, a brief consideration of which may be of some interest.

The most important of these is undoubtedly the non Bessemer

*Iron ore was first discovered in the Lake Superior region in 1844 near the site of the old Jackson mine at Negaunce.

character of the Iron River ores. The decade preceding the opening of the Iron River district witnessed the movement of the center of iron manufacture from the Lehigh Valley to the head waters of the Ohio, and a gradual but rapid substitution of steel for iron. With the development of the Bessemer process of steel making came an increased demand for Bessemer ores. Only under exceptional conditions of the iron trade in these early years was there any real demand for Lake Superior high phosphorous ores such as occur in the Iron River district, while ordinarily these ores were with difficulty salable at all. Consequently there was little incentive for investment of capital in exploration for new deposits, especially when it was correctly infered, as later developments have shown, that such deposits if found would be of non Bessemer character.

With the opening of Bessemer ore deposits on the Vermilion range in 1883 and the Penokee-Gogebic range in 1884 mining capital was promptly attracted to these more promising districts to the disadvantage of the Iron River and neighboring areas. But aside from the non Bessemer character of the ore there are adverse natural conditions confronting the explorer in the Iron River district which do not exist to the same degree in other Michigan ranges. These for many years have stood in the way of mining development. The rocks are buried beneath thick deposits of glacial drift. Rock exposures are so few and scattered that in themselves they offer insufficient data for guidance in either exploration or accurate geologic mapping. The rocks can be reached in most places only by drilling or deep pitting. Yet had the early discoveries been of more promising character there is no doubt that active development would have followed despite the natural difficulties involved in exploring a heavily wooded and deeply drift-covered region.

That the extent and character of the ore-bearing fields remained for so many years unknown is not, however, altogether due to the foregoing causes. Titles to a large acreage of lands were for many years in litigation. This was an outgrowth of conflicts between homesteaders who had "squatted" on lands which previously had been claimed under various railroad and canal grants. The history of these disputes regarding land titles has no present interest beyond the fact that during their progress the lands involved were eliminated from the market and to that extent exercised a deterrent effect on mining development.

A fourth and least factor which operated to retard development is found in a certain notion held by many of the earlier prospectors and explorers regarding the origin of the iron ores. Since the earlier known ore deposits were in the narrow valley of Iron River, by a curious but not surprising inference the idea became prevalent in the minds of many that the occurrence of ore was in some unexplainable manner genetically related to the valley and was not to be searched for elsewhere in this district. Even to the present day a valley or "draw" presents alluring prospects to many explorers as is shown by the location of several of the more recent operations. The idea is not without *some* scietific basis as will be discussed in a later chapter.

During this period, with the exception of a prospect in Sec. 26, T. 43 N., R. 34 W., now known as the Chicagon mine, operations were confined to the valley of Iron River in the vicinity of the villages of Iron River and Stambaugh, where the Iron River and Nanaimo mines, with a few struggling prospects, kept the industry alive up to the financial depression of 1893.

An attempt at local smelting was made at the Nanaimo mine in 1884. In this year an organization known as the Iron River Furnace company built a charcoal furnace with a capacity of seventy tons and a row of charcoal kilns north of the mine on the opposite side of the river. The plant was never operated successfully.

Of the five years from 1893 to 1898, inclusive, there is little to record of the mining industry at Iron River. A glance at the table of productions on page ... tells the story. These were gloomy times. Those districts having the less desirable ores to market are always the hardest hit and slowest to recover in times of general depression in the iron and steel trade and mining at Iron River received a death blow in the panic of 1893. Thereafter until the gradual resumption of mining beginning in 1899 the villages of Iron River and Stambaugh found practically their only support in the agricultural and lumbering industries. With the panic of 1893 came the opening of the great Mesabi range. The Mesabi district presented a matchless field for the explorer and the mining capital of the Lake Superior region was promptly absorbed in the opening of the new district. The discovery of the enormous high grade Bessemer deposits of the Mesabi, which can be mined at a cost per ton far below that for the old ranges, together with the low prices following the panic, brought about a condition much to the disadvantage of the old districts. However, the softness of the Mesabi ores made them less desirable in furnace practice than the harder old range Bessemer ores and it was in great measure the demand of the furnacemen for hard ores to mix with the soft Mesabi ores that sustained the market for the old range Bessemer product, while the Crystal Falls and Iron River districts with nothing to sell but non Bessemer ore were for a time all but entirely eliminated from the mining industry. But the steady and rapid increase in the consumption of pig iron since 1897, and the heavy and ever increasing draughts on deposits of high grade Bessemer ores has finally brought the more phosphoric ores permanently into the market. With each succeeding year the mines find it increasingly more difficult to meet the demand of the furnaces for low phosphorous ore. The result has been a gradual development of open hearth steel manufacture at the expense of the Bessemer process and a strengthening of the market for the more phosphoric ores.

A market once firmly established, the devolpment of the Iron River district was assured and has gone steadily forward. The last decade, forming the third period under discussion, has been one of expansion. The annual shipments with the exception of that for 1902 have each year shown an increase over the preceding year and have grown from 5,009 tons in 1898 to 1,151,871 tons in 1909. Active development began in 1896 when the Mastodon Iron Company of Crystal Falls began exploring the property now known as the Dober mine. Later this mine came into the hands of the Oliver Iron Mining Company by whom it has been developed into one of the largest producers of the district. The Baltic was explored by the Verona Mining company in 1900 and shipments began in the following year. In 1900 the Hiawatha was added to the list of shippers and the Caspian in 1902. The following year operations were resumed at the old Iron River mine which had been idle since 1892, and a year later the Youngs mine was added to the number of producers. The James and Brule mines made first shipments in 1907, the Berkshire and Zimmerman in 1908, while last year saw two more producers enter the list, the Fogarty with a shipment of 77,356 tons and the Baker with 45,002 tons. There were in all 11 producing mines in 1909 and in addition a number of promising explorations, some of which will undoubtedly become shippers in the near future. During the last decade, and especially in the past four years, much exploratory work has been done increasing in proportion our knowledge of the character and extent of the ore-

bearing strata. From the narrow valley of Iron River, explorations have been pushed outward in all directions, but chiefly to the north, east and southeast of Iron River.

The future of the Iron River district never looked brighter than at the close of 1909. The shipments for the year were approximately double those for each of the preceding three years, while the amount of exploratory work accomplished and projected was unprecedented in the history of the range. There are at present 15 different companies conducting mining and exploratory operations and several others are contemplating entering the field. There is appended a table of productions covering the years from 1882, when first shipments were made, to the end of 1909.

TABLE OF SHIPMENT OF IRON ORE FROM THE IRON RIVER DISTRICT, 1882-1909.

Mines.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.
Nanaimo	2,480	29,221	37,620		5,400	30,460	5,744		3,441	13,200					
Iron River (Riverton)	29,115	100,369	52,583	55,693	78,591	{ 39,493 { 83,018	} 110,000	179,238	155,458	59,345	1,176				
Selden					790	1,302									
Beta					1,585	1,226				1,400					
Sheridan								1,102	595	7,137	45,745	2,234		16,754	3,419
Hiawatha												1,683		1,201	
Dober (Riverton)															
Baltic															
Caspian															
Youngs															
James															
Brule, Chatham No. 1 and No. 2															
Berkshire															
Zimmerman															
Baker															
Fogarty															
Total	31,595	129,590	90,203	55,693	86,366	155,499	115,744	180,340	159,494	81,082	46,921	3,917		17,955	3,419

Mines.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.	1909.	Total.
Nanaimo								9,086	91,238	91,792	53,778	305		373,765
Iron River (Riverton)														944,079
Selden														2,092
Beta														4,211
Sheridan	146		31,104	8,063										116,299
Hiawatha				11,098	20,355	74,596	53,828	38,288	9,704	20		138,190	136,740	485,613
Dober (Riverton)		5,009	13,242	120,207	119,860	215,850	97,633	81,543	82,611	161,704	90,358	47,073	171,200	1,206,290
Baltic					17,326	64,664	123,236	151,114	133,246	186,495	189,119	129,037	174,220	1,168,457
Caspian							2,088	4,242	10,248	80,875	138,867	102,628	189,023	527,971
Youngs									10,926	47,583	92,632	70,094	154,150	375,385
James											2,360	59,760	90,851	152,971
Brule, Chatham No. 18, No. 2											14,883	45,826	68,730	129,439
Berkshire												3,440	34,296	37,736
Zimmerman												1,832	10,303	12,135
Baker													45,002	45,002
Fogarty													77,356	77,356
Total	146	5,009	44,346	139,278	157,541	355,110	276,785	284,273	336,973	568,469	581,997	598,185	1,151,871	

CHAPTER II.

PHYSIOGRAPHY.

GENERAL FEATURES.

The topography of the Iron River district is of glacial origin slightly modified by preglacial forms and by postglacial erosion. In general the area presents a series of hills or parallel chains of hills elongated in a direction about S. 20° W. which is the direction of ice movement as recorded on striated and grooved rock surfaces in the southwestern and northern parts of the area. The ridges are separated by corresponding hollows which hold swamps and lakes connected by creeks forming the minor drainage courses. The major drainage is independent of the natural northeast-southwest "grain" of the country, for the larger streams, the Brule, Iron, and Paint rivers cross diagonally the general southwest trend of the hills and valleys. The Paint river in the northern part of the district follows, in general, the strike of the underlying rocks, outcrops being comparatively numerous along its course. The same may be said of the Brule river in the southern part of the district. Both of these streams may follow modified preglacial courses. This is, however, certainly not true of the Iron river for this stream is known to cross at least two well defined drift-filled, preglacial valleys which fall toward the northeast nearly at right angles to the course of the Iron. These valleys are separated by a rock ridge which protrudes through the drift in Stambaugh hill on which is built the village of Stambaugh. (See Plate 1).

In contrast to the independence of the major streams the minor drainage is controlled absolutely by the topography of the drift mantle which may be readily inferred from a study of the topographic map. Frequently the lakes occupying depressions between the ridges are, like them, elongated in a northeast-southwest direction. The best examples are Stanley and Iron lakes; others are Minnie, Chicagon, and Trout lakes occupying parts of the same depression in the eastern part of the area. Most of the lakes are drained by streams, but some, as Bennan, Snipe, and Scott lakes have no outlets.

The combination of elongated ridges and corresponding depressions forms a distinctly drumloid type of topography. However, there are but few typical drumlins. The most nearly perfect example occurs just north of Iron River village, crossing the south line of Sec. 23, T. 43 N., R. 35 W. A terminal moraine formed by the Langlade lobe (Weidman) of the Wisconsin ice sheet occurs not far to the south in Wisconsin, following a general northwesterly course at a high angle to the trend of the drumloid hills of this area. This is a characteristic relation between drumlins and terminal moraine found elsewhere, notably in New York and Southern Wisconsin.

Thickness of Glacial Drift.—The thickness of the drift varies from nothing up to above 300 feet. It is of course thinnest along the depressions and major drainage courses where the underlying rocks are frequently exposed and on the average thickest in the hills between them. In some instances postglacial and preglacial valleys coincide in general trend and carry greater thicknesses of drift than bordering hills. This is true of the preglacial valley extending diagonally northeast through Sec. 1, T. 42 N., R. 35 W. and Sections 31 and 29, T. 43 N., R. 34 W. (See map Pl. 1.)

While the elevation of many of the hills is accounted for by the relatively great thicknesses of drift under them there is abundant evidence that the preglacial topography of this region was more rugged and presented greater vertical range between hills and valleys than does the present surface. The highest hills are in the southwestern part of the district and are of preglacial origin. Sheridan hill in Sec. 20, T. 42 N., R. 35 W. has an altitude of 1,840 feet and rises 460 feet above the lowest point in the district, the valley of the Paint river where it leaves the area in Sec. 36, T. 44 N., R. 34 W. The elevation of the rock surface near the center of Sec. 29, T. 43 N., R. 34 W. is 1,280 feet. Thus the maximum difference in elevation was in preglacial times at least 100 feet greater than it is now.

GLACIAL DEPOSITS.

In order that the non technical reader may better understand the following description of the glacial geology of the district, the discussion is prefaced by a brief explanation of the meaning of

the terms most commonly used in the description of glacial deposits.

In a collective sense deposits which are made directly and indirectly by continental glaciers are all included in the term *drift.* On the basis of composition, mode of deposition, and resulting topographic forms of the deposited material numerous subdivisions are made. Deposits referable more directly to ice deposition are composed of *till.* Till is composed mainly of clay, which may be more or less sandy, with varying quantities of rock fragments or boulders of sizes sometimes ranging up to many tons in weight. *Boulder clay* is another term for this class of deposits. On basis of topographic form, which is dependent mainly on mode of origin, deposits of till are subdivided into *drumlins, moraines,* and *till sheets,* the latter forming largely the *ground moraine.*

Drumlins are "smooth surfaced oval hills and ridges composed of till, the larger axes of which are parallel to the direction of the flow of the ice which shaped them." The ratio of short to long axes may vary from 1 : 1½ or 2 up to 1 : 20. Intermediate values are commonest. A *drumlinoid* is a hill composed of till and resembling in form a drumlin but being less symmetrically shaped although referable to the same mode of origin.

Moraines are formed at the margins of glaciers by the accumulation of till commonly in irregular ridges of hummocky or irregular character and usually accompanied by undrained basins or hollows which, when small and relatively deep, are termed *kettles.* A retreating glacier recedes haltingly, depositing at each stage of its recession a moraine. Sometimes during general recession an advance of the ice occurs and existing moraines are obliterated in the newly ice-covered area to be reformed during the succeeding halting stages of recession. Both the advance and retreat of a continental glacier is measured by the algebraic sum of numerous backward and forward movements. The records of recessions (moraines) are usually distinct, of advances, very much less distinct.

Till sheets are formed beneath the ice sheet and inside the moraines by ice deposition of till, i. e., mainly unstratified boulder clay. They form a blanket-like cover of greatly varying thickness above the rocks on which they are deposited. Till sheets are, areally considered, the most important of the deposits formed by continental glaciers.

Deposits, more or less perfectly stratified, which are formed by the joint action of glacier ice and water, are described under the term *glacio-fluvial.*

Glacio-fluvial deposits are subdivided on basis of topographic form and mode of deposition into *valley trains, outwash aprons* (outwash plains), *eskers,* and *kames.*

Glacial streams escaping from beneath the ice are nearly always loaded with more sediment that they can carry, some of which is, therefore, deposited in the form of gravel, sand, and silt in the bed of the stream, forming a *valley train* beginning at the edge of the glacier and extending down the valley of the stream indefinitely. At the margin of a continental glacier *valley trains* may coalesce to form a broad marginal sheet of *debris* called an *outwash plain* or *outwash apron.* The valley train of continental glaciers is characteristic of the more rugged regions where the margin of the ice sheet may fringe out in narrow lobes extending down the valleys, being separated from one another by ridges of land forming the divides. "Where streams of considerable size form tunnels under or in the ice, these may become more or less filled with wash, and when the ice melts the aggraded channels appear as long ridges of gravel and sand known as *eskers.*"[1] Similar ridges may perhaps be formed in other ways as in valleys cut in the ice, bottomed by land but flanked by ice walls.

Kames are irregular hummocky hills of stratified sand and gravel heaped up at the edge of the ice in the mouths of ice tunnels and ice channels by escaping glacial streams. They are especially associated with marginal moraines.

Glacial deposits are often interbedded and intermingled with glacio-fluvial deposits, although the latter are especially characteristic of a zone extending to some distance inside the ice margin but having its greatest development in an outside marginal border.

In the Iron river district the glacial deposits are far more important than the glacio-fluvial deposits and, as will be explained below, antedate in age the formation of the latter, although in their present form the origin of both is a result of the action of the same ice sheet. (Wisconsin, or last continental glacier.)

[1]Chamberlin and Salisbury. Geology. Volume I, p. 306.

GLACIAL DEPOSITS IN THE IRON RIVER DISTRICT.

Till. By far the greater part of the surface of the Iron River district is covered with till. It seems originally to have formed beneath the ice a nearly complete cover above the underlying hard rocks. With the progressive exposure of the land as the ice retreated northward the present streams were formed. These became lines of glacial drainage down which glacial *debris* was carried and in part deposited on the valley bottoms as sand and gravel. Later, when the streams were no longer overloaded with glacial outwash they were able to erode channels in their aggraded beds, removing much of the sand and gravel with which their beds were clogged, and in case of the larger streams, frequently discovering the underlying hard rocks. The till areas of the present surface are found on the higher lands above the levels of glacial drainage.

The till is frequently composed almost entirely of firm boulder clay but more commonly the clay is somewhat sandy. The content of sand is usually sufficient to lighten the soil so that it maintains good tilth under cultivation but occasionally "sticky" or heavy clay soils occur. Stratified sand and gravel in the form of lenses are abundant in the till but are more common at buried horizons than on the surface. The most conspicuous character of the till is its unusually high content of boulders, a feature which may be observed in any section and is rendered prominent by the number of stone fences around cultivated fields and the large piles of boulders in the fields themselves, representing an expenditure of labor the magnitude of which can not be appreciated by one unfamiliar with agricultural conditions on the till soils.

Russell in 1905 made a study of the till areas of the southern part of the district,[2] which in all respects are similar to those in other parts of the area, and pointed out certain differences in character between the till of this region and that occurring west of Chicagon lake in the Crystal Falls district. The description of the gray till of the Iron River district is clear and accurate, but the author disagrees with Russell's ideas regarding the origin of the till and the direction of glacial movement. Russell says in part:[3] "In travelling west from Crystal Falls on the road leading to Iron River, one passes from a region where red till forms

[2]Russell, I. C. The Surface Geology of Portions of Menominee, Dickinson and Iron Counties, Michigan. Geological Survey of Michigan, Annual Report for 1906, pp. 7-91.
[3]Ibid. p. 50.

a veneer on the surface underlying rocks, to a region of massive moraines composed of gray till. The change occurs at the slough connecting Chicagon and Trout lakes, but whether these two lakes and the sluggish water channel connecting them are precisely on the boundary line or not remains to be determined.

The boundary referred to not only separates two regions in which the color of the soil is different, but several other contrasts in conditions accompanying this change, such, for example, as the thickness of the surface blanket of *debris,* prevalence of hard rock outcrops, character of the topography, abundance and nature of the boulders strewn over the surface, etc., as well as in variation in the aspect of the forests and conditions favoring agriculture. These contrasts are so definite and important that they demand a somewhat detailed consideration:

The red till on the uplands in the vicinity of Crystal Falls is on an average some ten feet thick, and forms merely a veneer on the glaciated rock surfaces. The gray till in the numerous bold hills to the west of Chicagon and Trout lakes is, in general, from one to two hundred feet thick, and in at least one locality, as shown by a well at Bates, is in excess of 212 feet deep."[4]

"The topography in the region where the red till forms the surface, is controlled to a great extent by the relief of the hard rock on which the till rests, and the hills are characterized by their comparatively small size and irregular outlines; while the topography of the gray till, as for example between Chicagon and Stanley lakes, has for its dominant features, bold, steep-sided, convex hills, with symmetrically curved bases, which efficiently conceal the relief of the rocks on which they rest. Accompanying this change in topography is an increase in the relief of the land above sea level. As one travels westward from Green Bay, the land rises gradually and * * * in the region to the west of Chicagoan and Trout lakes the broad uplands attain an elevation of 1,700 feet, and, in some instances approach 1,800 feet. The marked increase in elevation that occurs where one passes westward from the red to the gray till, coincides with the increase in thickness of the glacial *debris,* and seems to be due principally to this cause.

The heavy moraines of gray till to the west of Chicagon and

[4]For thicknesses of drift, see map. Plate I.

Trout lakes has a breadth of at least ten miles[5] and trends approximately northeast and southwest."

"The gray till is less sandy than the red till adjacent to it on the east, and as is judged, contains a larger percentage of clay-like material."

"Certain suggestive facts in reference to the relation of the red to the gray till may be mentioned, although they require supplementary evidence before their full significance can be satisfactorily determined. At the excavation made in connection with iron mining near Iron River and Stambaugh, gray till rests on reddish stratified sand and gravel, and along the road between Iron River and Atkinson to the northwest of a belt of bold moraines composed of gray till, the surface deposits consist of red till of the same general character as the main body of the red till which extends eastward from Crystal Falls, etc. These occurrences, and others of a similar nature, seem to show that the gray till was deposited at a later time than the red till and overlaps its westward extension. That such is in reality their true relation is little more than a suggestion * * *."

"No striæ have been observed which might serve to demonstrate the direction of glacial flow, but judging from the topography and the presence of sand and gravel deposits in the valley of the Iron and Brule rivers, etc., the ice lobe which formed the moraine lay to the northwest, and, on melting, its margin withdrew in that direction. Although only a beginning has been made in the study of the gray till, the conclusion is ventured that in the region examined, it pertains to the Chippewa lobe of the Wisconsin ice sheet."

Russell's rather tentative conclusions may be stated in brief as, (1) the so-called gray till of the Iron River district is younger and overlies the westward extension of the red till of the Crystal Falls district to the east of the Chicagon-Trout lake depression; (2) the topography of the till west of Chicagon and Trout lakes is morainal; (3) the gray till of the Iron River district is referred to the terminal moraines of the Chippewa lobe of the Wisconsin ice sheet which in this region retreated toward the northwest and presumably advanced from the northwest toward the southeast.

While there is some basis for distinction on the basis of *color*

[5]The gray till here extends from the east to the west side of the district and beyond—a width of at least upwards of twelve miles.—Author.

and general character of the boulder content between till of the Iron River district and that of the Crystal Falls district to the east of Chicagon and Trout lakes, this distinction is not a sharp one, and is certainly less conspicuous than might be inferred from the stress which Russell has laid upon it. There is little room for distinction even in color between the so-called *gray* till of the Iron River district and the *thicker* deposits of *red* till of the Crystal Falls district. It is suggested that the red color of the thinner parts of the till sheet of the Crystal Falls district is due in great measure to the fact that it *is* thin. The redness of the till is due to its content of red iron oxide which existed in the mantle of weathered rock from which the ice largely obtained the clay and boulders which form the till. It is usually true that local material is dominant in any till area and where the till is thin it is to be expected that local material would lend character to the deposit. It is equally true that in a thick till sheet such as occurs in the Iron River district local material is apt to be generally more abundant near the bottom than at higher horizons. Ferruginous rocks are abundant in both districts and their weathered mantle probably furnished an unusually large supply of red clay to the moving ice which deposited the till. The redness of certain basal portions of the Iron River drift, as noted by Russell, is not in itself a basis for correlation with the Crystal Falls drift on the one hand or for separation from the lighter colored deposits above it on the other.

That Russell should have considered the topography of the southern half of the Iron River district as morainal is somewhat surprising and it is believed that had his observation been more widely distributed his view would have been altered. The first impression that one gains from an inspection of the topographic map is that the N. E.-S. W. trend of the hills, valleys, and lakes, and the beautifully elongated and smoothly rounded forms of many of the hills were the result of *moving* ice and not of chaotic marginal deposition at successive fixed stages of ice retreat. The correctness of the impression is verified on examination of abraded rock exposures. There are few localities where satisfactory observations can be made, but a sufficient number were taken in the western half of the area to determine beyond doubt the direction of the ice movement, which is indicated on the map (Plate 1) by arrows at the points where the observations were made. The data is tabulated below:

(1). N. E. ¼ of S. E. ¼ of Sec. 21, T. 42 N., R. 35 W.
S. 10° W.
S. 5° W.
S. 6° W.

(2). S. W. ¼ of S. W. ¼ of Sect. 6, T. 43 N., R 35 W.
S. 35° W.
S. 33° W.

(3). N. E. ¼ of N. E. ¼ of Sec. 1, T. 44 N., R. 36 W.
S. 20° W.

(4). N. W. ¼ of N. E. ¼ of Sec. 3, T. 44 N., R. 35 W.
S. 14° W.

At all of these localities glacial grooving is distinct especially in (1) and (4) where the grooves are inches in depth and occur on beautifully smoothed rock surfaces. In none of these localities are there more than one set of striæ or grooves and these are in each case almost exactly parallel.

Further evidence of the southwestward movement of the ice in this district is afforded by the relation between the direction of glacial grooving here and the orientation of the drumlinoid hills with the trend of morainal tracts to the north and south. Leverett has traced a morainic area from the vicinity of Hackley, Wisconsin, westward missing by only a few miles the southwest corner of the quadrangle. Northeastward another morainic tract extends northwestward through Amasa, touching the northeast corner of the Iron River quadrangle, and thence swinging a little more westerly across the country north of the district.[6] The trend of these two moraines is essentially parallel and nearly at right angles to the direction of glacial grooving and topographic orientation in the Iron River district lying between them.

Origin of the Drumloid Topography.—It is suggested that the drumloid character and "graining" of the topography of the quadrangle was produced by ice erosion of a till sheet. Glaciers, like rivers, under a certain class of conditions erode their beds, and under another deposit material upon them. If these are balanced

[6]Unpublished work of Frank Leverett. Field season of 1909.

equilibrium results, and neither appreciable erosion nor deposition occurs. Thus in the end, glacial erosion and deposition are exactly balanced. However, this equilibrium is rarely maintained at any given locality, the net result being in favor of one or the other of the opposing forces. In general, glacial erosion predominates near the center of ice dispersion, deposition in a zone sharply limited in one direction by a morainic margin marking the limits of ice advance, usually fringed by glacial outwash, and in the opposite direction, grading into an intermediate zone in which erosion and deposition are more nearly balanced. In a particular locality a glacier may erode at one time and deposit at another and there may be, in fact, several oscillations from the one condition to the other.

The erosive effects of moving ice on *hard rocks* are plainly recorded in polished, grooved, and striated rock surfaces and other markings on the rocks such as *chatter marks*[7] (crescentic cracks, usually convex toward direction of ice movement). Projecting rock masses are often smoothed and rounded forming *roche moutonné* and frequently glaciated rock knobs or hills exhibit *lee* and *stoss* effects due to greater abrasion on the side of the hill (*lee* side) opposed to the moving ice. On the other hand the erosive effects of moving ice on unconsolidated material such as a till sheet are not so easily discernible. If a glacier has eroded a till sheet earlier deposited by it or an older ice sheet, providing the deposit is not swept entirely away, the record of such erosion is preserved in the truncation of the interleaved, stratified sand and gravel beds which may terminate abruptly at the eroded surface or against the base of later drift deposited upon it. Hills and valleys are more or less perfectly oriented with their longer dimensions parallel to the direction of ice movement. The symmetrical, oval, till hills called drumlins are believed to have been formed in this way although such origin can rarely be proven and there are some geologists who believe that drumlins are more often formed by depositional rather than by erosive action. Russell[8] has shown that drumlins in the Menominee region, particularly in the vicinity of Hermansville, were almost certainly formed by ice erosion of a till sheet and it is probable that the same explanation applies to many other drumlin areas.

[7]For discussion of manner of formation of chatter marks see Russell, I. C. Annual Report Michigan Geological Survey, 1906, pp. 31-33.
[8]Russell, I. C., Michigan Geological Survey, Annual Report, 1906, pp. 42-45.

In the Iron River district we have seen that the ice advanced from the northwest toward the southeast. By studies in comparison with other districts to the south, particularly in Wisconsin, it has been shown by the work of several geologists that the till sheet which covers this area was deposited by the Wisconsin or last continental glacier. If an earlier till sheet existed here it was swept southward by the Wisconsin glacier which left the record of its strongly abrasive action on the hard rocks, producing rounded, polished, and grooved rock surfaces. Later, a thick deposit of till was formed, filling the valleys and covering the tops of the hills; almost completely obscuring the topography of the rock surface beneath it. It is not inferred that abrasion preceeded deposition in all parts of the district, nor that the two processes did not occur simultaneously in different localities but the *end* result was deposition of a thick till sheet on an ice eroded rock surface. During the deposition of the till, water, formed largely by the melting of the ice, was active in building stratified lenses of sand and gravel which became interleaved with the unstratified deposits of boulder clay. Thus far in our analysis we are treading on safe ground but the question now arises, whether the *last* action of the ice sheet was erosional or depositional, whether the topography of the till sheet, which is *about* the same today as it was when uncovered by the ice, was *sculptured* out of a till sheet by ice erosion or was formed mainly by till deposition. Whatever may be the true explanation it is reasonably certain that *moving ice* was the agent which "grained" the topography, and in view of Russell's important determination of drumlin origin in the Menominee country it is thought probable that the action of the ice was erosional rather than depositional. A study of many of the drumloid hills for lee and stoss effects reveals the fact that the steeper slopes are often opposed to direction of ice movement. However, since it is known that glacial movement is often deflected mainly *around* an obstruction, however small it may be, with the result that steeper faces are often formed on the side of the obstruction presented to the moving ice (*stoss* side) rather than on the opposite side (*lee* side) this observation has no important bearing in this connection.

The topography of the Iron River district is drumloid, i. e., the elongated oval hills and chains of hills *approach* the drumlin in

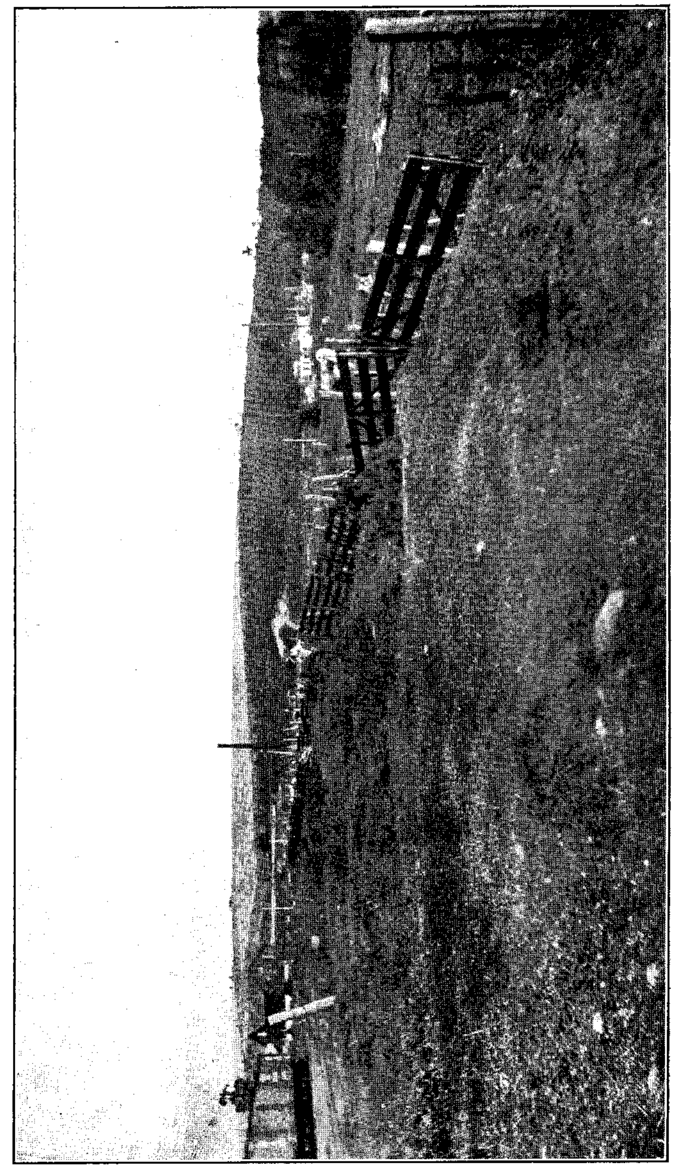
[9]Ibid. pp. 44-45.

form but are less symmetrically shaped. A few of the hills in the central part of the district approach the symmetry of drumlins. They occur in a belt beginning near the center of Section 22, T. 43 N., R. 35 W., extending southeast to the oval hill crossed by the west line of Section 32, T. 43 N., R. 34 W. (See map, Plate I.) The rounded outlines of the drumlinoid hill just north of Iron River are shown in Plate 2.

THE TILL SOILS.

The character of virgin soils in forested areas is reflected to large extent in the forest growth upon them. In the Iron River district, and also in the Northern Peninsula of Michigan in general, the till soils support heavy stands of hardwood. Much of the primeval hardwood forest is still preserved on the till uplands of the Iron River district. Maple is the most abundant tree; birch, elm and basswood are plentiful; while hemlock, spruce, and pine occur to some extent in clumps and colonies usually on the more sandy till. It would be more accurate to say that the pine trees *did* occur for practically all that is now left of them are the stumps on which they grew. Even the occasional "lone pine" has fallen prey to the lumberman. Mining companies are persuing a far sighted policy in buying extensive hardwood tracts in order to insure themselves a supply of mine timber for the future. A considerable part of the forested till areas is held by companies and individuals for speculative purposes. The value of the hardwood and also the land on which it grows is steadily appreciating.

Sooner or later, with increase in population, and the consequent greater demand for land the till areas will be cleared of their forests and in their place will be cultivated fields. Experience has already proven that the till areas respond bountifully to cultivation. Good drainage is assured by the high and rolling character of the till and, as already stated, the till soils maintain as a rule excellent tilth under cultivation. Sticky clay or gumbo soils are exceptional owing to the sandy character of the till and the natural humus content of the soil layer. The summer season is short, but hay, small grains, and vegetables adapted to the climate yield excellent crops. The chief draw back to agriculture here is not the climate or poor soil but the extreme bouldery character of much of the till. This, however, is an obstacle which can be overcome here as it has been in other areas. The writer has been strongly impressed with



A DRUMLIN NORTH OF IRON RIVER. LOOKING NORTHWEST.

the agricultural possibilities of this area and believes, with Russell, that in time the main industry here will be based on agriculture. In agricultural possibilities the Iron River district is undoubtedly one of the most favored areas of the Northern Peninsula.

GLACIO-FLUVIAL DEPOSITS IN THE IRON RIVER DISTRICT.

The glacio-fluvial deposits of stratified sand and gravel are confined to the stream valleys and the depressions between the more elevated till areas. They were formed by running water derived from the melting glacier and in smaller part from the rains. During the time when these deposits were forming the streams were much larger and flowed more swiftly than at present. They were able to transport rock fragments several inches in diameter, large enough to be called boulders. That this is true is shown by the manner in which these fragments occur with the stratified finer materials making up the main body of the deposits. If we assume that precipitation was not greater than now, much the larger volume of water was contributed from the melting glacier. The volume of water and hence its speed of flow and carrying power were subject to great variations. This is indicated by the interstratification of coarse gravel and fine sand. A stream deposits on its bed only such material as it is unable to carry and the character and quantity of the deposits vary with the material contributed and the power of the stream to transport it. During the deposition of the glacio-fluvial deposits the streams were overloaded with sand and gravel and consequently were forced to deposit material in their beds. As the ice retreated northward beyond the headwaters of the streams in this area the glacial drainage was directed into other channels. When this occurred the streams which had been overloaded with sand and gravel were relieved. They shrank in volume to perhaps about their present size, but the shrinkage in volume was not relatively so great as shrinkage in material contributed at or near their sources. Consequently the action of the streams was reversed. Having less material than they were able to carry they began to acquire load from their beds by picking up material which had been previously deposited with the result that the present streams, i. e., the Paint, Iron, and Brule rivers have sunk their channels many feet below the old levels of glacial outwash. These levels which represent the former elevations of the beds of streams are preserved in sand and gravel plains and *terraces* which occur along the valleys of the Paint, Net, Iron and Brule rivers.

Extensive sand and gravel plains occur at the junction of the North and South branches of the Paint river, at the mouth of the Net, and at the junction of the Iron and Brule. It is interesting to note that both the Paint and the Brule rivers have been deflected southward at their respective junctions with the Net and the Iron. The sand and gravel plains developed at these junctions seem to have been formed most largely by the tributary streams (Net and Iron) heading northward more directly toward the margin of the retreating ice sheet. The Iron seems to have continued to receive large amounts of glacial outwash after the ice had receded north of the valley of the Brule, and still later the Net was a carrier of outwash material after the ice had receded north of the valley of the Paint river.

The level of the glacial drainage on the Paint river near Atkinson is about 40 feet above the river, at the mouth of the Net about 50 feet, and in Sec. 36, T. 44 N., R. 34 W. about 65 feet. The fall of the present stream between Atkinson and Sec. 36, T. 44 N., R. 36 W. is, roughly, a little less than 5 feet per mile, while the level of the glacial drainage has a fall in the same distance of, roughly, 3½ feet per mile. The Iron river in its course across the district falls about 120 feet, or roughly a little less than 8 feet per mile, but the fall in the level of the glacial drainage is but slightly if any less.

THE GLACIO-FLUVIAL SOILS.

The sandy and gravelly outwash was formerly heavily timbered with pine. In every instance one can follow with the eye the line marking the level of glacial drainage on the sides of the hills by the change in forest growth. The change from soft wood to hard wood is abrupt and is brought out in very striking manner on the valley sides since the pine lands have usually been cut and burned over up to the hardwood line. These lands now support a second growth of jack pine and popple in contrast to the maple, birch, etc., of the forested till soils.

The sand and gravelly soils are little utilized for agricultural purposes. The till soils on the whole are much more desirable from the standpoint of fertility and durability. However, there are soils on the outwash areas which should yield abundantly under proper cultivation. These contain considerable clay or silt content. The prospective settler or purchaser of these lands for agricultural purposes should investigate carefully before buying. Some areas have been repeatedly burned over to the final destruction of all or part of the natural humus content of the soil. These lands have received an injury which, under the conditions obtaining here, time alone can repair. If fires are prevented vegetation will slowly gain headway and finally in the course of years restore the humus to the soil.

ORIGIN OF THE LAKES AND DRAINAGE COURSES.

Character of the pre-glacial surface.—The lakes and drainage courses are of glacial origin, i. e., they were super-imposed on the drift covered surface exposed on the melting of the Wisconsin ice sheet. Just what relation, if any, exists between the present drainage lines and those which existed prior to glaciation can not be ascertained with certainty except in areas where rock exposures and drilling operations have furnished data for the reconstruction of the pre-glacial surface, as in the vicinity of Iron River and Stambaugh. Here, by assembling this data, we have been able to reconstruct in a general way the pre-glacial rock surface which is shown in green contours on the general map of the district. (Plate I). By reference to this map it will be seen that there are two well marked pre-glacial valleys extending in a general northeast direction. The southernmost heads southwestward into Section 10, T. 42 N., R. 35 W. and extends thence northeastward into the S. W. ¼ of Section 21, T. 43 N., R. 34 W. Probably it has a considerably greater northeastward extent but mapping must await further drilling in this direction. The drainage in the valley was certainly northeastward as far as the northern part of Section 32 T. 43 N., R. 34 W., where possibly it may have turned southeastward across the northeastern quarter of the section, tributary lines coming in here from the northwest and northeast.

A second pre-glacial valley seems to head eastward across Section 27, T. 43 N., R. 35 W. Eastward through Section 26 it coincides with the valley of Iron River which here turns south through a depression in the pre-glacial rock divide trending northeast through Stambaugh Hill while the older drift-filled valley continues a little northeasterly under Ice Lake. East of Ice Lake the depression seems to divide into two, one swinging northeast and another southeast, probably connecting with the valley first described in the S. W. ¼ of Section 29, T. 43 N., R. 34 W.

It appears then that the Iron River cuts indifferently across valleys and divides in the old pre-glacial rock surface. The Brule river, on the other hand, seems to follow in a general way a preglacial valley, although its former bed does not closely coincide with the present one. The same is probably true of the Paint river from the vicinity of Atkinson eastward. With the probable exception of the Brule and Paint the changes in drainage lines produced by glaciation in the vicinity of Iron River and Stambaugh may be taken as an indication of what has happened elsewhere in the district.

The physical history of the district will be developed in a later chapter and it will therefore suffice here to look backward just far enough to construct a mental picture of its surface aspect just prior to glaciation. Just before the advent of the ice age the surface of the Iron River district presented a somewhat rugged aspect. The total relief was some hundred or more feet greater than the present. The hills did not present the smooth and rounded outlines of the present ones, but on the other hand were bolder and rougher and frequently presented very steep slopes. Sheridan hill was then, as now, the highest point in the district. This hill and the ridge south of the Brule river at Saunders dam have about the same appearance now as they possessed in pre-glacial time and they may be taken as examples of many others, which in the area to the north have been buried or partially buried in glacial drift. Yet it must be remembered in this connection that Sheridan Hill and the Saunders ridge, being made of hard siliceous rocks, stand higher above the surrounding rock surface than did other hills composed of softer rocks of the slate series lying north of the Saunders formation.

In pre-glacial time there were probably no lakes or swamps. The land was dissected by stream channels and was completely drained. The area had been subjected to stream erosion for long ages and considerable thicknesses of strata had been worn away. This is shown by the occurrence of flat lying remnants of Ordovician limestone and sandstone which formerly may have covered the entire district and above these it is possible that still younger strata existed. These rocks were all but entirely removed before glacial time and the old erosional surface of the Algonkian rocks on which the Palaeozoic members rested and which now forms the rock surface beneath the glacial drift was again exposed. To accomplish this required a long period of erosion. Pre-glacial drainage was probably southeastward, as now, since the rock surface seems to slope in that direction.

Having before us a general idea of the preglacial surface we are better able to understand the changes in topography and drainage produced by glaciation. The preglacial topography of the Iron River district was such as to have presented little opposition to the southwestward movement of the continental ice sheet. The parallelism, in a single general direction, of glacial striation on rock surfaces and trend of glacially formed ridges and depressions show that the ice rode indifferently over hills and valleys alike, depositing here and eroding there, filling valleys, cutting down hills and generally obliterating drainage courses. Consequently, when the ice withdrew on its final northward retreat a new surface was uncovered. On this new surface the present drainage system developed. Water gathered in basin-like depressions forming lakes and ponds, low areas became swamps, and the newly formed major streams found their way southeastward in the direction of land slope by following the breaks in the southeastward trending ridges as in the case of the Iron River and in other cases perhaps by utilizing in part preglacial valleys not completely obliterated by glacial filling such as the valleys of the Brule and Paint. The minor streams naturally followed the depressions between the ridges, consequently the major streams receive their tributaries from the northeast and southwest.

CHAPTER III.

GENERAL GEOLOGY.

KEEWATIN AND LOWER HURONIAN.

It will be convenient in discussing the general geology of the district to consider each separate formation as a unit, beginning with the Archean or oldest rocks and taking each formation separately in the order in which it appears in the geologic column. Without knowledge of the geology of the other iron ranges of the Lake Superior region, especially those adjoining on the north and west, the task of deciphering the structure and age relations of the various formations would have been a more difficult undertaking. Where correlations with formations in adjoining districts to the west are uncertain local names have been introduced, i. e., Saunders formation, and Sheridan formation, to designate respectively the cherty dolomite and quartzite formation of Lower Huronian age typically developed near Saunders village, and the Palaeozoic member occurring in the vicinity of Sheridan Hill. In all other cases, i. e., where equivalency with formations heretofore described is more certain, the names in use in adjoining districts by the U. S. Geological Survey are extended to cover the equivalent formations in the Iron River district.

Owing to absence of rock exposures and other data there are meagre grounds for drawing formational boundaries on the Iron River map. Such has been attempted only where facts seem to warrant. Except in the case of the Vulcan formation colors have been omitted on account of the indefiniteness of formational boundaries. The map embodies known geologic information in so far as it can be shown on a map. The scale of the map, 2 inches to the mile, is large enough so that rock outcrops, drill holes, pits, shafts. etc., i. e., the data on which the geologist relies for drawing formational boundaries, can be shown. When such is done colors are largely unnecessary.

GENERAL STATEMENT.

The age relations of the various formations which have been discriminated appear in the table below:

Pleistocene deposits. Boulder till, sand and gravel.

	Unconformity.		
Paleozoic	Ordovician.	Sheridan Formation.	Limestone, sandstone and conglomerate.
	(Unconformity)		
Algonkian	Middle-Upper Huronian Group.	Michigamme (Hanbury) Slate	Hanbury Slate containing Vulcan iron formation. Basic volcanics associated with Hanbury Slate.
	(Unconformity?)		
	Lower Huronian Group.	Saunders Formation	Cherty dolomite and quartzite and slates.
	(Unconformity)		
Archean	Keewatin	Brule volcanics,—ellipsoidal greenstone and green schists equivalent to Quinnesec schists.	

Not considering the Pleistocene or glacial deposits, and with the further exception of a few remnants of Paleozoic rocks, the entire area is underlain by rocks of Algonkian and Archean (?) age, and these span the entire gap from the youngest Huronian, the Michigamme (Hanbury) slate, to the oldest Archean, the Keewatin (?) greenstones of the Brule formation. The Michigamme slates of the Marquette district have been traced by the U. S. Geological Survey southward into the Crystal Falls district where they seem to connect stratigraphically with the undivided Upper Huronian slate series of Clements, and westward with the same slate series in the Iron River district. The Brule volcanics in the southern part of the quadrangle are correlated with the Quinnesec schists of the Menominee district, but this correlation is more or less arbitrary since the relations between the Brule volcanics and the adjacent Saunders formation north of it and the Archean (?) granite a short distance south in Wisconsin are not known. Presumably unconformably above the Brule volcanics and Archean granites, the Saunders formation is correlated with the Lower Huronian Randville and Sturgeon formations of the Crystal Falls and Menominee

districts, and more provisionally with certain quartzites and conglomerates in seemingly like stratigraphic position with reference to the Basement complex and overlying slates in the southern Florence district.

From the base of the Saunders formation to the top of the Michigamme there is no evidence of an important unconformity in the Iron River district, but lack of evidence should not be taken as proof that unconformities do not exist. In fact the existence of great unconformities in the Huronian of the Marquette, Menominee and Penokee districts would lead one to believe, in the absence of conclusive proof to the contrary, that unconformities exist in the Huronian of the Iron River and Crystal Falls districts where, from the nature of the geological conditions, they are less easily found.

Since there are no known unconformities it is not apparent just where the dividing line between the Lower Huronian and the Middle-Upper Huronian should be placed. Some suggestion is afforded in the similarity of successions here and in other parts of the Menominee region. The Saunders formation is satisfactorily correlated with the Sturgeon and Randville formations of the Crystal Falls and Menominee districts. The Randville in the Crystal Falls district is overlain by the Hemlock volcanics at the top of which Clements places the separation between Lower and Upper Huronian. Likewise, in the Iron River district the Saunders formation seems to be overlain by a considerable thickness of volcanic greenstone with interbedded slate layers. Volcanic activity was recurrent at various intervals from this time on through the Michigamme. The geologic conditions during Saunders time were markedly different than those which characterized Michigamme time and it seems that the natural dividing line between the Upper-Middle and Lower Huronian is at the top of the Saunders formation, although it is recognized that in the interests of uniformity little objection can be offered to the correlation of the greenstones overlying the Saunders with the Hemlock of the Crystal Falls district, thus placing the division between Upper-Middle and Lower Huronian above rather than below the volcanics.

Within the Michigamme series there is no evidence of important unconformity. Finely conglomeratic layers associated with the iron formation are frequently encountered in drilling, but since the entire series gives evidence of shallow water deposition little significance can be attached to these occurrences. Therefore, we are not able to discriminate between a Middle and an Upper Huronian series. Both series, if present, are included in the Michi-

		Series.	Marquette district.	Penokee—Gogebic district.
Algonkian.		Keweenawan series (copper bearing).		Gabbros, diabases, etc.
Algonkian.	Huronian Series.	Upper Huronian (iron bearing).	Michigamme slate (locally replaced by Clarksburg formation). Bijiki schist (iron bearing). Goodrich quartzite, containing productive detrital ores at its base.	Tyler slate. Ironwood formation (iron bearing and productive). Palms formation (quartz slate).
Algonkian.	Huronian Series.	Middle Huronian (iron bearing).	Negaunee formation (iron bearing and productive). Siamo slate. Ajibik quartzite.	
Algonkian.	Huronian Series.	Lower Huronian.	Wewe slate. Kona dolomite. Mesnard quartzite.	Limestone of Bad River. Quartzite.
Archean or Basement Complex.		Laurentian series (intrusive into Keewatin).	Granite, syenite, peridotite. Palmer gneiss.	Granite and granitoid gneiss.
Archean or Basement Complex.		Keewatin series (iron bearing).	Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of non-productive iron bearing formation.	Greenstones, green schists, and fine grained gneiss.

gamme of this report which is the equivalent of the Middle and Upper Huronian series of the Marquette and Menominee ranges.[1]

The correlation of the Pre-Cambrian series with that of the other Michigan ranges is shown in the following table. The correlations for the Marquette, Penokee-Gogebic, Menominee and Crystal Falls districts are those of the United States Geological Survey.

Menominee district.	Crystal Falls district.	Iron River district.
Hanbury slate, being in lower portions calcareous slates, etc., containing siderite and iron oxide. Vulcan formation, consisting of three members: Curry iron bearing member, Brier slate member, Traders iron bearing member.	Michigamme slate, containing a productive iron bearing horizon not separated in mapping for much of the district. With basic volcanics.	Michigamme slate containing iron formation lenses in at least four horizons. Productive in central part of district (vicinity of Iron River and Stambaugh). Associated with basic igneous rocks—mainly extrusive.
——(Unconformity?)——	——(Unconformity?)——	——(Unconformity?)——
Randville dolomite. Sturgeon quartzite.	Hemlock formation (basic volcanic). Randville dolomite. Sturgeon quartzite.	Saunders formation. Cherty dolomite, quartzite, and slate.
Granites and gneisses.	Granite.	Granite (in Wisconsin). (The age of these granites is doubtful. May be Huronian.)
Quinnesec schists. (Doubtfully referred to Keewatin. May be Upper Huronian).		Brule schists. Mainly ellipsoidal basalt. Exposures rare. (Keewatin are very doubtful. May be Huronian.)

[1] A Middle Huronian has recently been discriminated in the Menominee district by the U. S. Geological Survey.

KEEWATIN (?). THE BRULE VOLCANICS.

Basaltic extrusives with surface textures similar to those of the Quinnesec schists of the Menominee district and the Hemlock formation of the Crystal Falls district are exposed in isolated outcrops north and south of the Brule river in an east-west belt across the southern part of the district. These rocks possess no lithological or structural peculiarities which may safely be used as a basis for their correlation. Most of the outcrops are north of the adjacent Saunders formation, while a few are south of it, but since detailed mapping has not been done south of the Brule river the extent of the volcanics in this direction is not known. The volcanics are nowhere exposed in contact with the Saunders formation, hence their stratigraphic position can be determined only by their areal relation to the Saunders formation in reference to the structural attitude of the latter. The available data, while not conclusive for all parts of the Saunders formation, indicate a general northward dip. Applying this criterion, the volcanics north of the Saunders are probably stratigraphically above it and those south of it are stratigraphically below it.

Exposures of the Brule schists occur in the northern part of Sections 19, 20, 21 and 22, T. 42 N., R. 35 W. south of the Saunders formation. These are the only rocks in the area which are regarded as possibly Keewatin in age. The Keewatin age of these rocks is doubtful. There is evidence that they may be interbedded with the Saunders formation or they may be of even later age.

Interesting exposures occur in the S. E. ¼ of Section 21, T. 42 N., R. 35 W., beginning with a few low outcrops in the N. W. ¼ of the S. W. ¼ and extending with interruption for about a half mile in a direction slightly northeast, across the east line of the section just south of the east quarter post into Section 22, and at the dam on Brule river in the N. E. ¼ of the S. E. ¼ of Section 19 of the same township. In the first locality there are two main groups of exposures, the easternmost, crossed by the section line, shows beautifully developed ellipsoidal structure which is very obscure or absent in the westernmost outcrops.[2] The ellipsoids are of varying size up to above two feet in greatest dimension, being elongated in about E-W. direction, i. e., parallel to the trend of

[2]For description of the ellipsoidal structure see J. M. Clements, Mon. 36, U. S. G. S., pp. 112-126.

the folds and the schistosity in the rocks in this part of the district. There can be little doubt that the ellipsoids have been brought into this position by distortion accomplished by the forces which produced the general east-west folding and parallel secondary structures in the rocks of this part of the district. When there is considered the metamorphism and deformation to which these rocks have been subjected one wonders at the remarkably distinct outlines of the ellipsoids. That the ellipsoidal structure has not been obliterated or obscured is proof that whatever the agents and forces concerned in the anamorphism of the rock the end result as shown in the outlines of the ellipsoids was in the nature of a homogeneous strain. The ellipsoidal structure may be observed to best advantage on the polished surface of the exposure at the dam in Section 19, T. 42 N., R. 35 W. Here the flattening of the ellipsoids is most noticeable; the various individuals are fitted closely together, as though they had been molded and pressed together while in plastic condition, but the flattened ellipsoidal outlines are perfectly distinct.

Between the ellipsoids, mainly in the triangular spaces, occurs a matrix of chloritic and epidotic schistose material very frequently carrying considerable calcite or dolomite and some quartz. The quantity of matrix is small compared with the ellipsoids.

A structural characteristic of the Brule schists is the occurrence of torsion cracks. These are best shown on the non-ellipsoidal basalt exposed in the N. W. ¼ of the S. E. ¼ of Sec. 21, T. 42 N., R. 35 W. These cracks are usually open and from an inch up to three or four inches in length and may be arranged in sets forming a miniature *stockwerk*.

On fresh fracture these rocks are dense, fine grained, and grayish-green in color. Pyrite is irregularly disseminated through the rock in small grains, weathering out to form a pitted surface, calcite is abundantly present in fracture planes and chlorite is visible. A couple of slides from the last named locality were examined. Under the microscope chlorite is seen to make up the body of the rock, next in point of abundance is calcite, widely disseminated in clusters of crystals and ramifying in small veinlets, highly decomposed plagioclase is present and also pyrite, biotite, and epidote. The biotite in many specimens is porphyritic in appearance.

THE LOWER HURONIAN.

SAUNDERS FORMATION.

DISTRIBUTION.

The Saunders formation occurs in a belt of varying width extending in a general direction a little north of west across the southern part of the district and westward an unknown distance. Outcrops are infrequent on the whole and absent in large areas supposed to be underlain by this formation. It is well developed in Sheridan hill in Section 20, T. 42 N., R. 35 W. and vicinity. This hill owes its altitude, 1,840 feet, to the resistant character of the Saunders formation. Westward in Section 22, T. 42 N., R. 35 W., another hill rises to a height of about 1,800 feet and is presumably underlain by the Saunders formation. East of Saunders village and south of Brule river in Wisconsin this formation again assumes topographic prominence in an east-west ridge about two miles long. In the N. E. ¼ of the S. W. ¼ of Section 23, T. 42 N., R. 35 W., cherty phases are exposed in outcrops, slaty and dolomitic phases occur in a number of pits in Sections 26 and 35 and in outcrop on the west side of Brule river a short distance southwest of the north quarter post of Section 34.

LITHOLOGICAL CHARACTERS.

The Saunders formation embraces a wide variety of facies. Cherty dolomite is the most prominently developed. Associated with it is massive white and pink dolomite, quartzose dolomite, impure carbonate slates, quartzites, and talcose slates. The rocks of this formation are so rarely exposed that a general description of the lithology and succession of the various facies of the formation as a whole should not be considered complete. A description of the rocks in known occurrences is given and such generalizations suggested as may be warranted by known facts.

PARTICULAR OCCURRENCES OF THE SAUNDERS' FORMATION.

Saunders Dam.—At the base of the ridge south of the Brule river at Saunders dam about a mile southeast of Saunders station is the best known single exposure of the Saunders formation. The rocks are exposed in a cliff some two or three hundred paces long from which massive blocks have been detached forming a talus

Publication 3, Geology 2, Plate III.

Michigan Geological and Biological Survey.

EXPOSURE OF BRECCIATED, SILICEOUS DOLOMITE OF THE SAUNDERS FORMATION AT SAUNDERS DAM.

which partly obscures the rock in place. Three distinct phases of the formation are exposed in the face of this cliff, viz., pure white, coarsely crystalline dolomite, banded cherty dolomite, and almost pure white and gray chert occurring in layers on the average about an inch thick. The rock in most places is brecciated and shattered to an extreme degree and the bedding is practically obliterated except in a few detached blocks of banded chert. The crushed and fractured cherty fragments are embedded in the greatest confusion in secondary infiltrated silica and carbonate, silica being dominant, forming a chert breccia. (See Plate 3.) In the cherty dolomite the more siliceous bands stand out prominently on weathered surfaces producing a ribbed appearance.

An analysis of the purer phase of dolomite by Prof. A. C. Clark of the Michigan Agricultural College gave:

ANALYSIS OF SAUNDERS DOLOMITE.

CO_2	43.90
SiO_2	6 10
Al_2O_3 / Fe_2O_3	.49
CaO	29.33
MgO	19.98
H_2O at 105°	.07
H_2O at 115°	.05
	99.92%

Every gradation from the rock represented by this analysis into almost pure silica occurs in the exposure, but when the chert content becomes important it shows a tendency to segregate from the dolomite in bands.

Owing to the brecciated character of the rock satisfactory structural data is not afforded in this outcrop. At the north end the dip is apparently very steeply northward. The strike of the formation is undoubtedly that of the ridge which it forms, slightly west of north. Another similar exposure of the Saunders formation occurs in Wisconsin on this ridge about a mile west and one-fourth mile south of Pentoga station. From this point the dolomite ridge strikes northwestward to Saunders Dam then turns southwestward and dies out in about a mile and a half.

Railroad Cut South of Saunders.—On the strike of this dolomite ridge in a cut on the Connorsville branch of the C. & N. W. Ry. at a point about 2,100 feet south of the railroad bridge across the Brule river the Saunders formation is again exposed. Here the rock is less siliceous than at Saunders dam and is intensely sheared with marked slaty structure of nearly vertical dip and almost east-west strike. In the south end of the cut where greatest shearing has taken place the rocks have weathered to a brick red. Toward the north end less weathered and more massive bluish phases occur. These rocks are seen under the microscope to consist chiefly of carbonate with coarse interlocking texture enclosing areas of finely granular silica. Sericite and ferric oxide are abundant and pyrite occurs in aggregates of small grains. The ferruginous appearance of weathered portions of these rocks is doubtless mainly due to the ferrous iron content of the bluish carbonate.

Sections 26 and 35, T. 42 N., R. 35 W.—Very similar phases of the Saunders formation are exposed in another locality about 3 miles west in Sections 35 and 26, T. 42 N., R. 35 W. In the bottom of a shallow well in the N. W. ¼ of the S. W. ¼ of Section 26, there is exposed an impure, bluish-gray, schistose, carbonate rock similar to those occurring in the C. & N. W. Ry. cut south of Saunders. The strike of the schistosity is N. 65° W., and the dip vertical. Similar rocks associated with well banded, varicolored, ferruginous and aluminous dolomitic slates occur on the dumps of pits dug by Mr. R. D. Williams in the S. W. ¼ of the S. W. ¼ of the section. Bedding in the slates is usually obscured by the schistosity but in a number of specimens bedding laminæ are well shown cutting the schistosity at a high angle. The ferruginous character of these slates is shown by the abundance of iron oxide developed in weathering which has here invited to exploration for iron ore. The following analysis of a typical specimen may be taken as characteristic:

ANALYSIS OF FERRUGINOUS DOLOMITIC SLATE.

CO_2	24.50
SiO_2	25.3
Al_2O_3	13.78
Fe_2O_3	3.25
FeO	2.93
MnO	Trace
CaO	17.28
MgO	7.86
Na_2O	.42
K_2O	2.68
Total H_2O	2.04
	100.04

More massive, quartzose and ferruginous dark colored dolomite occurs in a pit on the N. E. ¼ of the N. W. ¼ of Section 35, about 165 paces south and 30 paces west of the N. ¼ corner. The material from the bottom of the pit where weathering has been less effective is similar to that found in the well on the N. E. ¼ of the S. W. ¼ of Section 26.

A dark, bluish, schistose, slaty phase of the Saunders formation occurs in a fine exposure in the bank of the Brule river on the Wisconsin side, about 20 rods south of the section line between Sections 27 and 34, T. 42 N., R. 35 W. This rock shows no bedding but a perfect cleavage parallel to schistosity. The rock has parted into great plates striking N. 80° W. and dipping N. 57°. This exposure is locally known as the "Green Rock" or the "Green Stone." The latter name is inappropriate since the term "Green Stone" is used in geological nomenclature to designate an igneous rock of basaltic composition. There is no doubt that the rock in this exposure is a part of the aluminous and ferruginous slaty dolomite series uncovered in Sections 26 and 35, in railroad cut south of Saunders, and in Section 19, T. 24 W., R. 35 W.

A still more schistose phase of the Saunders formation occurs on the north side of the Brule river a short distance east of the west line of Section 19, T. 42 N., R. 35 W. The schistosity is about vertical and strikes N. 50° E. Although analysis was not made, the composition of the rock seems to be more nearly that of a true mud slate than that of other described phases of the Saunders formation. In color it is dark bluish gray, on some cleavage planes a light silvery gray, doubtless due to development of sericite. Minute specks of pyrite are visible, plentifully disseminated through the rock. The pyrite content is largely responsible for the rusty weathering, but the appearance of some fresher surfaces suggests, also, the presence of ferruginous carbonate.

Sheridan Hill and Vicinity.—The Saunders formation is exposed in a number of places on the north side of Sheridan Hill, occurs on the dumps of many pits, mainly on the north and east sides, and outcrops eastward through the S. ½ of the S. W. ¼ of Section 18 adjoining. Here the formation shows a wide range of facies, but exposures are not frequent enough to disclose stratigraphic relations between them.

The dominant phase is a highly siliceous dolomite ranging in color from dark bluish gray through lighter shades of pink and yellow to almost white. The rock is everywhere crushed and shattered to an extreme degree. Original textures have been obliterated by recrystallization and rearrangement of the constituent minerals. The cherty siliceous material occurs in blebs, stringers, and confused masses of irregular fragments of various angular sizes and shapes, down to the smallest grains, forming breccias held together by siliceous dolomitic cement. Frequently the carbonates have been completely dissolved out leaving a mass of cherty quartz full of vugs and irregular cavities which are frequently lined with layers of minute crystals of secondary quartz, less often of dolomite. Iron oxide is widely disseminated through many of the specimens and frequently incrusts the walls of cavities.

Examined under the microscope these rocks without exception exhibit a closely fitting crystalline structure. The silica occurs in a fine mosaic which may surround areas of carbonate, sometimes as single crystals but more often in compound aggregates. Carbonate is sometimes included in a single quartz individual. Quartz is present in all specimens examined and in some exists to the exclusion of all other minerals. The carbonate, like quartz, varies in quantity but is always associated with more or less quartz. Iron oxide is usually present in greater or less amount, and in some slides is seen to have developed by oxidation of ferruginous carbonate. The iron now in the form of iron oxide, abundantly developed in these rocks, was doubtless partly introduced by infiltrating solutions from sources outside the Saunders formation, but the greater part was originally present in the formation in the form of ferruginous carbonate. The bluish gray color of some of the dolomite is referred to its content of ferrous iron.

The siliceous dolomite grades into masses of almost pure quartz as at Saunders dam. Under the microscope these rocks appear as fine mosaics of completely interlocking grains of crystalline silica.

Another phase of the Saunders formation which is important, judging from the number of its drift boulders seen in this vicinity, has not been observed in natural outcrop. It is a massive, pinkish-red, fine grained quartzite. This rock is reported by Mr. O. W. Wheelwright to have been encountered at a depth of 244 to 254 feet by Mr. Oberg in a churn drill hole about 375 paces north and 300 paces west of the south quarter corner of Section 17, T. 42 N., R. 35 W. A sample of cuttings from this depth is identical with float boulders found on the surface. In the hole the quartzite is reported to be overlain by dolomite and soft slaty material, probably soapstone.

Soft, yellowish-white to red and ferruginous talcose slates occur in a couple of pits about 400 to 425 paces west and 75 to 100 paces south of the N. E. corner of Section 20, T. 42 N., R. 35 W. The strike of the bedding is N. 45° W. and dip 70° N. E. The bedding is cut by a well defined cleavage with strike parallel to the bedding and dip N. E. at an angle of 85°. There can be little doubt that these slates are a part of the Saunders formation, although they have been considered by some explorers to belong to the iron bearing series of the Upper Huronian. They are probably interbedded with the siliceous dolomite which outcrops both north and south of their line of strike within 350 paces of the pits and may be on the same horizon as similar slates reported to have been encountered in the drill hole described above.

Eastward, the Saunders formation assumes topographic prominence in a hill in the N. W. ¼ of Section 22, which rises to an elevation of 1,780 feet, outcrops in siliceous phase in the eastern part of the N. E. ¼ of the S. W. ¼ of Section 23, and is reported to have been encountered in the bottom of a well in the S. E. ¼ of the S. E. ¼ of the same section. A specimen of siliceous, pink dolomite said to have been taken from the bottom of this well was shown the writer. There is little doubt that the Saunders formation underlies the prominent hill crossed by the south line of Section 24, beyond which, eastward, it probably crosses the Brule river into Wisconsin.

It should be noted here that the volcanic greenstones in the apex of the sharp northward bend in the Brule river in Sections 19 and 30 and in Section 29, T. 42 N., R. 34 W., are in the strike of the Saunders formation and may be interbedded with it.

RELATIONS TO ADJACENT FORMATIONS.

The few occurrences in the above widely separated localities form the only basis for present knowledge of the lithology and distribution of the Saunders formation. These occurrences are indicated on the map (Plate 1) and form as may be seen only meagre data for drawing formational boundaries. The boundaries indicated have been drawn by the writer to exclude the outcrops of the volcanic greenstones, overlying the Saunders on the north, and the Brule volcanics on the south. Not a single contact between the Saunders and adjacent formations has been found and the formational boundaries are but roughly approximate at the best. Doubtless the north boundary is more nearly correct in the vicinity of Sheridan Hill and Saunders dam than elsewhere, since in these localities the data is more nearly adequate, but between these two localities data is lacking for drawing an approximately correct boundary. With the exception of perhaps about three miles in the southwestern part of the quadrangle, the south boundary of the Saunders formation is in Wisconsin and was therefore not mapped.

Since the Saunders formation is stratigraphically the lowest known sedimentary rock in the district and is adjacent to the Archean on the south and, furthermore, is lithologically similar to the Lower Huronian of the Crystal Falls and Menominee districts on the east it is thought to be of Lower Huronian age. In as much as the Lower Huronian is elsewhere unconformably above the Archean, such relations are inferred to exist between the Saunders formation and the Archean south of it. Whether the Brule formation, here very doubtfully correlated with the Keewatin, is unconformably below or is interbedded with the Saunders formation is not here apparent.

The Saunders formation is overlain on the north by volcanic greenstone interbedded with more or less slate. There is no evidence of any kind to indicate either the presence or absence of an erosion interval between them. Possibly the greenstones are to some extent interbedded with the Saunders. Both formations are, in general, steeply inclined northward, and have been affected by the same general folding, hence their approximate structural conformity is inferred.

STRUCTURE.

Satisfactory structural observations can not be made on known exposures. In the cherty and quartzitic phases bedding is destroyed by excessive brecciation, in the slaty phases it is obscured by schistosity and in the purer, massive, dolomitic phases bedding is not shown, being doubtless destroyed by recrystallization and rearrangement of the minerals in the rock. In the north face of the ridge at Saunders dam there are banded cherty phases showing steep northward dip but folding and brecciation are here of such character as to indicate that these dips may be local. Where developed the schistosity is usually steeply inclined northward and is about parallel to the trend of the formation. Distinct bedding is shown in slaty fragments on the dumps of pits in the S. W. ¼ of Section 26, T. 42 N., R. 35 W., but here the pits are filled with debris and the rock could not be observed in place. At this place the schistosity cuts the crumpled bedding laminæ of the slate nearly at right angles. As the schistosity is elsewhere steeply inclined northward it may be inferred that the dip of the bedding is here northward at a very low angle. A northeastward dip is shown in talcose slates near the base of the northeast side of Sheridan Hill. These observations are unsatisfactory but considered with the position of the Saunders formation between the older rocks south of it and rocks to the north which are certainly younger they indicate a general northward dip.

East of Section 21, T. 42 N., R. 35 W., the Saunders formation seems to widen and swing southeastward. This is probably due to flattening of dip on an anticlinal cross fold. If the axis of this fold be extended northward it coincides approximately with the direction of the axis of a broad anticline in the northern part of the district. As will be pointed out later, it is probable that the entire district has been folded on this axis thus extended.

Thickness.—A close estimate of the thickness of the Saunders formation can not be made. If we take the width of the formation across Sheridan Hill at 4,000 feet and assume the dip to be 75° the thickness will be 3,750 feet. Doubtless the formation is very thick but the above figures may be a thousand or more feet too great. The average dip of the rocks in Sheridan hill may be less than 75° and the calculation is further weakened because the apparent increase in thickness due to minor folding cannot be approximated.

CHAPTER IV.

THE UPPER HURONIAN GROUP.

Michigamme (Hanbury) Slate Series.

DISTRIBUTION AND GENERAL CHARACTERS.

The Michigamme slate formation occupies much the larger part of the district. It is limited on the south by the Saunders formation and extends north, west, and east beyond the limits of the district, in the latter direction connecting with the Upper Huronian slates of the Menominee, Crystal Falls and Florence districts.

The rocks include a wide variety of facies. Graywackes, with textures varying from conglomeratic to fine grained, and their schistose equivalents are dominant in the northern part of the area where they are interbedded with lenses of black pyritiferous and carbonaceous slates, micaceous and chloritic slates, and narrow lenses of iron formation which occur in the vicinity of Atkinson, on Morrison creek, in Section 24, T. 44 N., R. 35 W., and doubtless in other areas which are drift covered. Southward the clastics become finer grained on the whole and less metamorphosed. Slates are dominant and iron formation is more extensively developed. However, graywackes and fine conglomerates are not wanting and are often found associated with rocks of the Vulcan iron formation. Black, pyritiferous and carbonaceous slates are common associates of the iron formation.

The relations between the various facies of the Michigamme formation are those of gradation and interbedding. Any single type of the rock may grade by mineralogical and textural variations into any other type. The variations take place in the direction of bedding and across it with the result that, in general, the entire formation is made up of dovetailed lenses of various dimensions and compositions with indefinite gradational borders between them. While gradation is the rule, abrupt transitions from one type to another frequently occur, especially between black slates and iron formation.

Ellipsoidal, agglomeratic, and tuffaceous, extrusive, greenstones are interbedded at various horizons with the Michigamme formation. They seem to be especially abundant at the base of the series just north of the Saunders formation and at higher horizons, particularly in the central and in the northern parts of the district. Of less common occurrence, there are igneous rocks of similar composition but with well developed interlocking crystalline texture. These are probably intrusive.

STRUCTURE.

In attempting to work out the structure in detail of the group one is met with the insupperable difficulty of identifying horizons in the slates. Rocks of identical character are repeated at different stratigraphic horizons and the same stratigraphic horizon may exhibit, even in a small area, facies which are of very different composition and texture. Inasmuch as this fact is not appreciated by many who explore for iron ore in this district it should be emphasized here.

(1) *Any given horizon of the Michigamme series cannot be depended on to maintain the same character over any considerable area. It follows that* (2) *cross sections through the same stratigraphic horizons may differ widely in a given small area and consequently* (3) *similar sequence of formations in adjacent areas does not necessarily imply stratigraphic equivalence unless the various similar beds are known to be continuous from the one area into the other.* Especially is this true if the two areas compared are widely separated. Observations in the field and in mine workings and microscopic study of the rocks establish beyond doubt the truth of the above statement as will appear on later pages.

The iron formation layers locally serve as guides to the structure in the southern part of the district, and in the northern part, where graywacke phases are especially abundant and exposures are more numerous, general lines of structure are well brought out. Beginning on the east side of T. 44 N., R. 34 W., along the Paint river, the rocks are observed to strike slightly west of north and to dip vertically or steeply to the northeast. Following up the Paint river to its junction with the Net and thence westward toward Atkinson, the strike swings sharply westward, and then south of west, the dip varying from north to northwest. Southwest of Atkinson to the limits of the district and at least several miles

beyond, the southwesterly trend continues and the dips are to the northwest. Brittle layers have been gashed by tension cracks, in general, normal to the strike. Cleavage is subordinate to bedding in the northeastern part of the district, but westward the rocks become more and more schistose until the bedding is mainly obliterated. This is perhaps due chiefly to change in character of the sediments. The rocks in the northeastern part of the area are commonly coarse grained to finely conglomeratic, becoming finer grained toward the west. In this direction the dip of schistosity becomes on the average flatter and where compared with the bedding the two structures generally dip northward, the schistosity being the more steeply inclined.

The general structure of the northern part of the district is that of a truncated, broad, northward pitching, assymmetrical anticline, with steeper limb on the east and axis trending 15° or 20° east of north. If this axis is projected southwestward across the center of the district it will coincide, with slight allowance for change in direction, with the axis of the anticlinal cross fold affecting the Saunders formation indicated in the widening and the southeastward swing of the formation in the big bend of the Brule river. That the entire district has been folded on this axis is borne out by surface and underground observations in the vicinity of Iron River and Stambaugh and southeastward and northward. North of Iron River the strikes are approximately east and west, so far as known, corresponding to their position on the axis of the anticline. From Iron River southeastward the general trend of the Michigamme formation is undoubtedly southeastward, although it is affected by an intricate and complex system of cross folds. South of the Baltic and Zimmerman mines there are no exposures but the formation of necessity swings more to the eastward in line with the Saunders formation below it. The general strike at the Chicagon mine, six miles east of Iron River, seems to be northeast thus being in line with the strike of the rocks on Paint river to the north. A northeast trend is also indicated in the N. W.-S. E. elongation of the magnetic field in Section 33, T. 43 N., R. 34 W. In general, then, it seems that the Michigamme formation enters the district from the east with northwest trend, swings westward in the entral part of the district, and then southwestward.

While the folding on the slightly northeast-southwest axis described is a major feature of the structure it is believed to be subordinate to folding in the opposite direction especially in the southern part of the district. Here the dips in the Michigamme formation are, on the whole, steeper than in the northern part of the district although locally they vary from nothing to 90° due to complex minor folding. The general east-west trend of the steeply inclined Saunders formation and the east-west strike of the secondary structures in it and the adjacent greenstones indicate the main structural line for this part of the district. Since the Upper and Lower Huronian are in structural conformity here as well as eastward in the Crystal Falls, Menominee, and Florence districts, the Michigamme formation with its interbedded lenses of Vulcan iron formation which are best developed in the southern part of the area may be expected to extend beneath the drift west of Iron River beyond the limits of the district. The westernmost exposure of the Vulcan member is in the S. W. ¼ of the S. W. ¼ of Section 33, T. 43 N., R. 35 W.

It follows from the above that in passing from the southern to the northern part of the area successively younger strata are encountered although doubtless there is considerable, though not determinable, repetition of horizons due to folding.

The truth of this may not be apparent from a study of the map (Plate I) except to those closely familiar with the geology of the district, therefore, the argument in support of the hypothesis is outlined in the following paragraphs.

Broadly considered, the rocks north of the Saunders formation may be divided into three belts, each having broad, distinctive, lithologic characteristics. The southernmost of these belts (1) lies between the Saunders formation on the south and a belt composed dominantly of greenstone on the north. This belt carries the iron ore producing area and is composed chiefly of slates carrying iron formation lenses. The second belt (2) is several miles in width but the boundaries are ill defined. It enters from the east and swings in a convex northward curving course across the district parallel to the trend of the Paint slates north of it. This belt carries greenstone outcrops in its eastern, western, and central parts; the presence of interbedded slates is inferred though not as yet proven. The northern belt (3) comprises slates and graywackes with their altered equivalents, interbedded volcanic greenstone and lenses of iron formation. In discussion of general structure these three belts may be considered as units. The possibility of major faulting as a factor influencing field distribution is not considered since major faults are not now known to be present. The southernmost belt (1) is adjacent to the Saunders formation on the south except for the presence of a belt of greenstone of undeterminable but varying thickness between and is, therefore, younger than the Saunders. Now if the central belt of greenstone (2) is equivalent to that adjacent to the Saunders formation, the structure of belt (1) is necessarily *synclinal* since an anticlinal structure would throw it *beneath* the Saunders formation, where it obviously does not belong for reasons advanced in the discussion of the Saunders formation. If the structure of belt (1) is *synclincal* it follows that the structure of belt (2) is *anticlinal*. Now if belt (2) is anticlinal the rocks of belt (1) should occur adjacent to belt (2) on the north, but in place of them there occur a series of rocks of such decidedly different characteristics on the whole that they cannot be correlated with those of belt (1) except on the assumption that the conditions of original deposition were such as to account fully for the lithological dissimilarity of the two belts. Such an assumption is not violent but its verity is doubted notwithstanding that the writer is fully impressed with the belief that lithologic variations on a given horizon may be rapid and complete even in a small area.

The alternative hypothesis, which is the one here accepted, places the rocks of belt (3), the Paint slate series, stratigraphically *above* the volcanic greenstones of belt (2) and these in turn above the slate-iron formation rocks of belt (1). Within each belt there is probably considerable repetition by folding, since calculations of thickness based on observed dips would otherwise indicate thicknesses so great as to be far beyond the limits of reasonable probabilities. It should be recalled here that belt (2) is continuous with a greenstone area extending eastward to Crystal Falls, which Clements correlated with the Hemlock greenstone which overlies the Randville dolomite, and mapped with anticlinal structure[1] thus placing it below the Michigamme series (the "undivided Upper Huronian" of Monograph 36, U. S. Geological Survey) of the Crystal Falls district which is areally continuous with the Michi-

[1]Clements, J. Morgan. U. S. Geological Survey, Monograph 36, p. 74 and Plate IV.

gamme slate series of the Iron River district. The evidence deduced from studies in the Iron River district favors the view that these greenstones which are characterized by the textures of surface flows and volcanic ejectamenta are interbedded with the Michigamme slates and are well up in the series.

The foregoing account of the general structure is purely descriptive and offers no explanation of the direction of application, and the character of the forces which produced the folding. When it is said that the area has been folded in two general axial directions it is not implied that general folding in one direction preceded or followed general folding in the other direction. The probabilities are that forces tending to produce folding in both general axial directions were operative at the same time. The general structural elements are not complete but are segments of larger structural features affecting a much wider area, and should be recognized as such in any discussion which seeks to elucidate the manner in which deformation was effected. A broad discussion of this nature is beyond the scope of this report.

THE VULCAN FORMATION (IRON BEARING).

DISTRIBUTION AND EXPOSURES.

The term Vulcan has been applied to the iron bearing members of the Michigamme slate following the use of this name by the United States Geological Survey to designate equivalent formations in the Menominee and Crystal Falls districts. There are few exposures of the Vulcan formation. Our knowledge of the distribution is based mainly on occurrences in underground workings and in drill holes put down in search of iron ore and therefore is largely limited by the extent to which these operations have been conducted. There are indicated on the map those areas which are known to be underlain by this member and the position of the drill holes in which the formation has been penetrated. All of these areas include more or less slate, and interbedded slate is shown in many of the drill holes which are indicated as cutting the Vulcan member. Most of the drill cores were examined but some are unavailable; in the latter case we have had to rely on the superintendent's and drill runner's records. An attempt has been made to discriminate between the more unaltered iron formation rocks on the one hand and ferruginous cherts and slates and iron

ores on the other. There are all gradations between the various phases of the iron formation, but since the ores and highly oxidized phases are related to structural conditions which largely influence ore concentration it is thought that the discrimination attempted will have some practical usefulness in suggesting lines for further exploration.

A discrimination between ferruginous chert and the cherty carbonates and slates of the Vulcan formation is made by explorers in the field. Rocks here called ferruginous cherts and slates in local terminology are termed "ore formation" in recognition of the association of ferruginous cherts and slates with iron ore. The more or less unaltered rocks of the Vulcan formation are usually included by the drillmen in the term "slates," the different kinds of slate being discriminated mainly on the basis of color, as gray slate, black slate, etc. However, the terminology used by explorers is not uniform and for this reason where cores or cuttings are not preserved the drill records very often offer little information regarding the character of the rock penetrated. In a district like this, where almost the only working information available is that afforded by drilling and underground exploration, great care should be exercised in obtaining and preserving drill cuttings and cores. Most companies and explorers are now doing this, but records of many of the earlier explorations and some of the more recent ones were not preserved.

Referring to the central part of the district, it will be seen by a study of the data on the map that the relations between slate and iron formation are exceedingly complex and in most instances it is impossible to exclude the slates from any considerable area. The explanation lies in the interbedding of the slate and iron formation coupled with complicated folding.

The iron formation lenses are closely and intricately folded and interbedded with the associated slates and are usually steeply dipping. Erosion has cut deeply into the series doubtless removing the iron formation over considerable areas where it once existed. Where exposed the iron formation occurs at the surface mainly in narrow bands, frequently twisting and contorted, but in some cases retaining an approximately straight course for distances of several miles, as in the James belt. With this general idea in mind it will be readily understood that any attempt to draw formational boundaries of the Vulcan member will be more misleading than helpful. The distribution and structure will be further discussed in connection with descriptions of particular areas.

LITHOLOGICAL CHARACTERS OF THE VULCAN FORMATION.

The Vulcan formation is made up of ferruginous cherts and slates, slaty and cherty iron carbonate rock, magnetitic, chloritic, sideritic slates, and iron ores. The various facies possess no characteristics which are peculiar to this district. These rocks have been repeatedly described in detail in the United States Geological Survey monographs on the Penokee-Gogebic, Marquette and Menominee districts and some of the descriptive paragraphs which follow are necessarily partly a repetition of matter found elsewhere in print. For the benefit of readers who may not have access to the above volumes and for the purpose of emphasizing the significant characteristics of the Vulcan formation, short descriptions of the main phases of the rocks are here given.

Slaty and Cherty Iron Carbonates.—The iron carbonate rocks may be recognized in the field by their finely laminated and platy structures, commonly gray color on fresh surfaces, dense, fine-grained texture, and rusty-brown, sugary weathering on exposed surfaces and in fracture planes. The color is subject to variation, frequently becoming dark with impurities such as carbonaceous matter, but the banding, texture, and weathering furnish criteria by which these rocks may be easily discriminated from others with which they are associated.

Siderite (iron carbonate) is the most important mineral. It occurs in rounded grains and in rhombs some of which in rare instances may be seen without the use of a lense. Siderite may make up almost the entire body of the rock, but in this district such occurrences are rare. Silica, mainly in finely crystalline form but in smaller part chalcedonic or semi-amorphous, and in many cases detrital, is an essential mineral. The proportional amounts of silica and siderite may vary widely, both minerals are practically always present but either one may be dominant. *Cherty siderite* or *sideritic chert* are terms which are used to express the dominance of one or the other of these minerals.

The character and composition of the cherty iron carbonate varies with the variety and relative abundance of the accessory minerals

of which a number are nearly always present. The most prominent of these are calcium and magnesium carbonates, pyrite, biotite, and sericite. Earthy and carbonaceous material is frequently abundant and hematite is often present as an oxidation product of the siderite. When the siderite becomes completely or nearly completely oxidized the rock becomes either *ferruginous chert* or *ferruginous slate.* The average mineral composition of the rocks which may be classed as cherty and slaty iron carbonate would be difficult to express. Some idea may be gained from the following tabulation of the minerals found in microscopic examination of 16 typical specimens nearly all taken from drill holes in the productive part of the district.

Minerals found in 16 typical cherty and slaty iron-carbonate rocks in the Iron River district:

Number of thin sections examined	16
" " " " containing siderite (and other carbonates)	16
" " " " " quartz	16
" " " " " chlorite	10
" " " " " carbonaceous and earthy material	8
" " " " " hematite	7
" " " " " iron pyrite	6
" " " " " biotite	5
" " " " " sericite	3
" " " " " titanite (alteration product of biotite?)	1

A specimen of cherty iron carbonate taken from one of the pits of the Gleason Exploration in the N. E. ¼ of Section 33, T. 43 N., R. 34 W., was analyzed by Prof. A. J. Clark of the Michigan Agricultural College. For purposes of comparison this analysis is tabulated below with others representing typical cherty iron carbonate rocks from the Penokee-Gogebic and Vermilion districts and from Gunflint Lake in Minnesota.

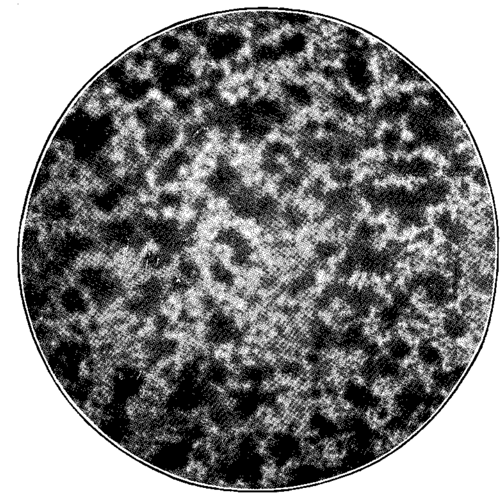
ANALYSES OF CHERTY IRON BEARING CARBONATES.*

	Penokee-Gogebic.				Gunflint Lake.		Iron River.
	1.	2.	3.	4.	5.	6.	7.
SiO_2	15.62	28.86	46.01	3.16	58.23	46.46	66.01
TiO_2	....	.20	0.12	....	trace	trace	....
Al_2O_3	4.27	1.29	0.83	.08	.06	0.24	3.50
Fe_2O_3	8.14	1.01	1.35	.93	5.01	0.64	8.32
FeO	32.85	37.37	26.00	15.18	18.41	26.28	9.90
MnO	5.06	0.97	2.09	1.15	0.25	0.21	0.60
CaO	0.81	0.74	0.63	26.65	0.38	1.87	0.52
MgO	2.66	3.64	2.86	11.01	9.59	3.10	0.50
CO_2	30.32	25.21	17.72	41.10	5.22	19.96	10.71
P_2O_5	....	trace	.07	.06	0.03	0.13	....
FeS_2	....	....	.11	.34	0.14	0.11	....
Na_2O	....	....	....	....	....	....	0.42
K_2O	....	....	....	....	....	....	0.13
Water at 105°	....	none	....	....	....	....	....
Water at 110°	....	....	....	....	0.07	0.07	....
Water at red heat	0.63	0.68	1.71	0.54	2.01	1.15	....
Total	100.41	99.97	99.50	100.20	99.40	100.22	100.61

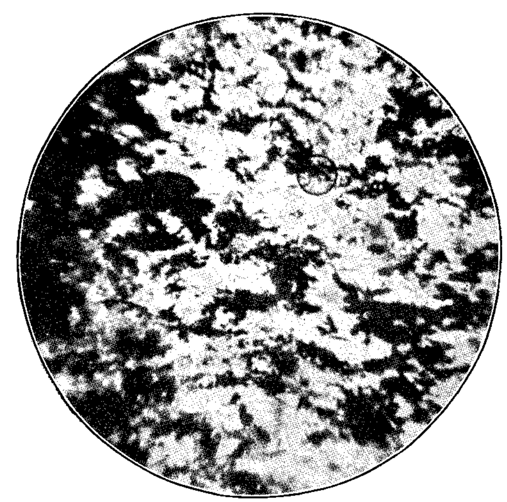
*Analysis Nos. 1, 2, 3, 4, 5, 6 are taken from the U. S. G. S., Monograph 19, p. 192.

While the analyses of these seven types of iron bearing carbonates vary considerably in proportions of the various constituents essential similarity in constitution is apparent. In the Iron River specimen the content of alumina and silica is conspicuously high and the predominance of ferric over ferrous iron is unusual. The specimen analyzed was examined microscopically for ferric iron as hematite or hydrous hematite, but none was found. It is possible that error was made in determination of ferric iron. (Plate 4A.)

Ferruginous cherts and slates.—Ferruginous slates and cherts are common associates of the ore bodies. They represent gradational phases between cherty iron carbonate on the one hand and iron ores on the other. In local terminology they are called "ore formation." *Ferruginous slate* is derived from cherty iron carbonate by complete or partial oxidation of the iron bearing carbonates *in place,* which means that oxidation is accomplished without extensive rearrangement of the materials in the rock. The



(A) CHERTY IRON CARBONATE FROM THE VULCAN FORMATION, NEAR CENTER OF THE N. E. ¼ OF SECTION 35, T. 43 N., R. 34 W. IN PARALLEL POLARIZED LIGHT WITHOUT ANALYZER, MAGNIFIED 80 DIAMETERS. THE DARK SPOTS ARE SIDERITE. THE WHITE MOTTLED AREAS ARE MAINLY FINELY CRYSTALLINE QUARTZ.



(B) FERRUGINOUS SLATE FROM THE VULCAN FORMATION, WILDCAT SHAFT. ABOUT 1,450 FEET SOUTH OF THE CENTER OF SECTION 18, T. 42 N., R. 34 W. PARALLEL POLARIZED LIGHT WITHOUT ANALYZER. THE DARK AREAS ARE HEMATITE, SECONDARY AFTER SIDERITE. THE LIGHT AREAS ARE MAINLY QUARTZ.

banding or lamination shown by the cherty iron carbonate rocks is preserved in the ferruginous slates and emphasized by the conspicuous colors of the red and yellow oxides of iron. The "red slates" so frequently penetrated in drill holes are good examples of this type of rock.

As katamorphism progresses both the silica and iron contents of the rock become more extensively rearranged with tendency toward segregation. Frequently the silica and iron oxide occur in alternate bands or layers forming the "banded ore formation" of this district, which is equivalent to the "soft ore jasper" of the Marquette district. More often the ferruginous cherts are broken and crushed forming a breccia, in which the banding is partially or wholly obliterated. The breccia in extreme phases presents the appearance of jumbled masses of irregular cherty fragments, in color varying from pure white to red and yellow according to the amount of disseminated iron oxide in them, to dark colored if high in carbonaceous matter, irregularly mixed with stringers and pockets of iron oxide which form ore bodes when of sufficient size to be mined.

Stated briefly, the difference between *cherty iron carbonate* and *ferruginous slate* consists only in the substitution in the latter of iron oxide in the place of the iron bearing carbonates of the former. In the *ferruginous cherts* the silica and iron oxide have been extensively rearranged. The rearrangement is accomplished by recrystallization, which involves solution of the silica and iron, transportation to varying distances in the rock, and redeposition from solution.[1]

During the process of recrystallization there is a tendency toward segregation of the iron oxide in "bands and shots" of ore which, mixed with chert, forms the *"mixed rock and ore"* of the miner's phraseology. When the process of segregation becomes sufficiently well advanced ore bodies result. The genetic relations between ferruginous cherts, "mixed rock and ore," and iron ore are well understood by the miners as gradational phases are exhibited in every mine in the district. The only practical difference between ferruginous chert, "mixed rock and ore," and iron ore is in relative proportions of iron oxide and silica. When ferruginous chert

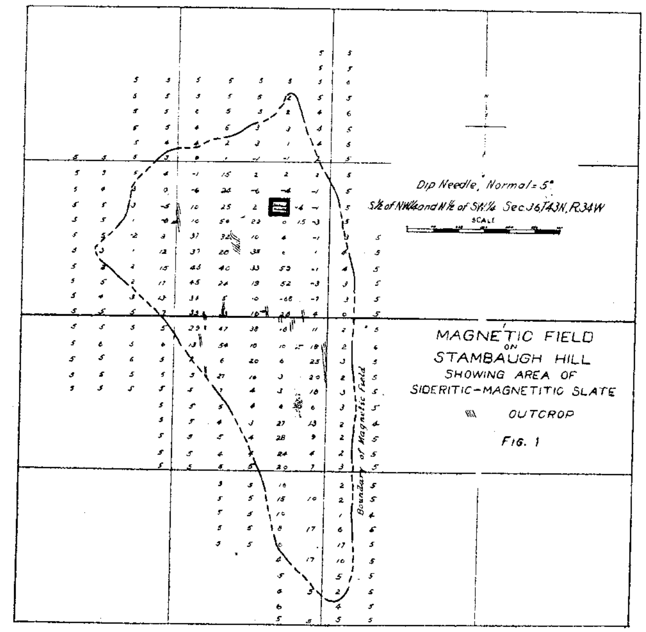
[1]The banding in ferruginous cherts is thought in many if not the majority of cases to be the result of original deposition rather than segregation during subsequent alteration although the *tendency* toward segregation cannot be denied and may in some cases emphasize and in other actually produce alternate bands of silica and iron oxide.

or "mixed rock and ore" grades into iron ore by decrease in silica or chert content and increase in iron content the "ore formation" is said by the miners to "clean up," an expression which exactly fits the case. (Plate 4B.)

Magnetitic-Chloritic-Sideritic Slates. — Magnetitic-chloritic-sideritic slates are *known* to occur in but one locality, viz., on Stambaugh Hill, Section 36, T. 43 N., R. 35 W., in an elongated area of about forty acres. The general structure is simple, the strike being N. 30°-35° W., and the dip vertical or highly inclined toward the southwest 75°-90°. Superimposed on this structure are minor folds producing a wavy and contorted appearance of the banding conspicuous on outcrops. The magnetic properties of these rocks furnish a means by which they may be easily mapped without the aid afforded by natural exposures. The magnetic field on Stambaugh Hill is shown in figure 1 in relation to outcrops. The elongation of the field is in the direction of strike of the rocks. A similar magnetic field, likewise elongated in a direction believed to be that of the strike of the rocks, N. W.-S. E., occurs in the S. W. 1/4 of Section 33, T. 43 N., R. 34 W. This field (see fig. 2) is of about the same size and character as the one on Stambaugh Hill and probably outlines an area of magnetitic slates similar to those in the latter locality, although in the absence of exposures such cannot be certainly affirmed. Other magnetic fields would doubtless be found if the area were carefully magnetically surveyed. It is regretted that the means at the disposal of the writer did not permit of such survey being undertaken.

As shown in the exposure on Stambaugh Hill the magnetitic-chloritic-sideritic slates exhibit prominent banding, well marked on outcrops by alternating laminæ of lighter and darker shades. Weathered surfaces are yellowish to brown, fresh surfaces are gray to black, the shade of color depending mainly on the relative abundance of magnetite. Thin bands of chert and jasper are occasionally found but they are discontinuous and not characteristic of the rock as a whole. All of the minerals are microscopic in size giving the rock a dense aphanitic texture.

Under the microscope these rocks are seen to be made up of the following minerals: chlorite and magnetite are abundant and about equally developed; carbonate, probably mainly iron bearing, is somewhat less abundant although conspicuously present; sericite is present in small crystals oriented with long axes in plane of bed-



MAGNETIC FIELD ON STAMBAUGH HILL SHOWING AREA OF SIDERITIC-MAGNETITIC SLATE

FIG. 1

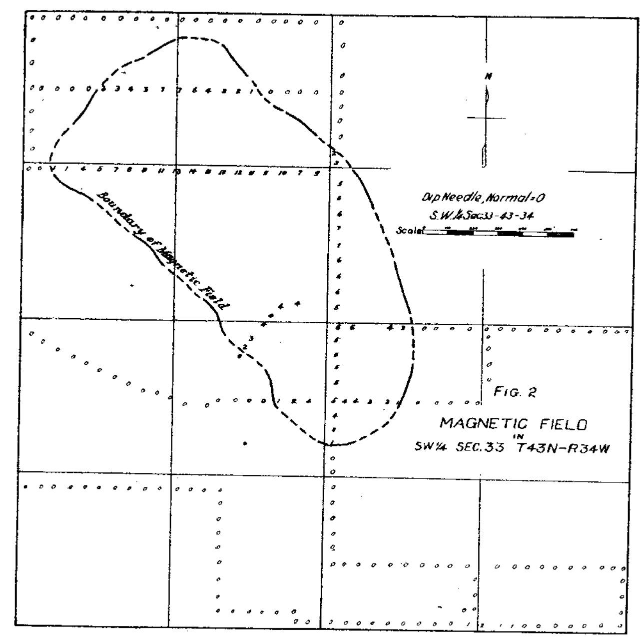


FIG. 2

MAGNETIC FIELD IN SW¼ SEC. 33 T43N-R34W

ding; hematite occurs in small flakes and grains and quartz is present in extremely minute particles disseminated throughout the rock. Associated with these minerals there is a dense felty viriditic matrix in which the individual particles cannot be differentiated with a magnification of 600 diameters.

The magnetitic-sideritic slates are probably the metamorphic equivalents of impure carbonate slates so abundantly developed in the Vulcan formation. The original minerals seem to have been carbonate, quartz and aluminous and feldspathic mud. From these have developed, by metamorphism, magnetite, chlorite, sericite and hematite.

In composition and origin these rocks present some analogy to the amphibole-magnetite rocks of the Penokee-Gogebic and Marquette districts which, as shown by VanHise, have developed through anamorphism of a cherty iron carbonate rock. That the analogy is incomplete seems to be due to differences in composition of the original rock and degree of metamorphism.

In the Penokee-Gogebic and Marquette districts a rock consisting almost entirely of carbonate and quartz was anamorphosed to a rock containing magnetite, amphibole, (actinolite or grünerite) and quartz with minor amounts of biotite and sericite. In the Iron River district a rock composed originally of carbonate and aluminous and feldspathic muds with some quartz was anamorphosed to a magnetitic-chloritic-sideritic-sericitic slate.

The Iron River rocks, compared with their type analogues of the Penokee-Gogebic and Marquette districts, are finer grained, contain much less quartz and magnetite, have abundant chlorite instead of amphibole and carry more residual carbonate. Their fineness of grain and the presence of more residual carbonate indicate a lower degree of anamorphism.

For the Penokee-Gogebic rocks VanHise has shown by microscopical study that magnetite is secondary after siderite and amphibole is formed by interaction between siderite and quartz. Type reactions are given below:[3]

(1) $\overset{\text{siderite}}{3FeCo_3} + O = \overset{\text{magnetite}}{Fe_3O_4} + 3CO_2$

(2) $\overset{\text{siderite}}{2FeCO_3} + \overset{\text{pyrite}}{FeS_2} + 2H_2O = Fe_3O_4 + 2H_2S + 2CO_2$

(3) $\overset{\text{siderite}}{FeCO_3} + \overset{\text{quartz}}{SiO_2} + 2H_2O = FeSiO_3 + CO_2 + 2H_2O$

[3]United States Geological Survey Mon. 19, p. 392.

The genesis of the magnetite in the magnetitic-sideritic slates of the Iron River district is somewhat obscure. The magnetite is much more commonly associated with chlorite than with siderite. Perhaps 90% of the magnetite grains are actually embedded in chlorite while pseudomorphs of magnetite after siderite have not been observed. However, the material surrounding some of the magnetite grains resembles in part chlorite and in part carbonate to the extent that frequently the color and characteristic pleochroism of chlorite in parallel polarized light without the analyzer gives way to the double refraction and interference colors of carbonate under crossed nicols. Evidently this material is neither chlorite nor carbonate, but its occurrence in association with carbonate, magnetite, and chlorite suggests a dependent relation upon the formation of the two latter most abundant secondary minerals. It is possible to conceive that magnetite and chlorite are developed simultaneously by interaction between the carbonates and the aluminous constituents of the rock and the phenomena above described may be taken as evidence that such reaction has occurred. If we take the mineral mesitite to represent the composition of the carbonates and the mineral kaolin that of the associated aluminous muds, the character of the reaction may be represented by the following equation:

$$\overset{\text{Mesitite}}{4(MgFe)\ (CO_3)_2} + \overset{\text{Kaolin}}{Al_2O_3.2SiO_2.2H_2O} + 30 + SiO_2 =$$
$$\overset{\text{Chlorite}}{Hg(MgFe)_5Si_3O_{18}} + \overset{\text{Magnetite}}{Fe_3O_4} + 8CO_2$$

The other two important secondary minerals, biotite and sericite, are common constituents of metamorphosed aluminous and feldspathic mud slates.

The magnetitic-chloritic-sideritic slates are to be considered the metamorphic equivalents of an original carbonate slate in which the associated constituents were mainly of the nature of aluminous and feldspathic muds instead of quartz. (Plate 5A.)

SOME PARTICULAR CHARACTERISTICS OF THE VULCAN FORMATION.

The descriptions given in preceding paragraphs refer to *type phases* of the Vulcan formation and it must not be understood that *every* specimen that might be taken will fall readily within one of the three main classes of rocks described. The relations between the various types are those of gradation and any one of the three main types of the Vulcan formation may grade by relative increase of clastic material into the slates and graywackes of the Michigamme formation.

Clastic material in the Vulcan formation.—The Vulcan formation is characterized by the presence of associated clastic material and resulting alteration products. Fragmental quartz grains are abundant in many specimens and are clearly distinguishable from the matrix of crystalline silica of fine interlocking texture in which they are often enclosed. Less commonly there are grains of feldspar. If the intermixed clastic material is of very fine grain impure sideritic slates or impure ferruginous slates result and these, by decrease in the carbonate and the cherty constituents, grade into ordinary aluminous and siliceous slate. Through metamorphism the impurities in the iron formation rocks give rise to secondary products, mainly chlorite which is nearly always associated with biotite and lesser amounts of sericite. Carbonaceous impurities are especially abundant and are responsible for the dark color of much of the cherts of the iron formation. Pyrite is a common associate of the carbonaceous impurities, but may occur in smaller amount in the purer phases of the rock. In the least altered rocks the iron is present mainly as carbonate, being changed to limonite and hematite as oxidation progresses, but by anamorphism occasionally giving rise to magnetitic-chloritic slates usually carrying more or less residual iron carbonate.

In short the typical iron bearing rock of the Vulcan formation—mainly a cherty iron carbonate—shows all possible gradational phases to slate on the one hand which is nearly always highly chloritic, usually biotitic and sericitic, and frequently more or less carbonaceous grading into highly graphitic varieties, to graywacke on the other, and, moreover, it is to be noted that, considering the formation as a whole, the purer forms of iron formation rocks are subordinate in amount. A laboratory study of these rocks discloses the characters that they may be inferred to possess from their intimate field relations to various types of interbedded slates and graywackes. Indeed, it is impossible to describe adequately the rocks of the Vulcan formation without reference to the clastic rocks with which they are so closely associated.

Occurrence of altered greenalite in the Vulcan formation.—As was to be expected, microscopic study has revealed the probable original presence of small quantities of greenalite in the Vulcan

formation. What are believed to be the altered forms of this mineral are present in some sections but generally they are absent or at least not recognizable.[4]

Spurr* found in 1894 that the least altered phase of the iron formation member (Biwabik formation) in the Mesabi district of Minnesota contains numerous small green granules of ellipsoidal and ovoidal form which, from their general habit and composition, he considered to be glauconite. Later study by C. K. Leith, while confirming in general the earlier work of Spurr, brought out the fact that the composition of the green granules is dissimilar in several essential respects to that of glauconite and does not conform to that of any other known mineral. Leith, therefore, concluded to call the green granules greenalite.

Greenalite is essentially a hydrous ferrous silicate of iron corresponding to the formula $FeSiO_3 . nH_2O$. The ferrous iron may be replaced by variable small quantities of magnesia. In constitution greenalite is analogous to siderite ($FeCO_3$) the ratio between base and acid being the same 1:1.

The general association of greenalite and siderite in the iron formations of the Lake Superior region is an interesting fact established since the work of Leith on the Biwabik formation of the Mesabi district. In the latter district the ferrous silicate, greenalite, greatly predominates over the ferrous carbonate, siderite, as the original iron bearing mineral from which the ore bodies have been mainly derived by processes of oxidation and concentration. Northeastward, in the Animikee district iron formation equivalent to the Biwabik of the Mesabi district contains proportionately more carbonate, while in the iron ranges south of Lake Superior iron bearing carbonates are vastly more abundant than the ferrous silicate, greenalite.

In the Iron River district greenalite was probably present in greater abundance in the Vulcan formation than might be inferred from a microscopical examination of miscellaneous thin sections. In the more highly altered phases all traces of greenalite have been apparently obliterated by recrystallization and rearrangement in different new combinations of the elements forming the minerals

[4]For detailed description of greenalite, see C. K. Leith, United States Geological Survey, Mon. 43, pp. 101-115.

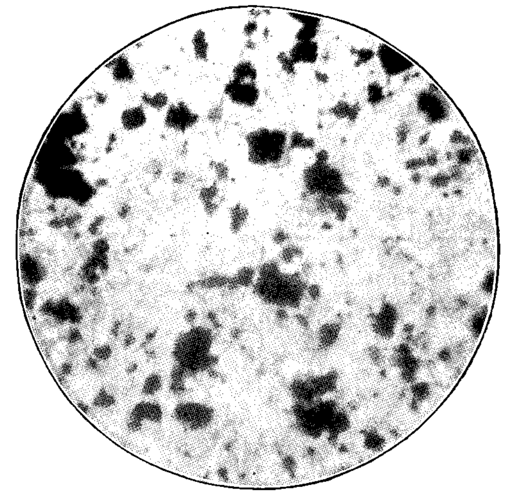
*Spurr, J. E. The iron bearing rocks of the Mesabi range in Minnesota. Geological and Natural History Survey of Minnesota, Bulletin 10, 1894, pp. 1-268.

in the rock. It was only after identification of better preserved forms in a few sections that its original presence in others was determined. Various late stages of the alteration of the greenalite granules are observable in thin sections, but nothing approaching unaltered greenalite has been found and it should be stated that the forms described in the following paragraphs as altered greenalite appear as such only to the observer who is familiar with the occurrence of the mineral in rocks where the fresh and all the various altered conditions have been fully studied as by Leith in the Mesabi district of Minnesota.

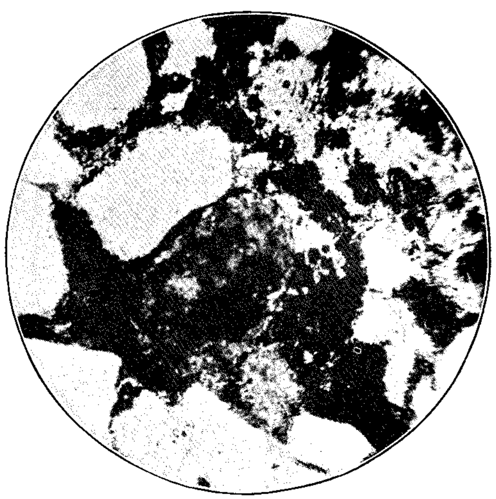
A particular occurrence of altered greenalite.—The occurrence of altered greenalite from a depth of 215-219 feet in a drill hole 200 feet north and 150 feet west of the center of Section 29, T. 43 N., R. 34 W., is characteristic for the entire formation so far as studied. Under the miscroscope the rock is seen to consist of varying proportions of quartz, carbonate, hematite, chlorite, sericite, amphibole, apatite, and confused masses of undifferentiated viriditic materials. The most conspicuous mineral in the thin section is quartz occurring in rounded to subangular grains, frequently as isolated individuals surrounded by other minerals, but also often clustered in colonies forming quartz mosaics. The quartz is free from strain shadows and in many cases carries inclusions of sericite in single crystals and in aggregates. Almost as common as sericite as an inclusion is a green amphibole. Its usual habit is an elongated fibrous shred or prism, rarely it is stumpy or tabular. In the fibrous habit the extinction is nearly parallel to the elongation, but the tabular crystals show angles of 26° to 30°. Some of the quartz is also penetrated by crystalline needles of hematite.

The notable feature in this rock is the occurrence of oblong areas consisting largely of semi-crystalline to finely crystalline silica. Associated with the silica in these areas are fine meshes composed of sericite, a little chlorite, and some of the green amphibole. Hematite is nearly always present and sometimes, but not often, carbonate, while grayish and greenish felty stringers and masses of unidentified alteration products may occur anywhere and occasionally are abundant. Some of these areas are identical in shape with greenalite granules described by Leith* and are plainly the survivors of an original mineral with rounded to ellipsoidal

*Ibid. pp. 101-102.



(A) MAGNETITIC SLATE FROM STAMBAUGH HILL. PARALLEL POLARIZED LIGHT WITHOUT ANALYZER, MAGNIFIED 66 DIAMETERS. THE OUTLINES OF CRYSTALS OF MAGNETITE ARE WELL SHOWN. THE LIGHT AREAS ARE MAINLY CHLORITE.



(B) ALTERED GREENALITE GRANULE (IN CENTER) FROM DRILL HOLE 250 FEET NORTH AND 150 FEET WEST OF CENTER OF SECTION 29, T. 43 N., R. 34 W. PARALLEL POLARIZED LIGHT WITHOUT ANALYZER, MAGNIFIED 66 DIAMETERS. THE DARK AREAS IN GRANULE ARE HEMATITE. THE LIGHT AREAS ARE COMPOSED OF QUARTZ, SERICITE, CHLORITE AND GREEN AMPHIBOLE.

outline. Furthermore, in mineral composition they exhibit some analogy to altered greenalite granules in the Biwabik formation of the Mesabi district. The only marked difference consists in their content of sericite and chlorite which seems to take the place of the amphibole in similar forms in the Biwabik formation, although, as stated, amphibole is present in small amount in some of them. The outlines of the oval areas are more distinct when looked at in light transmitted through the polarizer only, in fact with crossed nicols the outlines are usually not discernible, being obscured by the double refraction of the chert. (Plate 5B.)

With the forms described in the preceding paragraph there occur others which are similar in outline but show a zonal arrangement of the constituent minerals.

(1) A clear, colorless quartz individual is surrounded by a border of carbonate and hematite about equally abundant. A second border, usually not complete, is composed of finely crystalline silica.

(2) The core is composed of finely crystalline silica which is surrounded by a border of hematite which, in turn, is enclosed in a second border of carbonate and the latter is encircled by a broken rim of hematite.

(3) Anyone of the minerals, hematite, carbonate, or quartz may form the core.

(4) The zonal structure may be absent, the minerals occurring in a confused aggregate retaining the oblong or rounded form.

The forms described in (1), (2), and (3), *may* be of concretionary origin, yet the zonal or concentric structure rarely approaches perfection and in the majority of forms is merely *suggested*. I cannot escape the conclusion that forms (1), (2), and (3) are merely modifications of the commoner form (4) in which concentric arrangement is not shown. It should be stated in conclusion that the identification of these oval and rounded mineral aggregates as derivatives of greenalite granules rests solely upon their similarity in shape and composition to analogous forms *which are known to have had such derivation.*

LOCAL MAGNETISM IN THE VULCAN FORMATION.

While in general the Vulcan formation is not magnetic, there are a few local areas in which magnetism is well developed. Other magnetic areas would probably be discovered were the district carefully magnetically surveyed. We have already referred to the magnetic line apparently following the northern edge of the greenstone in Sections 21, 22, and 23, T. 42 N., R. 34 W. Whether this line is caused by magnetism in the greenstone or in one of the lower members of the Michigamme formation is not known. The latter is considered the more probable.

A magnetic field of irregular and widely varying strength covers about 40 acres occupying the crest of Stambaugh Hill in the W. ½ of Section 36, T. 43 N., R. 34 W. (See fig. 1.) Here the rocks are well exposed in numerous outcrops on the top of the hill. The dip is about vertical and strike slightly west of north, which is the direction of elongation of the field. Under the microscope these rocks are seen to contain innumerable small grains of magnetite. Descriptions of these rocks have already been given, pp. 56-59.

A magnetic field of about the same size and shape occurs in the S. W. ¼ of Section 33, T. 43 N., R. 34 W., (see fig. 2), but here the field is elongated in a northwest-southeast direction which is likewise believed to indicate the strike of the rocks at this locality, although no exposures occur.

Local magnetism occurs in isolated patches in Sections 35 and 36, T. 43 N., R. 34 W. Here the magnetic rock is mainly a graywacke carrying abundant magnetite.

HORIZONS AT WHICH THE VULCAN FORMATION OCCURS.

From the foregoing it will have been anticipated that the Vulcan formation is not confined to a single horizon in the Michigamme slates. From analogy with Vulcan beds of the Menominee and Crystal Falls districts it might be inferred that they form at least two horizons near the base of the Michigamme slate series but it is reasonably certain that there are at least four iron bearing horizons in the Iron River district without making allowances for the possible occurrence of two or more horizons in the producing part of the area in the vicinity of Iron River and Stambaugh. In fact slate and iron formation are interbedded in such a way that any horizon of the Michigamme slate may somewhere become iron bearing. There are areas where the facts are more nearly expressed by the phrase, "Vulcan formation containing lenses of Michigamme slate" than "Michigamme slate containing Vulcan iron formation," and this is especially true of the central and southern parts of the district. Any attempt to unravel the structure of the Michigamme series which does not take into account these relations will certainly lead to erroneous results.

The known main occurrences of the Vulcan formation may be referred to three different areas, viz., (1) the Jumbo belt, just south of the Brule river in Florence county, Wisconsin, about 1½ miles east of Saunders, (2) the central area of unestablished boundaries extending north, east, south, and west of Iron River, and (3) the northern area including the Morrison creek belt in Section 24, T. 44 N., R. 35 W., and the Atkinson belt southwest of Atkinson. From the general structure of the district it is apparent that these different areas occupy as many different general horizons of the Michigamme formation, the southernmost belt being at the lowest horizon, the central area being somewhat higher, and the northern area being still higher than the central area.

DISTRIBUTION AND STRUCTURE OF THE VULCAN FORMATION IN PARTICULAR AREAS.

THE JUMBO BELT.

The only natural exposure on this belt occurs on the east side of Brule river about 200 paces east of the S. E. corner of the N. E. ¼ of the S. E. ¼ of Section 22, T. 42, N., R. 34 W. The rock is mainly a finely banded cherty iron carbonate locally altered to ferruginous chert and interbedded with carbonaceous any pyritic black slate. The strike is east and west and the dip is about vertical on the average although it varies widely on the limbs of the minor folds. From this exposure the formation is traced eastward for three quarters of a mile by numerous test pits of the old Jumbo exploration. The pits are now filled with debris but the dumps disclose slate and iron formation of the characters shown in the outcrop on the river. In the dump of the old Jumbo shaft at the east end of the belt are found an abundance of much altered greenstone, black carbonaceous and pyritic slate, roughly banded iron formation carrying much pyrite and secondary quartz and a small quantity of lean iron ore. The relations between Vulcan formation and greenstone are not shown but the two formations are probably interbedded. Interbedded siliceous, pyritiferous slate and highly altered greenstone are well exposed in an outcrop on the south bank of the Brule river just north of the Vulcan formation and seem to lie conformably above it.

The Jumbo iron formation-slate belt is overlain on the north, in probable conformity, by extrusive ellipsoidal greenstone which is well exposed in numerous outcrops north and south of the C. & N W. R. It is underlain by the Saunders formation which occurs about one quarter of a mile south. The Jumbo belt extends east and west beyond known limits. (See fig. 3).

THE CENTRAL AREA.

General Distribution.—This is the iron ore producing area of the Iron River district. The boundaries are not yet definitely known and are being rapidly widened by exploration. Taking Iron River and Stambaugh as a center, iron formation is known to occur northward to the southern part of Section 11, T. 43 N., R. 35 W., eastward to the Chicagon mine in the N. E. ¼ of Section 26, T. 43 N., R. 34 W., southeastward to the N. W. ¼ of the N. W. ¼ of Section 16, T. 42 N., R. 34 W., and westward to the S. W. ¼ of the S. W. ¼ of Section 33, T. 43 N., R. 35 W.

The area seems to be limited on the south by greenstone probably interbedded with slate. Connecting the scattered outcrops of greenstone occurring just north of the Saunders formation, a belt of varying width is formed extending across the entire district. While it is certain that this belt as shown on the map contains considerable interbedded slate and possibly iron formation, it seems to mark in a general way the south limit of the main slate-iron formation series. Beginning at the outcrops in Section 23, T. 42 N., R. 34 W., a magnetic line, probably marking the north edge of the greenstone, extends slightly north of west for about two miles where it dies out. If extended, this line would pass just north of the greenstone exposure in the N. W. ¼ of the N. W. ¼of Section 21. Thence the boundary swings more to the north and passes through the Wildcat shaft near the center of the south half of Section 18, and thence just north of the outcrops of greenstone in the N. ½ of the N. ½ of Section 13, T. 42 N., R. 35 W. Farther westward the boundary cannot be followed from lack of exposures and exploration.

Data for drawing a north boundary of this area are entirely inadequate. Probably it has no well defined north limit. A few greenstone outcrops occur in a broad belt of country several miles wide beginning about the middle of the east side of the district, where they connect with the greenstone area extending eastward almost to Crystal Falls, extending thence northwestward to the middle of the district, and thence southwestward. In this belt there are a greater number of square miles of territory than outcrops, and those that occur are confined to the eastern, central, and western parts. However, the wide distribution of the few outcrops that are known indicate a belt composed dominantly of greenstone extending across the district in a curving course in line with the structure of the graywacke and slate area north of it.

Of the structure and distribution of the Vulcan formation within this area we are by no means fully informed. Exploration has been actively prosecuted for the past four years but is still far from adequate. Locally, in the mine workings, the structure is well known but it is sometimes very difficult to connect the structure and stratigraphy shown in workings on a single 40 acres with those of an adjacent 40 acres. The explanation for this complexity has already been discussed.

Beginning in the southeastern part of the district, iron formation occurrs in drill holes in the N. W. ¼ of the N. W. ¼ of Section 16, T. 42 N., R. 34 W., and thence, in a curving line parallel to the supposed north boundary of the greenstone belt on the south, northwestward to the Zimmerman mine. Eastward from Section 16 the iron formation extends in all probability through Sections 15 and 14 and perhaps still further to the east but in this direction exploration has not yet been carried. It is a favorable line for exploration. North and east of this belt borings have generally penetrated black slate.

From the Zimmerman and Baltic mines the general course of the formation is northwestward up the valley of the Iron river. In detail the structure is exceedingly complex and thorough understanding will involve a description of the structure and succession in every mine on the belt. The Vulcan formation is here very generally underlain and interbedded with black slate and is usually in highly inclined position. The formation attains its greatest known width on the Caspian mine location where, with allowances for repetition by cross folding, it is probably above 300 feet thick.

At the Hiawatha mine and thence westward for about a mile, the

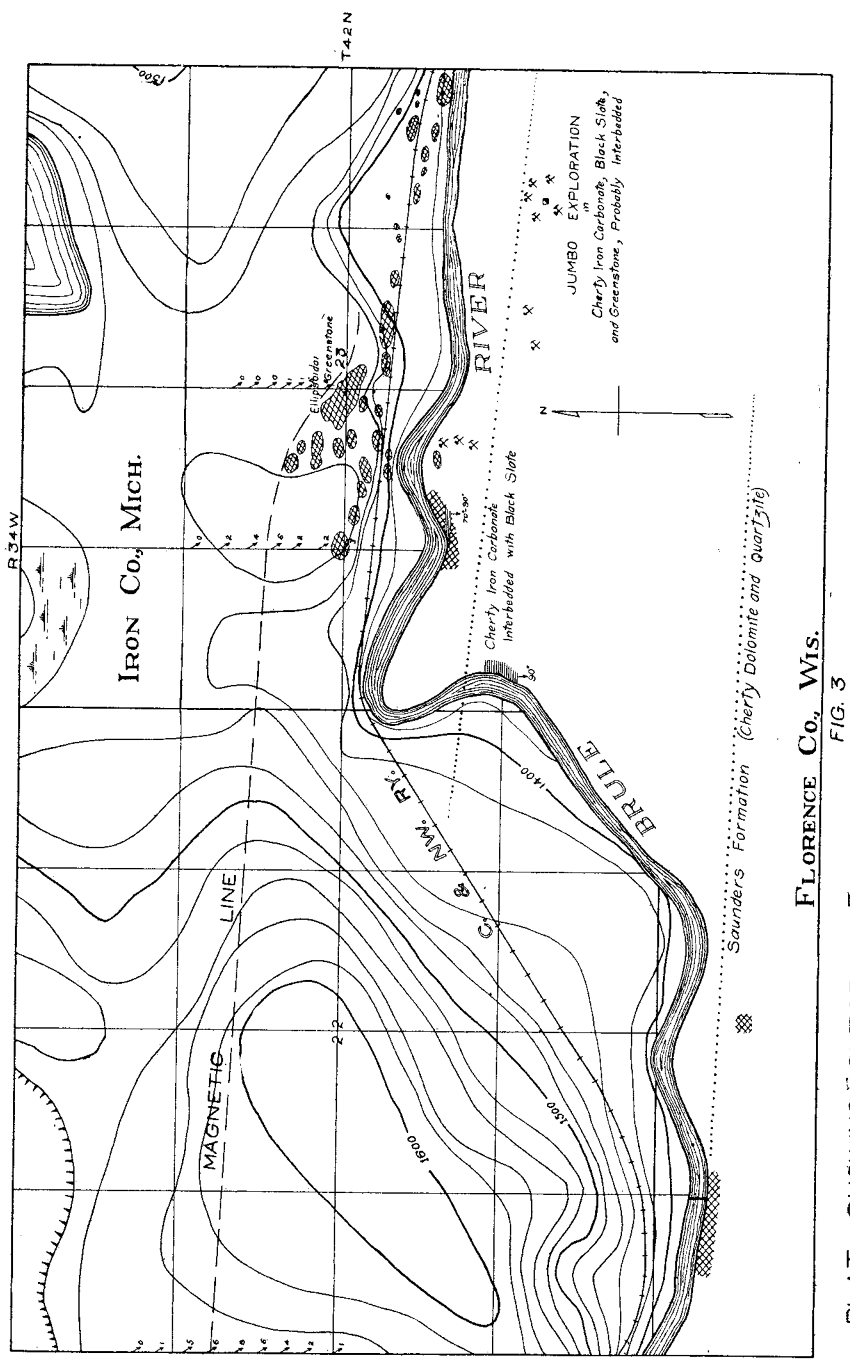


FIG. 3
PLAT SHOWING OUTCROPS ALONG BRULE RIVER NEAR JUMBO EXPLORATION
Scale 1 Mile

Vulcan formation strikes a little north of east and seems to dip, on the whole, steeply northward. Farther west this belt has not been traced.

From the Caspian mine northeast to the S. W. 1/4 of the S. W. 1/4 of Section 21, T. 43 N., R. 34 W., drill holes have penetrated what seems to be a more or less continuous belt of Vulcan formation. This belt is about at right angles to the belt along Iron river and with the extension of the Hiawatha belt forms with it a cross. However, we are by no means certain that the line of drill holes in iron formation extending northeastward from the Baker mine to the S. W. 1/4 of the S. W. 1/4 of Section 21, T. 43 N., R. 34 W., indicate a continuous belt of iron formation. The drill holes penetrating ore or ferruginous chert are on the north side of a preglacial valley which, aside from evidence furnished by the drill holes, seems from all available data to cut *across* the strike of the Michigamme series at a high angle.

North of Iron River the strikes are prevailingly about east and west. The Vulcan formation occurs in one main belt extending from the James mine slightly south and east through the Spies and Hall explorations to the N. E. 1/4 of Section 19, T. 43 N., R. 34 W., and slightly north of west to the S. E. 1/4 of the S. E. 1/4 of Section 15, T. 43 N., R. 35 W. The thickness of the bed exposed in the James mine appears to be not above 250 feet, making due allowance for thickening by folding. Black slate forms both foot and hanging walls in this mine. The dip varies from vertical to steeply southward or northward. Other lenses of iron formation occur both north and south of the James belt and its eastward and westward extensions but their importance and extent have yet to be proven by exploration.

ORE BODIES AND PARTICULAR OCCURRENCES OF THE VULCAN FORMATION IN THE CENTRAL AREA.

Zimmerman Mine.—The Zimmerman mine is located in the S. E. 1/4 of the N. W. 1/4 of Section 7, T. 42 N., R. 34 W. The Vulcan formation has been opened on the fourth or 350-foot level eastward from the hoisting shaft about 640 feet. The trend of the formation is on the average from 20° to 25 ° S. W. and the general dip steeply north but locally the dips vary widely due to folding. The iron formation seems to lie between black slate foot and hanging walls which are encountered in the ends of the cross cuts to the north and south of the main drifts which follow the strike. The north and south walls so far as exposed have no dissimilarities. Frequently the wall slates are very cherty and more closely resemble the Vulcan formation than typical carbonaceous slate. The hoisting shaft is in the Vulcan formation, but an air shaft 40 feet east of it is said to be in black foot wall slates. The major folds are of the drag type and pitch slightly N. E. By reference to figure 4, published by permission of the mine management, it will be seen that the main ore bodies are probably in eastward pitching synclines in the foot wall slates. Thus far in the development of the mine two such ore bodies have been found. The first of these which has been stoped out lay between the second and fourth levels, about 100 feet west of the hoisting shaft. The E.-W. longer dimension of the ore body just above the fourth level was 90 to 100 feet from where it extended upward at an angle of about 70° to a point between the second and third levels. The south wall is black slate, well exposed on the third level, while the north wall is generally soap rock. The boundaries of the ore bodies are not sharply defined by these walls. In many places lean ore and highly decomposed chert intervene between the walls and the rich ore and both east and west the ore grades into ferruginous chert. At nearly a central point between the third and fourth levels the walls dip sharply inward and, it is thought by the superintendent, come together just above the fourth level where the ore body "pinches" out.

The second and largest of the ore bodies has been opened on the 350-foot level about 250 feet S. 60° E. of the former. It pitches slightly northeast. The north wall is black slate but the south wall is lean ore and ferruginous chert. So far as may be judged in the present state of development this ore body seems to lie in an eastward pitching syncline of the drag type, bottomed in slate.

Small unimportant bodies of ore are scattered erratically through the mine and seem to occur in those parts of the formation most highly folded and brecciated.

The thickness of the Vulcan formation in this mine is difficult to determine on account of the character of the folding and uncertainty of discrimination between wall slates and interbedded slates but seems to be not greater than 200 feet.

Baltic Mine.—From the Zimmerman mine the Vulcan formation extends northeastward into the N. W. ¼ of the N. W. ¼ of Sec-

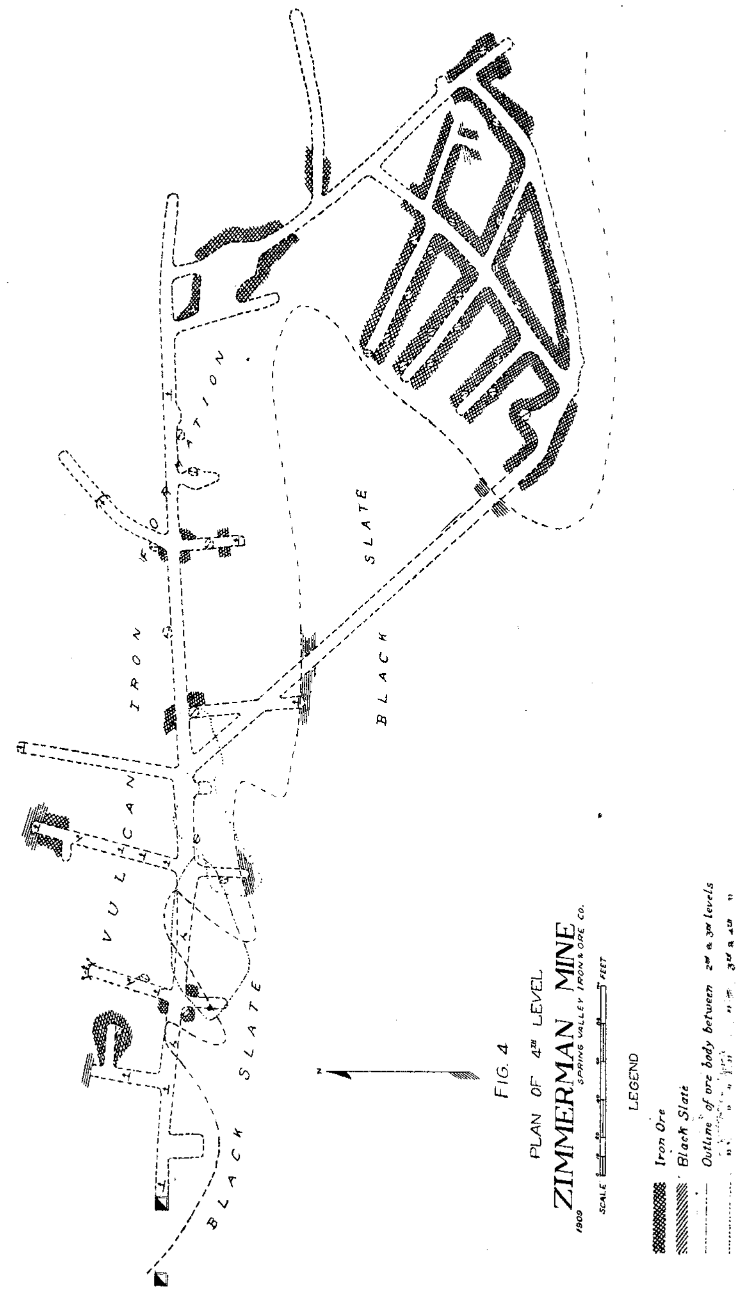


FIG. 4
PLAN OF 4th LEVEL
ZIMMERMAN MINE
1909 SPRING VALLEY IRON & ORE CO.

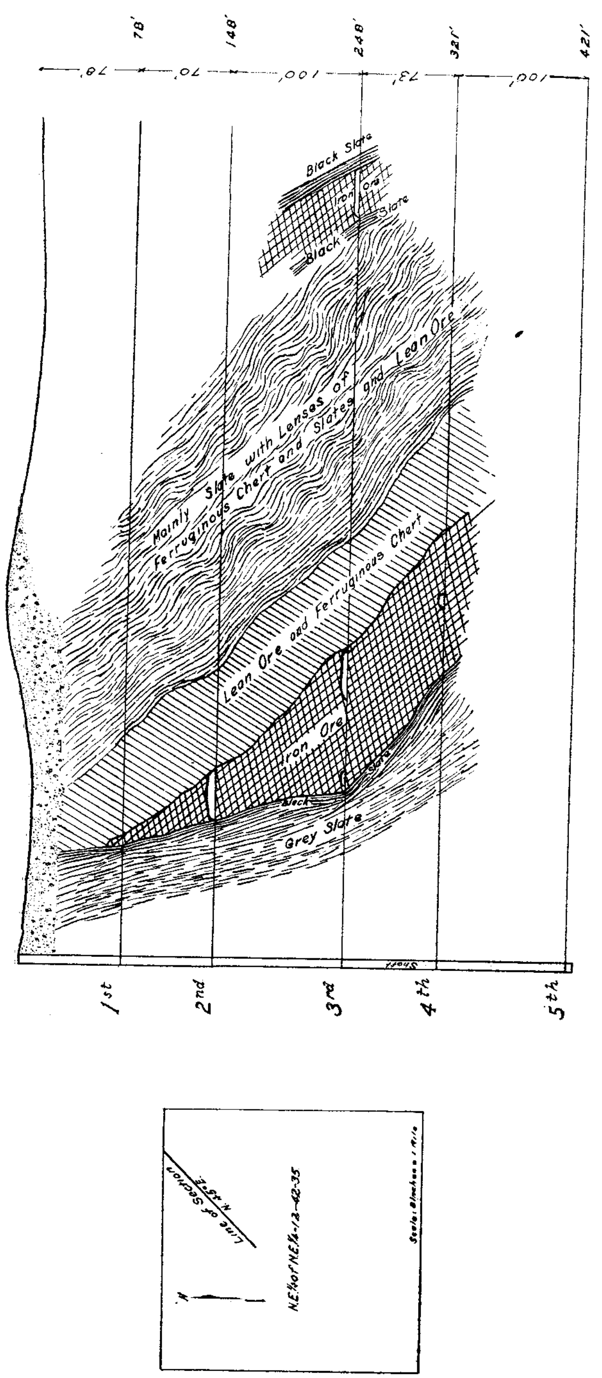


FIG. 5.

SECTION THROUGH YOUNGS MINE.
HURON IRON MINING CO
OCTOBER 1909
Scale 50 100 150 200 300 FT

tion 7, where it is opened in the workings of the Baltic mine. From an examination of the plans and sections of this mine through the courtesy of the Verona Mining company, it appears that the Vulcan formation is here folded in two northward pitching synclines carrying the Baltic ore bodies, the synclines being separated by a sharp anticline bringing up the foot wall rocks which are here black siliceous slate as in the Zimmerman mine. The folds are closely compressed which accounts for the general N.-S. strike of the beds and steep inclination from 70° to vertical.

Youngs Mine.—From the Baltic mine the Vulcan formation enters the Youngs location swinging in a curving northwesterly course across the northeast corner of the N. E. ¼ of the N. E. ¼ of Section 12, T. 42 N., R. 35 W., entering, northward, the Fogarty property of the Verona Mining company and thence swinging N. E. into the S. W. ¼ of the S. W. ¼ of Section 6, T. 42 N., R. 35 W.

In the Youngs mine the Vulcan formation is underlain by black and gray slates and dips northeast at angles of from 45° to 65°. Through the courtesy of the management a section is reproduced in figure 5. In this section the main or south ore body lies on a foot wall of black slate which grades downward into gray slates, the probable equivalents of the sericitic schists exposed in outcrop a short distance N. W. of the shaft, extending thence N. W. to the Iron River. The south ore body grades irregularly upward into ferruginous chert and lean ore which is overlain by a thick bed of slates carrying thin iron formation layers locally altered to ore. These rocks are succeeded by a second or north ore body, some 40 to 60 feet thick, with black slate foot and hanging walls. This ore body dips northeast into the workings of the Fogarty mine. Thus in the Youngs mine the Vulcan formation occurs in two separate main lenses, the southern or lower having a thickness of about 140 to 150 feet, the northern or higher a thickness of 40 to 50 feet, the two being separated by about 150 to 175 feet of slate interbedded with layers of the Vulcan.

Fogarty Mine.—Sections through the Fogarty mine (fig. 6) are given through the courtesy of the Verona Mining company. The main ore body of this mine is continuous with the upper or north body of the Youngs. It may be seen by reference to the sections that the foot wall slates of the Youngs mine are not exposed in the Fogarty workings. The character of the rocks west of the Fogarty

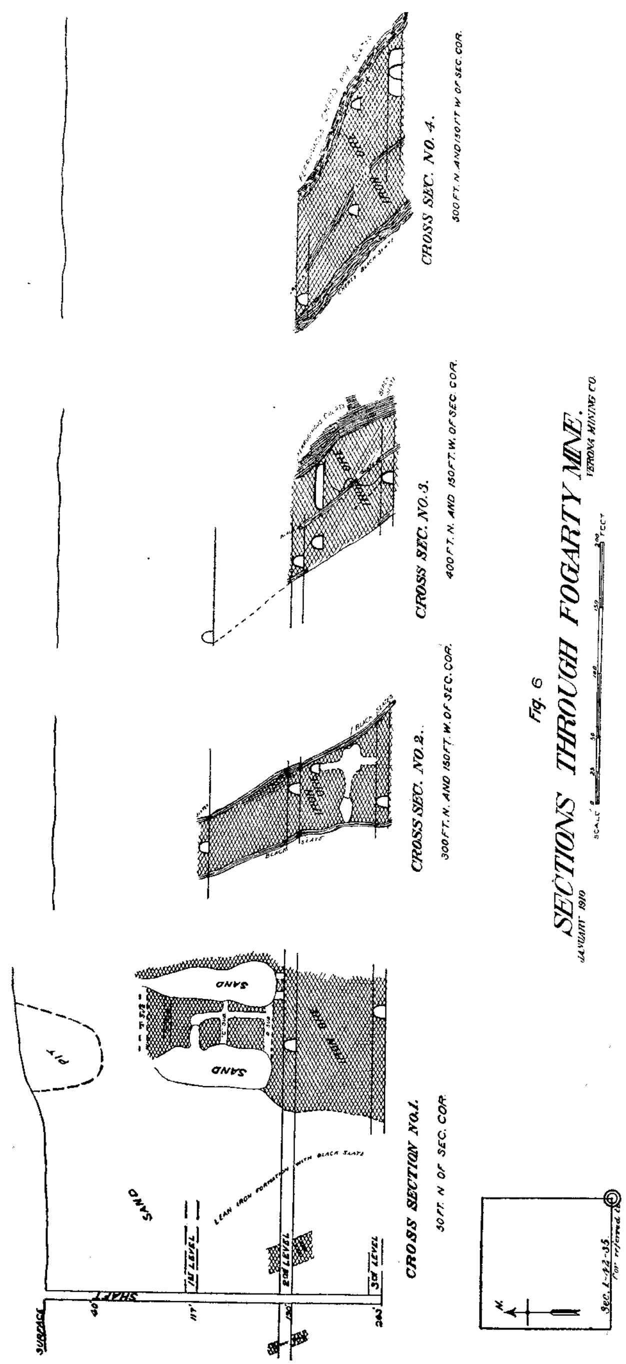


Fig. 6
SECTIONS THROUGH FOGARTY MINE.

workings is shown by a horizontal drill hole extending from a point about 450 feet north and 800 feet west of the S. E. corner of Section 1, T. 42 N., R. 35 W., from the workings of an old shaft, east 715 feet through the north end of the Fogarty mine. This hole penetrated a series of gray, green and red slates interleaved with thin layers of ferruginous chert and bands of ore. West of this hole the workings of the old shaft referred to appear to be largely in black slate, judging from material on the dump. Outcrops of impure cherty iron carbonate, in about vertical position striking N. W., occur in the river bank about 500 feet N. W. Thus it appears that the iron formation developed in the Fogarty mine is underlain on the west by several hundred feet of gray, green, red and black slates, carrying iron formation layers of varying slight thicknesses. It will be seen by reference to figure 6 that the various sections which are taken across the strike of a continuous stratigraphic horizon in the Fogarty mine do not closely correspond. Slate occurs in discontinuous lenses in the ore body and on both its foot and hanging walls as well as in the leaner parts of the formation. The occurrence of ore in this mine is evidently not dependent on the presence of impervious slate layers although the local favorable influence of these on ore concentration is apparent on examination of the underground workings. The Vulcan formation exposed in the Fogarty mine has a maximum thickness of about 300 feet which corresponds well with the Youngs mine section.

Berkshire Mine.—The Vulcan formation on the N. W. ¼ of the S. W. ¼ of Section 6, T. 42 N., R. 34 W., is exposed in the workings of the Berkshire mine. The strike is approximately E.-W. and the dip steeply south. From the workings of the mine the formation probably extends east into the Corry exploration, where the Verona Mining company has proved by drilling the occurrence of ore bearing iron formation, and west into the Cottrell exploration of the Oliver Mining Company. The drill cores of the Corry exploration indicate a much lower dip than prevails in the Berkshire mine. Just what connection there is between the Berkshire and Fogarty belts is as yet a matter of conjecture. They are probably in the same horizon but the possibilities of folding, faulting and truncation by erosion are such that the facts of occurrence might be explained on alternate hypothesis involving several different combinations of these factors which it seems unprofitable to discuss until data are more complete.

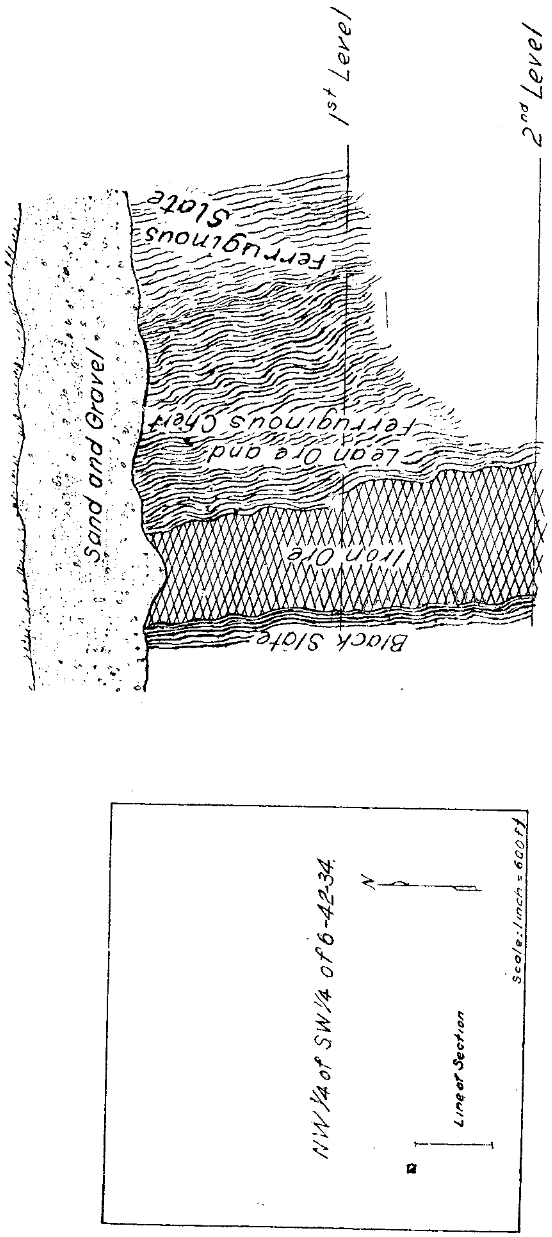


Fig. 7

SECTION THROUGH BERKSHIRE MINE.

SEPTEMBER 1909 BRULE MINING CO.

Scale 50 100 150 200 Feet

The main structural features of the Berkshire ore body are shown in figure 7 by permission of the Brule Mining company. In the west end of the mine the ore body lies on a wall of siliceous black slate grading into ferruginous chert toward the east. Whether this slate is basal to the Vulcan formation or is within it is not known but the latter is probably the truth. The ore body, from 50 to 80 feet thick, grades upward and laterally into ferruginous chert which is overlain by massive ferruginous slates. The top of the ore body is marked by a depression some 10 to 15 feet deep, probably the result of downward slump of the ore due to leaching of silica during concentration.

Caspian Mine.—Northwest of the Berkshire mine the Vulcan formation is unexplored to the Caspian mine. In this mine the formation strikes N. about 60° W. and is in vertical position. It has a maximum thickness of from 300 to possibly 400 feet, making due allowance for thickening by folding. In places the formation is entirely altered to iron ore. The east and west walls in this mine are not usually well defined. Many of the cross cuts have been discontinued near the limits of the ore body. The most common wall rock is black slate, in many places highly graphitic, in others cherty and siliceous. Slates, more or less ferruginous, and ferruginous chert are common wall rocks. Cross sections drawn by the writer from mine plats are shown in figure 8 through courtesy of the Verona Mining company. North of the Caspian, ore bearing Vulcan formation occurs in the Tully exploration in the S. W. 1/4 of the S. E. 1/4 of Section 36, T. 43 N., R. 35 W. It is believed by many that the Vulcan of the Caspian and Tully properties is connected across the N. W. 1/4 of the N. E. 1/4 of Section 1, T. 42 N., R. 35 W. Such connection is probable in view of the strike of the formation in the Caspian and the results of exploration on the N. E. 1/4 of the N. W. 1/4 of the section lying between the Caspian and the Dober properties.

The Barrass Mine.—North and east of the Tully, the S. E. 1/4 of Section 36, T. 43 N., R. 35 W., so far as exploration has shown, is underlain by Vulcan formation which extends north into the N. E. 1/4 of the section, as shown in the workings of the Barrass mine and drill holes one-quarter of a mile north of it, and east into the S. W. 1/4 of Section 31, T. 43 N., R. 34 W., where it is opened in the Baker mine.

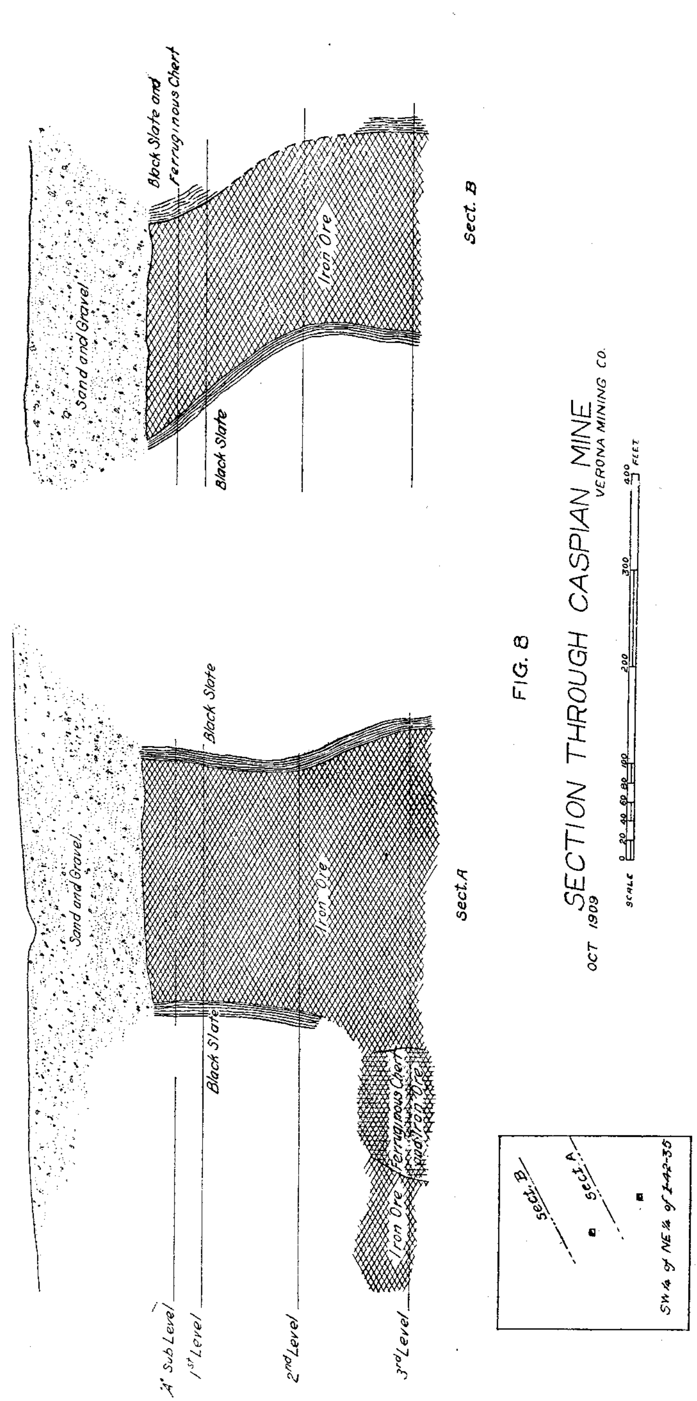


FIG. 8

SECTION THROUGH CASPIAN MINE

VERONA MINING CO.

OCT 1909

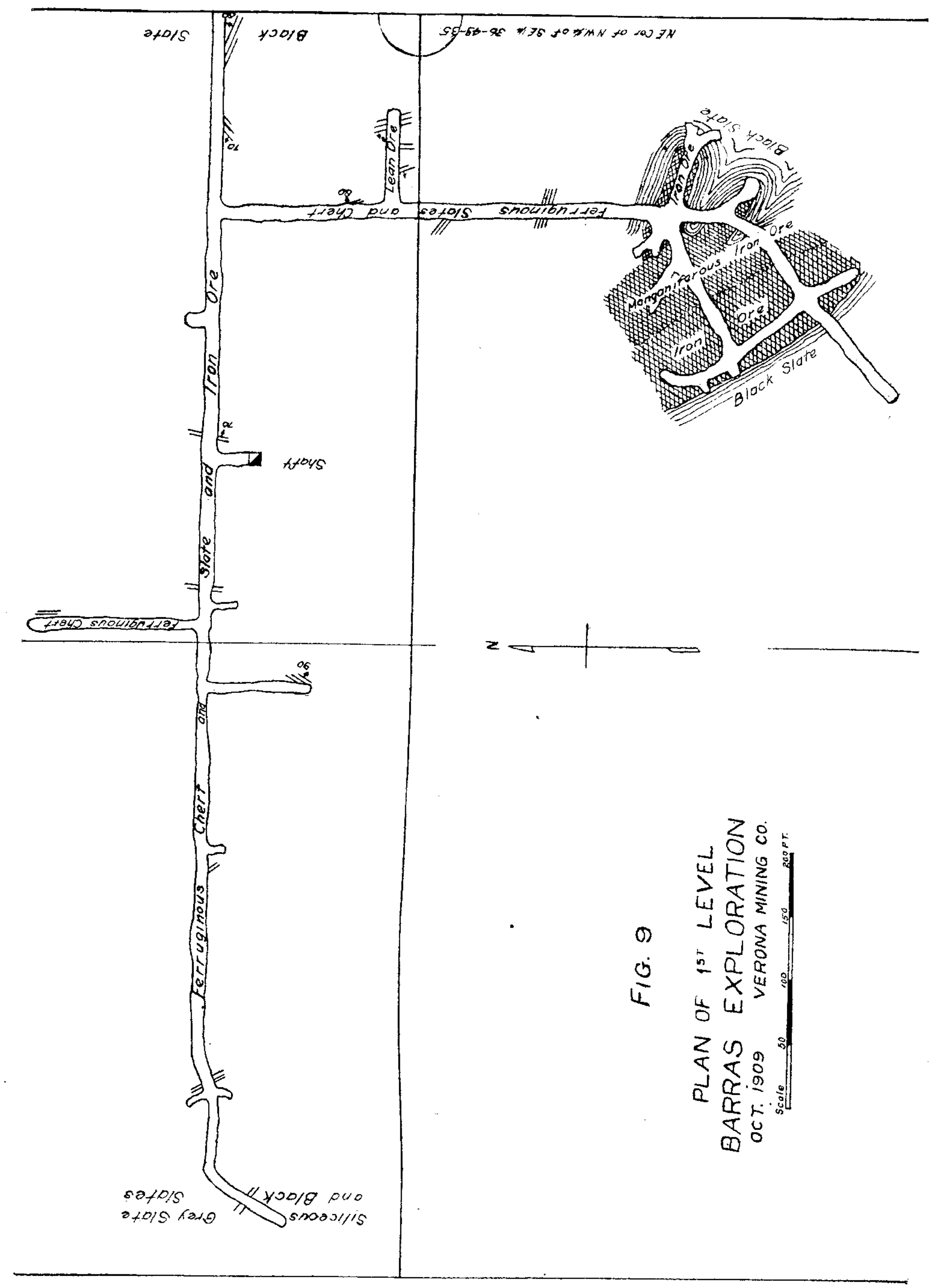


FIG. 9

PLAN OF 1ST LEVEL

BARRAS EXPLORATION

VERONA MINING CO.

OCT. 1909

A sketch of the first level of the Barrass mine is shown in figure 9 by permission of the Verona Mining company. It will be seen by reference to this sketch that the general trend of the formation is N. W., although locally the strike varies widely. The dip is about vertical on the whole but varies from place to place as much as 35°. The bedding is twisted and contorted to an extreme degree in some parts of the workings. The main ore body thus far discovered seems to lie on a folded foot wall of black slate and probably pitches northwest but work has not progressed far enough to disclose the exact structural relations. This deposit is notable for its high content of manganese. The manganese occurs as black oxide intimately mixed with hematite and is most abundant in the northeast side of the ore body. Caving prevented an examination of this deposit by the writer and we are indebted to Mr. I. N. Woodworth for the notes here given and also for the following partial analysis of an average sample of the hard and soft manganiferous ore which is published through courtesy of the Verona Mining company.

Partial analysis of average sample of hard and soft manganiferous iron ore from the Barrass mine:

Iron	23.20 %
Phosphorous	.434
Manganese	26.86
Silica	5.60
Aluminum	3.60
Sulphur	.136
Calcium oxide	2.15
Magnesium oxide	4.84
Volatile	13.00

The Baker Mine.—The workings of the Baker mine disclose a highly contorted, brecciated and shattered mass of ferruginous chert and ore. The writer was unable from careful examination of the workings to come to any conclusion regarding the general structural relations. Slate walls are not present and the bedding of the iron formation is so extremely contorted and brecciated that

attempts to work out the general attitude of the Vulcan formation proved futile. The ore bodies are scattered in pockets of irregular shapes through the ferruginous chert into which they grade by decrease in iron content and rise in silica. Adjacent to the ore bodies the ferruginous chert is in most cases highly decomposed, the chert being frequently so friable as to crumble readily between the fingers, in which state it is called "sandstone" by the miners.

The Isabella and Dober Mines.—The Isabella mine adjoins the Dober on the north. The two properties are operated by the Oliver Mining company from the shafts of the Dober. The general trend of the Vulcan formation in both mines is northeast and the dip northwest. In the Dober mine the dip is about vertical near the surface but becomes less steep in depth and from the fourth level downward averages between 40 and 50 degrees. The depth of the Dober workings is 600 feet but ore is known to occur to a depth of at least more than 150 feet below this level.

The relations of the Dober ore deposits to wall rocks are interesting and instructive. In the lower levels black slate and graphitic chert envelopes the ore body on the north, east and west and black slate occurs on the south wall. In the words of Captain Duff "one cannot get out of the Dober ore body without going through black slate." It was suspected that these relations are in part due to replacement along the bedding of iron formation by black slate and graphitic chert. A careful examination of the workings under the guidance of Captain Duff with this idea in mind soon established the truth of the supposition. In one place near the end of a cross cut on the fifth level rich ore grades into lean ore carrying carbonaceous material and this into black graphitic slate in a distance of three feet the bedding being continuous and unbroken from the ore into the black slate. Similar gradations of ferruginous chert into siliceous black slate occur at other places in the mine.

It has already been stated that the chief obstacle encountered in working out structure in the Iron River district lies in the difficulty of identifying stratigraphic horizons because of their ever varying changes in character from place to place in the direction of strike. The instance cited above is an illustration of the rapidity with which such changes often occur. This often leads to confusion in mine mapping since it is common in this district to include all dark or black rocks in the term black slate. The occur-