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CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

MEMOIR 147

No. 127, GEOLOGICAL SERIES

Michipicoten Iron Ranges

BY

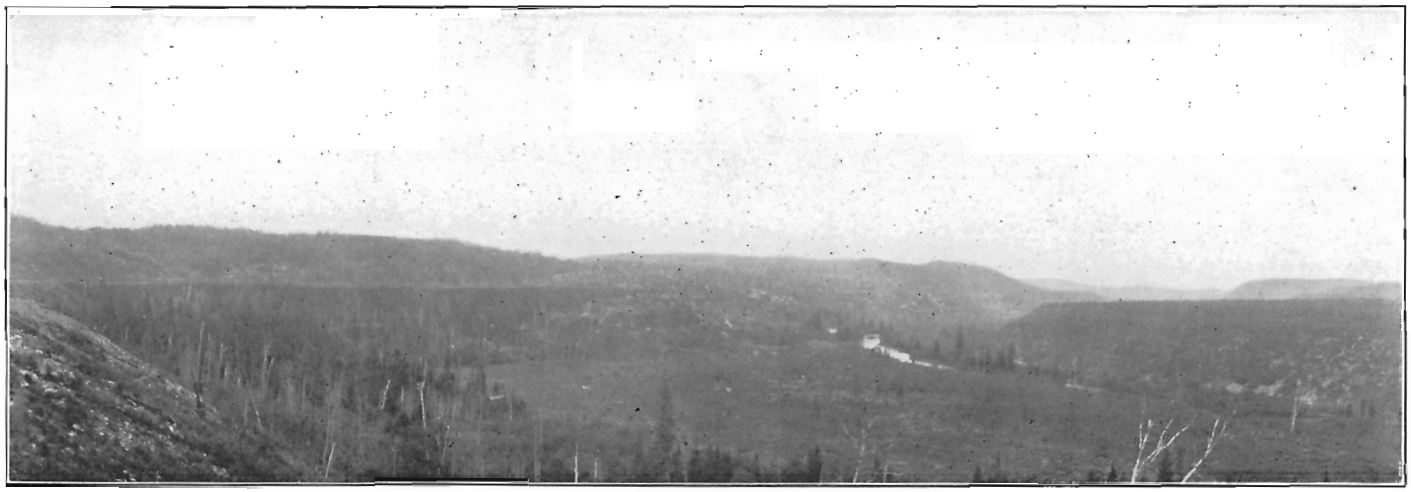
W. H. Collins, T. T. Quirke, and Ellis Thomson

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1926

Price, 30 cents

No. 2079

PLATE I



Wawa terrace from near mile-post 13, Algoma Central railway, showing erosion by Magpie river. (Page 45.)

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PART I

MICHIPICOTEN IRON RANGES

By W. H. Collins and T. T. Quirke

CHAPTER I

INTRODUCTION

Since the discovery and first operation of the Helen mine, Michipicoten district has been the chief producer of iron ore in Ontario. Between 1900 and 1918 the Helen mine yielded 2,823,369 tons of brown iron ore, as well as 51,930 tons of pyrite. This ore-body, which is now exhausted, was an oxidized pocket in an elongated mass, or " range," of siderite, many of which ranges have been found in the district. The siderite bodies were not regarded as commercial ore-bodies until 1909, when the Magpie mine was opened in one of these ranges. The Magpie ore-body was diamond-drilled in 1909 and experiments were carried on, mostly after 1912, with a plant for roasting the ore. A satisfactory product was eventually obtained and since 1913 the Magpie mine and reduction plant have raised and roasted into hematite about 1,250,000 tons of siderite. A great deal of experimentation was required with the roasting plant, involving interruptions in operation and a considerable loss of money in the enterprise. The experience gained seems likely, however, to be employed to advantage at the " New Helen " mine. It has been found by diamond-drill exploration that the siderite range, of which the old Helen ore-body was an oxidized part, contains between 70,000,000 and 100,000,000 tons of ore of about the same composition as the Magpie siderite. This body has been opened already by means of a tunnel, preparatory to mining the ore, and is commonly referred to as the " New Helen," to distinguish it from the exhausted brown-ore mine.

At the time of writing, the autumn of 1924, the Magpie mine has ceased production and operations at the New Helen are suspended until the prices of labour and materials decrease. Nevertheless, this is probably only a temporary interruption, such as has occurred before. Iron-ore mining in Michipicoten district appears likely to continue for many years, for, although the Helen siderite deposit is the largest and most favourably located body of ore known in the district, there are other ranges, smaller, lower in quality, and less favourably situated, which will appreciate in importance in the course of time.

An important pyrite-mining industry sprang up in the district during the war period. Some pyrite had previously been mined from the old Helen mine, but it was only after the large deposits at Goudreau were opened in 1913 that pyrite production began on a considerable scale. Between then and 1919 about 250,000 tons of pyrite ore were produced; but since 1918 the price and demand have fallen off, and production has ceased. If market conditions improve this industry will probably revive and increase, for besides the Goudreau deposits an ore-body containing about 900,000 tons of high-grade pyrite has been located on the Holdsworth claims, and other deposits of the same character have been found and are awaiting underground exploration.

Gold occurs in several parts of the district and has been mined at a number of places. In fact it was the discovery of gold south of Wawa lake in 1897 that led to the development of the iron ore deposits. Operations in the Wawa field have languished, but gold found in 1918 east of Goudreau has led to a considerable recrudescence of activity. During the summer of 1921 several promising discoveries were also made a few miles southwest of Goudreau, which are now being actively prospected.

Michipicoten district is apparently still one of the most promising fields in Ontario for intelligent prospecting, and it was mainly with a view to facilitating its economic exploration that the geological work dealt with in this report was undertaken. A great deal of work of the same kind has been done in the past by the Ontario Bureau of Mines. Professor Coleman and the late A. B. Willmott, together and singly, explored parts of the district at various times between 1897 and 1906. Dr. J. M. Bell also explored it in 1904 and Mr. A. L. Parsons in 1914. The district is a large one, however, and enough remained to be done to induce the Geological Survey to begin further exploration work in 1918.

WORK DONE

Two chief ends, geographical and geological, were held in view in the conduct of the work by the Geological Survey. First, information was obtained for a base map considerably more complete and accurate in respect to geographical features than any existing map. The district is still mainly a wilderness and dependable route maps are essential to prospectors and others travelling away from the railway.

The geography of Map 1972, accompanying this report, deserves brief description because of the effort that has been made to render the map accurate and permanent in value. Primary control was provided by making a precise chain and transit survey of all the railways within the map-area. All township crossings of the railways were located and marked with permanent iron posts, and the township lines were rechained to the nearest mile-post. In compiling the map the grid of township lines was found to require only a negligible amount of adjustment to the control survey of the railway. Mr. R. C. McDonald, of the Topographical Division, Geological Survey, who performed the survey of the railway, also made a survey of Magpie river and Wawa lake with transit and micrometer eye-piece. The lesser waterways, especially in the northern part of the area,

were surveyed with Rochon micrometer and prismatic compass by the writers' parties, all such surveys being connected with the township or railway control surveys. Isolated lakes and small creeks were located and sketched by pacing and compass traverses. The features in the southern part of the area are largely copied from Coleman's map. The geodetic position of the map-area depends upon the triangulation of lake Superior by the Canadian and United States Geodetic Surveys. It may be said, therefore, that the base map of Michipicoten area (No. 1972, in pocket) is precise enough for all present requirements and probably for future requirements, and is accurate enough to serve as a unit in any primary map system which northern Ontario is likely to require. The map of Missinaibi area (No. 2050, in pocket) which accompanies the report by Mr. Thomson, in this volume, has been prepared in the same manner and is similar in geographical value.

In the second place a systematic geological exploration, or revision of earlier work of this nature, was made. It may be pointed out in this connexion that all the known mineral wealth of the district except gold—that is, the pyrite and iron ores—originated in one rock formation of unique character, known as iron formation. Attention was accordingly concentrated upon this formation with the intention of mapping it as completely and accurately as possible, and also of inquiring into its character and origin.

Parts of three field seasons were devoted to this work. During the early half of 1918, with the assistance of Mr. Ellis Thomson of the Department of Mineralogy, University of Toronto, two areas, each of 25 square miles, which contain the more important pyrite deposits, were examined and mapped in detail. The results of this work were published in the Summary Report of the Survey for 1918. In 1919, two parties were employed. One, in charge of Mr. R. C. McDonald, devoted itself to control surveys of the railway, Magpie river, and Wawa lake. The other, conducted by the present writers, assisted by C. A. Poynton, H. F. Swann, and A. D. McGibbon, carried on an areal geological exploration and supplementary surveys of lakes and streams. Part of 1920 was spent by the senior author, assisted by Mr. W. F. James, in completing the investigation of the iron formation and principal ore deposits, and in adding various details to the work accomplished in 1919.

ACKNOWLEDGMENTS

The field work was carried out under highly favourable conditions. Valuable assistance was rendered by each of the gentlemen mentioned above. A great deal of information obtained in mining, diamond-drilling, and other explorations, not otherwise procurable, was made available by the Algoma Steel Corporation, the Nichols Chemical Company, the Rand Consolidated Mining Company, Judge John McKay of Port Arthur, and others. Acknowledgment is particularly due to the officials of the Algoma Steel Corporation for the generous manner in which their valuable records were placed at the writers' disposal. Field work was facilitated in many ways by officials of these mining companies and of the Algoma Central

railway. Moreover, a mass of useful information was obtained from the reports and maps by earlier workers in this field, a fairly extended list of which is given below.

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CHAPTER II

GENERAL CHARACTER OF MICHIPICOTEN DISTRICT

LOCATION AND ACCESS

The area described in this report is a rectangle 25 miles by 20 miles in what is commonly known as Michipicoten district. It is located so as to include a major part of the mineral-producing "Keewatin" schists and as little as necessary of the surrounding unproductive granite gneiss. Its position with respect to lake Superior and the railways is shown by Figure 1.

The area is traversed by branches of the Algoma Central railway in a manner which greatly facilitates access to any part of it. There are also wagon roads leading from The Mission to Wawa, from The Mission to the High Falls power-plant on Michipicoten river, and from Goudreau siding to the Murphy gold discovery; but, except for these conveniences, the area is a wilderness, and summer travel away from the railway is possible only by canoe.

TOPOGRAPHY

The map-area lies on the slope of the Precambrian Shield towards lake Superior. It shares one peculiarity with all other parts of the drainage area along the east and north coasts of the lake, that is, a marked steepening of the slope in the last 5 or 10 miles. A line joining High falls on Michipicoten river, the foot of Wawa lake, Black Trout lake, and Dore lake forms an approximate boundary between a comparatively steep slope to lake Superior and an almost horizontal though hummocky plain farther inland.

The change in grade is not directly visible, but it is distinctly expressed by the rivers and by the grade of the Algoma Central railway, and plays an important rôle in the chief engineering developments in the area. Thus, Michipicoten river is an easily navigated stream, with large expansions, down to High Falls power-plant; but in the remaining 6 miles to lake Superior there is a total descent of about 275 feet, accomplished in a broken fall of 128 feet, succeeded by rapids. Magpie river is, likewise, a placid stream with an average grade of 5 feet to the mile, measured in a straight line from its source to Steephill falls, most of this descent being taken up by occasional low waterfalls. From Steephill falls, which is about 375 feet above lake Superior and only 10 miles distant in a straight line, the grade increases from 5 to 37½ feet a mile. There are three falls of 63, 73, and 115 feet in this distance and the stream between the falls is swift and meandering. Dore river is a succession of falls and rapids from just below Dore lake to lake Superior, the total descent being several hundred feet; above Dore lake it has an easy gradient and is navigable for a good many miles.

The Algoma Central railway ascends from lake-level (602 feet) at Michipicoten Harbour to 961 feet at Wawa station, 1,111 feet at Helen Junction, and 1,260 feet at Helen mine, in straight-line distances of 4, 6, and 7 miles, respectively, from the nearest point on lake Superior. These are equivalent to uniform straight-line grades of 90, 85, and 94 feet to the

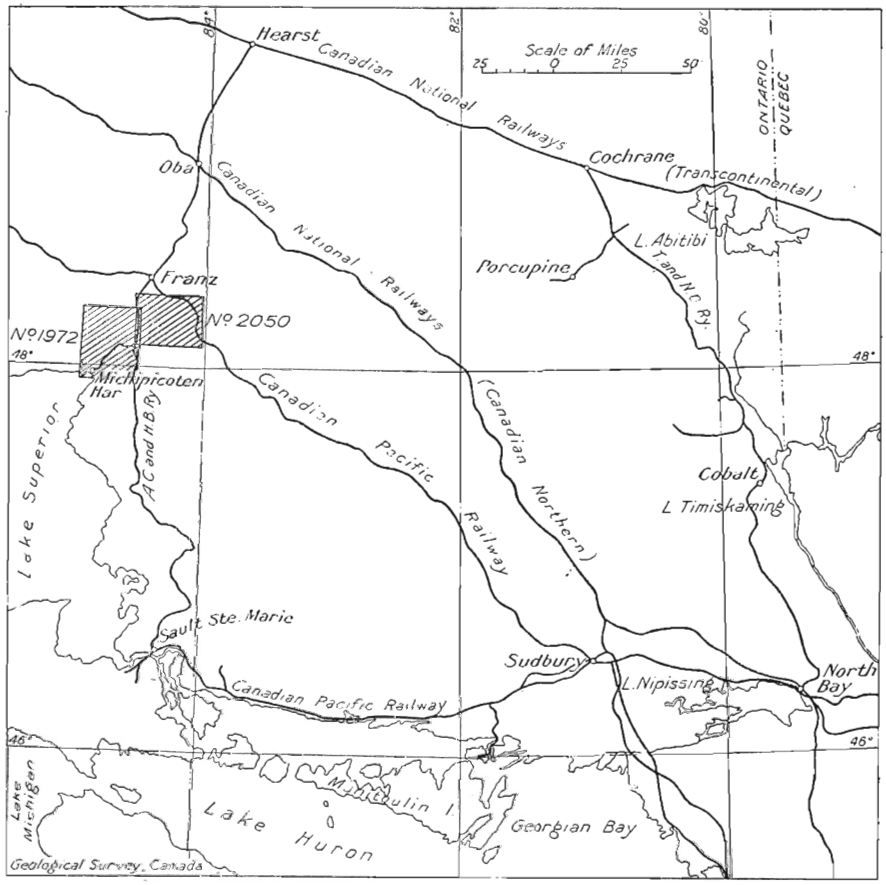

Figure 1. Index map showing locations of Michipicoten map-area (No. 1972) and Missinaibi map-area (No. 2050).

mile. In the flatter country beyond, the mean grades between such points as Wawa, Magpie Junction, Magpie mine, Goudreau, Hawk Junction, etc., range from 4 to 21 feet a mile, with 10 feet a mile the prevailing grade.

The effect of a bevelled plain carved in the solid Precambrian rocks is almost entirely obscured, however, by the hilly character of this plain. Except for occasional sand-plains that date from the Glacial period, the country is an unbroken succession of rocky hills and ridges ranging in

height up to 300 feet. To complete the idea of the general appearance of this country it is only necessary to conceive it as covered with a rather dense forest of mixed evergreens and deciduous trees, and with small lakes occupying many of the depressions.

Many of the larger elevations appear to be directly related to two of the solid rock formations—the iron formations and the younger diabase dykes. The great ridge east of Helen mine, from which a view can be had over nearly the whole map-area, is composed of iron formation. The iron ranges east of Parks lake and in the southeast corner of township 30, range 24, also stand up as conspicuous ridges. Exploration of the iron ranges is greatly facilitated by this circumstance. The younger diabase dykes give rise to high, rugged knobs instead of ridges.

In by far the greater part of the district the solid rocks do not carry enough drift to obscure sensibly their hilly surface; but in some places, this hilly, rocky country is diversified in the most striking manner by flat sand-plains of from less than 1 to 10 square miles in extent. Most of these plains are either burnt or covered by second-growth jackpine. They occur at various levels from lake Superior up to 1,225 feet above sea. Those which stand high and at a distance from lake Superior are very gently undulating or quite flat, except where they are being dissected by streams. The great sand-plain at the mouths of Michipicoten and Magpie rivers, however, is not only deeply dissected by these rivers and other streams crossing it, but descends to the lake in a series of sharply-defined, wave-cut terraces. The hair-pin bends shown in the wagon road from The Mission to Wawa are necessitated by the steep rise from one terrace level to the next.

DRAINAGE AND WATERPOWER

Nearly all the map-area is drained by Magpie river. The southeast corner and east side drain into Michipicoten river, and the west side into Dore river. The Dore is a small stream, but both the Magpie and Michipicoten are large enough to furnish an important waterpower supply. There is a drop of 68 feet at Steephill falls on the Magpie, at which the Algoma Steel Corporation has a well-equipped hydroelectric plant, capable of developing 2,600 horsepower, according to information supplied by Mr. J. B. Challies, Director of the Dominion Water Power Branch, Department of the Interior. This fall was utilized by the Algoma Steel Corporation to operate the Helen and Magpie mines. Between Steephill falls and lake Superior are four other falls not yet harnessed, but capable of developing considerable power. The uppermost is 73 feet high and is estimated by the Dominion Water Power Branch to be capable of developing 2,787 horsepower, if an average flow be maintained by storing the water supply. The other three, which are close together and near lake Superior, are accorded a combined fall of 115 feet and a combined energy of 4,390 horsepower. In 1918, the Algoma Steel Corporation built a storage dam at the outlet of Esnagami lake, at the headwaters of Magpie river and near the main line of the Canadian Pacific railway, which can increase the depth of water by 6 feet, providing a mean annual flow of 400 cubic feet a second at Steephill falls.

High fall on Michipicoten river is 128 feet high, and capable of developing about 7,500 horsepower. The Algoma Power Company's plant, situated there, is equipped for converting 1,700 horsepower into electrical energy for transmission to Magpie and Helen mines. Whitefish, Manitowik, and Dog lakes serve as natural storage basins. During 1920 surveys were made for building a concrete dam at the crest of the falls, which, if constructed, will increase the fall to 200 feet and create still water upstream as far as the Algoma Central Railway crossing. The various transmission lines within the map-area are shown on Map 1972 accompanying this report.

Magpie and Michipicoten rivers were used as canoe routes until the Algoma Central railway furnished a much better means of travel. Both streams are easy to navigate from the Canadian Pacific railway downstream as far as Steephill and High falls, nearly all the descent being taken up in a few falls and short rapids. But from Steephill and High falls, where they begin the much steeper descent to lake Superior, they are too swift and meandering to be easily travelled. Both have cut deep channels in the thick deposits of stratified sand and gravel that these same streams deposited in a deep bay of lake Superior during early post-Glacial time, when the lake stood over 300 feet higher than it does now. Their tributary streams and lakes were traversed in canoes during the exploration work of 1919, but these cannot be recommended for anything except light travel. The streams are all small and full of small rapids, and were it not for an extraordinary number of beaver dams many of them would not be navigable at all. The lakes are small and the portages from one to another are not used enough to be in good condition.

Dore river is reported to be unfit for canoe travel except for a distance of 3 miles above Dore lake, and for a short distance below.

FOREST AND AGRICULTURE

Fires have destroyed practically all the forest from 1 to 4 miles on either side of the main line of the railway. Township 30, range 23, and part of township 29, range 24, have been deforested in the same way. The remainder of the area, except for small burnt patches here and there, is clothed either with old forest or second-growth of various sizes.

Spruce is the prevailing tree. The best forests for cutting pulpwood lie west of Magpie river, in the drainage basin of Catfish creek. Except for a small stand north of Pine lake, there are only scattered individuals of white pine in the map-area, and red pine is nowhere abundant. Almost all the sand-plains, however, carry forests of jackpine, in some cases too young to be useful, but in other cases large enough for making railway ties. The best stands of jackpine seen are those at Hawk Junction, one in the northern part of township 30, range 26, and another in the western part of township 28, range 26. Splendid forests of canoe-birch and yellow birch that attain diameters of 2 feet were seen between Black Trout and Catfish lakes, and southwest of Loonskin lake.

There is no considerable area of good agricultural land in the map-area.

GAME AND FISH

The Indians at Michipicoten river and Gros Cap appear to have given less and less attention of late years to trapping, with the result that fur-bearing animals are now exceptionally abundant in the northwestern part of the map-area. Beaver, otter, and mink are plentiful. Black bears are common. A considerable number of moose and an occasional red deer were seen during the field season of 1919.

Pike, pickerel, and lake trout are found in the lakes. There does not appear to be any particular localization of these lake fish. Pike and pickerel occur almost everywhere, and lake trout are found chiefly in the larger and clearer lakes tributary to any of the rivers. Brook trout, on the contrary, are not known to occur in the Magpie or any of its tributaries, whereas they are plentiful in the Michipicoten and its feeders. This is all the more remarkable because the two streams have a common entrance to lake Superior, and there is no perceptible difference in the character of their waters or beds.

CHAPTER III

GENERAL GEOLOGY

OUTLINE

The rocks of Michipicoten district are separable into four main groups, so unlike one another that there is no difficulty in distinguishing them. It is quite a different matter, however, to separate these groups into smaller components.

(1) The oldest group, commonly called the Keewatin, is an extremely complex and varied assemblage of volcanic flows and fragmentals that alternate at several horizons, and apparently only locally, with clastic sediments—conglomerates, greywackes, and water-laid tuffs. It also includes the peculiar sedimentary deposits known as iron formations, to which the district owes its iron ore and pyrite deposits. One of the elastic sedimentary series is so thick, so widespread, and seems to represent so great a period of time that it serves to divide the volcanic complex into lower and upper parts. This is the Dore series, and in this report the volcanics beneath and above it are called respectively pre-Dorean and post-Dorean. The rocks in this Keewatin group have suffered intense folding, faulting, and schistification. They are the home of the iron-ore, pyrite, and most of the gold ore deposits.

(2) The granite gneiss areas constitute the second great group. These represent batholithic intrusions in the older schist group at or about the time the latter were deformed (presumably mountain-built). Both granite gneiss and schists are early Precambrian and much older than the succeeding groups.

(3) The third group comprises dykes of diabase that intersect the rocks of the preceding groups. There are two series of these dykes; an older series of diabase and quartz diabase and a younger, more numerous, series of diabase which occasionally contains olivine. The older series seems to have been intruded during or not long after a period of profound faulting, for many of the dykes occur along fault-planes and their general course —from north-south to northwest-southeast—corresponds with the general course of the faults. These dykes are also somewhat irregular in direction and have suffered some shearing. The olivine-diabase dykes on the contrary are remarkably straight, undeformed, fresh in composition, and do not coincide with faults. Both series are of late Precambrian age.

These two series of dykes occupy an insignificant total area, but because of their connexion with faults and the frequency with which they cut the older formations, they interfere greatly with the continuity of the iron ranges, and consequently with the iron-ore and pyrite deposits. From an economic point of view they are a nuisance.

(4) The sand, gravel, and other loose deposits constituting the drift sheet are the fourth group. These materials are, of course, vastly younger than any of the Precambrian solid rocks upon which they rest.

The structural relations of these four groups of rocks are expressed in Figure 2. Their age relations and chief subdivisions are given in the following table.

Group	Age	Subdivisions	Composition
4	Pleistocene		Unconsolidated boulder clay, and stratified lake deposits of gravel, sand, silt, and clay
3	Late Precambrian	Younger dykes	Fresh diabase, occasionally olivine-bearing
		Older dykes	Diabase and quartz diabase
2	Early Precambrian	Batholithic intrusives	Granite gneiss and its differentiates
1	Early Precambrian ("Keewatin")	Local sedimentary deposits (Eleanor slate of Coleman and Willmott)	Conglomerates, greywackes, and stratified tuffs, mostly of small extent and occurring probably at more than one horizon in the post-Dorean volcanics
		Iron formations (Helen formation of Coleman and Willmott)	Banded formations of silica, siderite, and pyrite, of small extent, occurring at various horizons in the post-Dorean, and probably also in the pre-Dorean volcanic group
		Post-Dorean volcanics	Acid to basic flows and pyroclastics
		Dore series	Conglomerate, greywacke, and stratified pyroclastic materials
		Pre-Dorean volcanics	Acid to basic flows and pyroclastics, and granitic rocks

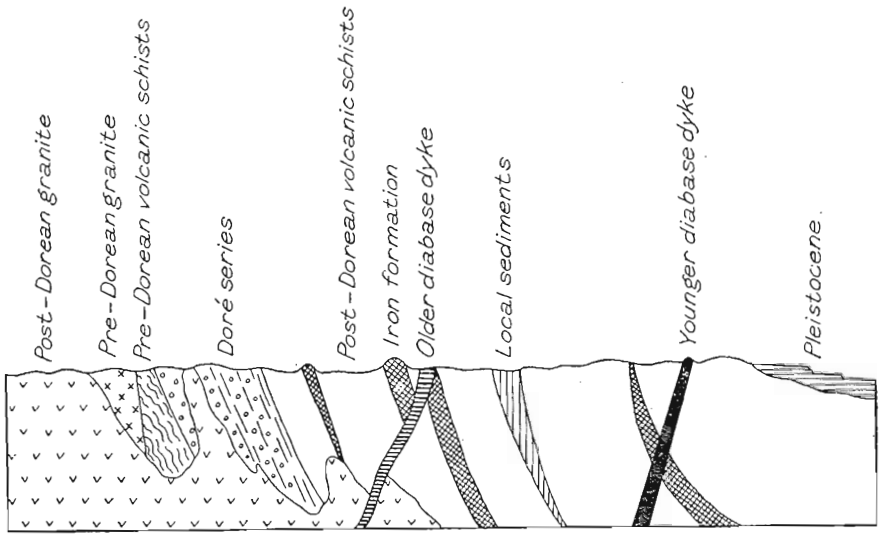

Figure 2. Diagrammatic vertical cross-section illustrating the geological relationships of the rock formations in Michipicoten district.

This statement of the geological succession differs in some essential respects from those of earlier investigators. The differences relate to the oldest of the four groups and mainly to the stratigraphic position in this group of the Dore series. Coleman and Willmott, who, after Logan, did most to explain the stratigraphy of Michipicoten district, place the Dore sediments unconformably above the group of volcanics, iron formation, and minor sedimentary deposits, because pebbles and boulders of materials like these occur in the Dore conglomerate. The writers place the Dore series within, and far down in, this same group because of the structural relations of these sediments to the rest of the group. The earlier writers were inclined also to place all the iron formations at one horizon at or near the top of the volcanic group. Evidence will be advanced in this report to show that iron formations occur at various horizons through a great stratigraphic range in the volcanic group. Again, Coleman and Willmott subdivided the volcanics into a lower, basic portion, which they called the Gros Cap greenstone, and an upper division of acid materials, called the Wawa tuffs. The present writers could not find any such general segregation of acid and basic volcanics. They did find in many cases that the iron formations are overlain by greenstones, usually ellipsoidal, and underlain by acid, prevailing tuffaceous materials; but this arrangement is of local extent only and the basic lavas are above, not below, the acid ones.

I

Coleman and Willmot[1]

Pleistocene: drift

Basic eruptives

Laurentian: granite gneiss

Upper Huronian: Dore conglomerate

Lower Huronian
- Eleanor slate
- Helen iron formation
- Wawa tuffs
- Gros Cap greenstone

II

Collins and Quirke

Pleistocene: drift

Late Precambrian
- Younger diabase
- Older quartz diabase

Early Precambrian: granite gneiss

Early Precambrian
- Post-Dorean volcanics with interstratified iron formations and local sedimentary deposits
- Dore series
- Pre-Dorean volcanics, presumably including iron formations

DORE SERIES

The Dore sedimentary series is the one outstanding member of this early Precambrian complex of volcanics and sediments (Keewatin) which is extensive enough and easily enough identified to be used in subdividing the complex. Its paramount value for this purpose is perhaps sufficiently indicated by the composition of the terms Dore, pre-Dorean, and post-Dorean, which are here applied to the subdivisions of the complex. It seems best, therefore, to begin a description of the formations with the Dore series, even if this procedure be somewhat out of the chronological order commonly used in geological reports.

[1] Ann. Rept., Ont. Bureau of Mines, 1903.

DISTRIBUTION AND STRUCTURE

There are two known bands of Dore sediments in the map-area. One of these, extending along the coast of lake Superior, enters the southwest corner of the map-area, runs northeastward to Mildred lake, and bends sharply westward, in which direction it has been traced across Magpie river and lost. The other band has a less acute V-shaped course along the north side of the map-area.

A few traverses across these bands are sufficient to make their structures clear. A cross-section passing near mile-post 2 on the railway, above Michipicoten Harbour, affords good exposures of the sediments and of the volcanics on either side. All these formations dip from 50 degrees southeast to vertical. Commencing at the southeast, there are fine-grained, basic tuffs. Approaching the Dore sediments these merge, in a distance of 50 feet or so, into a more greywacke-like material which may be regarded as the first of the Dore series. Thence to the railway the greywacke, which has been largely changed to mica schist, alternates with bands of boulder conglomerate. The conglomerate is full of pebbles and boulders of a great variety of volcanic materials, all of which have been greatly flattened by pressure; but it also contains many boulders of grey granite which have successfully resisted deformation (Plates II and III A, B). The pebbles and boulders were counted in two small areas near the railway. One of 14 square feet contained ten unflattened ones of coarse granite, forty-nine of finer granite and porphyry flattened, five of basic volcanic schists, and three of granular quartz. This was a coarse boulder conglomerate. The other exposure, of 12 square feet, showed nine boulders and pebbles of unflattened granite; two hundred and seventy of acid, fine-grained materials more or less flattened, eighteen of basic volcanics, and five of iron formation. The largest granite boulder was 30 inches across. Northwest of the railway for 4,000 feet, there is almost continuous boulder conglomerate, the only interruptions being occasional bands of volcanic materials, some dark, some light in colour. In this distance the boulder content of the conglomerate changes gradually from a diversified assemblage of granite, greenstones, light-coloured volcanics, etc., to one composed almost wholly of granite and a pale grey porphyry which looks like the granite but has flattened under pressure. In the next 4,000 feet the conglomerate becomes more interrupted by pale coloured igneous rocks and some dark ones, until there are only occasional beds of it, less than 100 feet thick, with the acid igneous rock intervening. Also, it loses its distinctly conglomeratic character by degrees, until the northernmost bands are composed solely of irregular, more or less flattened fragments of the pale grey, granite-like porphyry, with a darker micaceous material filling the narrow interstices. Finally, the last of these tuff-like or scree-like beds gives place directly to a continuous body of the same grey granite-like rock, the extent of which is not known, though it extends for several hundred feet along the line of section.

The volcanics on either side of the Dore series are quite unlike, and the sediments themselves exhibit a progressive and unmistakable change in character from one side to the other. There is every reason to believe

that the formations described are not repeated, but are tilted up in a single inclined band, or monocline.

The next question is, which side of this band is the top of the series? The abundant pebbles of grey, granite-like porphyry in the conglomerate presumably came from the formation of the same rock which lies on the northwest side of the Dore series, and, if this be so, the northwest side must be the bottom. The granite boulders, that resist deformation, are also more probably derived from that side than from the formations on the southeast side, for these latter have been well studied and do not include contemporary granite of any kind from which pebbles could have been derived. All the varieties of pebbles in the conglomerate appear to have counterpart formations northwest of the sedimentary belt, with the possible exception of iron formation, which has not yet been found there. The dip of the sediments towards the southeast at angles ranging from 45 degrees to vertical also indicates that the top of the series lies on that side. The secondary schistosity is also at higher angles than the bedding planes —a condition which indicates the Dore belt to be part of a normal fold, dipping southeastward.

Other sections made across the sediments between Dore river and Mildred lake yield similar evidence of the sedimentary band being a single succession dipping southeastward. At Mildred lake the band turns through an acute angle and extends westward to Magpie river at Steephill falls. The sediments in this wing of the great V-shaped band so formed dip northward at 40 or more degrees. The writers have concluded that this V-shaped band of sediments is the outcrop of a sharp anticline which pitches steeply eastward; that the volcanic formations inside the V are older than the sediments, and that those outside the V are younger.

An excellent section obliquely across the northern band of Dore sediments was found along the creek which follows the northern side of township 29, range 26. Next the sedimentary band on the south is a dense black, volcanic rock, probably tuffaceous in composition, for it passes into a dark green, fine-grained sediment by gradations too insensible for any boundary to be fixed. This sediment grows coarser proceeding eastward and eventually stray pebbles and thin conglomerate beds appear in it. Farther on, the conglomerate becomes practically continuous, the pebbles larger, more closely packed together, and granite pebbles predominate almost to the exclusion of all other kinds. Near the lake at mile-post 3, on the south boundary of township 29, range 27, where the rocks become concealed under sand, the conglomerate is made up of round granite pebbles and boulders, from 2 to 8 inches in diameter, closely packed together and held in a matrix of dark mica-schist which plasters tightly around each boulder. The series dips about 75 degrees south and is largely converted into mica-schist. The rest of the series could not be seen at this place. It was found well exposed 1 mile southeast of the lake, where a boulder conglomerate like that last described passes northward by degrees into more tuff-like aggregations of subangular granitic fragments that closely resemble those found towards the northwest side of the

sedimentary belt near Michipicoten Harbour. Beyond these is a granite formation which probably furnished the fragments, though the drift cover does not permit the relationship to be seen.

The senior author interprets this succession as that of a single monoclinal band dipping southward, with its top in this direction and its base towards the north. The evidence is practically of the same nature as that obtained for the southwestern band of sediments. The junior author came independently to the same conclusion after examining the band near Kabenung lake. Eastward, towards Goudreau, the Dore series is invaded from the north by a younger granite, and it is consequently not so easy to study the structure and succession.

These two great bands of sediments—the acute pitching anticline in the southwest and the less acute, southward dipping monocline along the north side of the map-area—are the guiding features of the geological structure of the map-area. If they are correctly interpreted all the minor fold structures to be mentioned later must conform with them.

LITHOLOGICAL CHARACTER

The Dore sediments vary in thickness and composition so greatly from place to place that they must be sectioned at fairly close intervals before any proper conception of them can be obtained.

They are fairly well exposed along Dore river and in the islets off the mouth of this river. The northernmost (lowermost) sedimentary material exposed is a conglomerate, mainly of porphyry and granite pebbles, near where the wood-road from Michipicoten Harbour crosses Dore river. Twelve hundred feet north, the next exposure is granite. A shorter distance downstream is a dark green, stratiform rock which may be sedimentary, but is more likely a fine-grained tuff, or ash rock. This material persists for about 2,000 feet across the strike, ranging in aspect from a stratified ash or greywacke to dense, dark green lava. There follows a drift-covered interval of 1,200 feet, across the strike, and then a distinctly igneous hornblende schist, nearly black and varying from massive to fairly stratiform. This volcanic material is about 800 feet wide. The next 500 feet is drift-covered. Then comes a width of 600 feet of dark, finely stratified material, probably greywacke. A drift-covered interval of 600 feet across the strike separates this from boulder conglomerate, which continues for another 600 feet to the mouth of the river. The conglomerate consists of well-rounded pebbles and small boulders of granite, and many varieties of volcanic rocks.

The islets off the mouth of the river are composed of alternating boulder conglomerate and dark, well stratified greywacke in beds ranging from 1 to 50 feet thick, which stand on edge (Plate IV A). These alternating conglomerate and greywacke beds, except for their metamorphism, resemble greatly the alternating deposits of Pleistocene stream gravels and silt or fine sand which are to be seen in the valleys of the North Thompson and other rivers in British Columbia. There are no volcanics interstratified with the Dore sediments in the islands, though they are cut by a few dykes of granite. These conglomerates and greywackes evidently

are close to the top of the Dore series, for on the mainland not far to the east is greenstone. The contact between this greenstone and the sediments is hidden in a drift-filled gully which extends to Michipicoten Harbour.

The conglomerate occupies possibly ten times as much space as the greywacke. It is crowded with well-rounded pebbles and small boulders of granite, diorite, porphyry, greenstone, and many other volcanic types, and an occasional one of iron formation. Coleman counted the pebbles in a square yard of surface and found thirty-eight of dark green schist, thirteen of granite, eleven of iron formation, eight of spotted grey-green schist, seven of porphyry, three of felsite, and one of conglomerate or breccia. The matrix of the conglomerate, which differs from the interbedded greywacke only in being prevailingly coarser, is dark green, and gritty in texture. On microscopic examination it proves to be altered to a mica-schist consisting of biotite, quartz, and feldspar mainly, with lesser proportions of garnets, pyrite, etc. In a majority of the thin sections of the greywacke examined there are large rounded or phenocryst-like grains of feldspar (plagioclase), and of quartz, around which the micaceous groundmass curves, producing a miniature but distinct "eye" structure. In some cases these grains are still well preserved (Plate IV B), in others they are more or less shattered into fragments and obliterated, but they were found in all the thin sections examined and appear to be characteristic of the greywacke and conglomerate matrix of the Dore series. The feldspar is quite clear and fresh. So conspicuous are these large grains that they were at first thought to be phenocrysts, and some of the greywackes in which they occur were thought to be sheared porphyry or porphyry tuff. If these sand grains are representative of the original greywacke material, as they seem to be, it must have been an almost undecomposed product of disintegration of igneous rocks.

Over sixty years ago these sediments near the mouth of Dore river were examined by Sir William Logan and given the name Dore series. A characteristically minute and exact description of the succession is given in his Geology of Canada,[1] 1863.

The section of the Dore series found at mile 2 on the Algoma Central railway was described a few pages back. It resembles the Dore River section in that from bottom to top there is a progression from a tuff-like, or scree-like type of deposit to normal conglomerate and greywacke, and a corresponding diminution of interbedded volcanics. The relations of the series to the underlying granitic formation and overlying greenstone are exposed in this section.

Not far east of this section a great fault has displaced the Dore sediments 12,000 feet northward. The series was located on the east side of this fault, but was not carefully sectioned. However, a cross-section made 1½ miles west of Black Trout lake bears a close general resemblance to that at mile 2. At this place a finely laminated mica gneiss with a distinct, though compressed, tuff-structure underlies what is mapped as Dore series. The Dore series is regarded as commencing where the mica gneiss first shows fragments and pebbles of pale grey granite or coarse porphyry,

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Geology of Canada, 1863," pages 53-55.

for here as elsewhere no distinct boundary exists. These inclusions are all of the same material. They are 4 inches or less in diameter, somewhat flattened by pressure, and appear to have had only rudely rounded shapes originally. It is difficult to say whether the formation is a conglomerate, of volcanic origin, or of the nature of talus or scree. It does not appear to be more than 50 feet thick. The next rock to the south is fairly well-foliated hornblende gneiss, and for 3,000 feet south the only rocks exposed are alternations of mica-schist, quartz porphyry, and other pale-coloured lavas and occasional recurrences of the conglomeratic type. Beyond this point, near the middle of the series, there is a much larger proportion of conglomerate, interbedded largely with a pale grey arkose or disintegrated porphyry. The inclusions in the conglomerate are rather well rounded, but consist principally of granite and grey porphyry. Near the township line the series includes a slaty phase of the arkose, altered to mica-schist, and the conglomerate interbedded with it carries pebbles of greenstone and other volcanics as well as the prevailing granite and porphyry types. There does not appear to be towards the top (south side) of this section nearly as much distinctly sedimentary greywacke and conglomerate as at Dore river and at mile 2 on the railway. Neither does the conglomerate show the same growing diversity of rock materials in its boulders; granite and grey porphyry pebbles prevail even to the top of the series. The passage from the sediments into the volcanics to the south is largely under swampy ground.

A poorly exposed section was obtained along the portage from Magpie river to Black Trout lake; but this section has some interest, inasmuch as the band of Dore sediments is much narrower than it is towards the west. At the lake is a pale rock, which is either a sheared porphyry or porphyry tuff. This grades into an arkose-like phase of the same material, and this, in turn, into a thin band of the tuff-like conglomerate, characteristic of the lower part of the series. At intervals farther south there are outcrops of arkose-like materials, feldspathic greywacke, and more tuff-like conglomerate. At Magpie river is volcanic green schist representing the overlying volcanic group.

Along the east boundary of township 30, range 24, the Dore series is represented only by a light-coloured porphyry tuff of the same sort as is found elsewhere towards the base of the series. Only in one place, just north of mile-post 4, does it resemble conglomerate. Three thousand feet farther east, however, there is a considerable thickness of conglomerate consisting of boulders from 2 to 8 inches in diameter closely packed together in a schistose, felsitic matrix. The boulders are mainly of light-coloured rock ranging from quite coarse granite to dense porphyry, but a few of greenstone and one of white quartz were also noted. This conglomerate evidently derived a large share of its materials from the same source as the porphyry tuff which lies on the north side of it.

Between this last section and Magpie river a fine-grained, delicately stratified slaty member makes its appearance, increases in thickness, and, by corresponding degrees, takes the place of the conglomerate and porphyry tuff. In this interval the series dips from 65 degrees south to vertical. The slaty member is evidently closely connected in origin with the tuffs, for easy

gradations from one to the other were found. On the north side are pale granitic porphyry and porphyry tuff; on the south the solid rocks are hidden by sand. The field notes made by one of the authors at the small lake just west of Magpie river contain the remark: "It is apparent that the Dore has, from about Black Trout lake eastward, changed from a distinctly conglomeratic series of sediments to a series of stratified volcanics."

From Magpie river to Mildred lake the Dore series is represented solely by the slaty, finely stratified member, except near the sharp bend in the series south of Mildred lake. At that point conglomerate of no great thickness, carrying granite, greenstone, and other pebbles, was found.

The reflexed limb which extends from Mildred lake to Steephill falls on Magpie river also consists wholly of the finely stratified slaty formation. A good section of it may be seen at Steephill falls. On the south or lower side is a volcanic schist of intermediate, chemical composition which passes without abrupt change into the slaty material. The latter dips 40 degrees towards the northeast. It consists mainly of very fine-grained, delicately stratified material of medium dark grey colour. Interbedded with it are layers of coarser, more sandy texture and lighter colour. On the north, or upper, side, these interstratified materials grade, in about 10 feet, into a coarse tuff of the same colour. Although no microscopic examination has been made of the slaty formation, it seems clear from its transitional relations to the overlying tuff that it is simply an extremely fine-grained phase of the same volcanic matter, stratified probably through deposition in water.

The northern band of the Dore series is much more uniform in character than the southwestern band, just described. It is also more highly metamorphosed owing to the close proximity of intrusive granite on the north side. A fairly good cross-section was obtained by the junior author on Kabenung lake, at the west side of the map-area. An alternation of green schists, rhyolite, and rhyolite tuff gives place southward to a poorly bedded greywacke-like formation that graduates into a finely laminated phase of more distinctly sedimentary appearance. This is taken to be the base of the Dore series, though here, as elsewhere in the map-area, the selection of this plane is, within certain limits, a matter of opinion because of the difficulty of making a distinction between pyroclastics and sediments. The greywacke is finely conglomeratic in places and passes southward into a thick boulder conglomerate. There are many exposures of this conglomerate along the eastern shore of lake Kabenung, but unfortunately the rock surface not exposed to the waves is nearly everywhere covered with a thin coating of black vegetable matter. In places favourable for observation, however, the conglomerate shows as a crowded aggregate of pebbles and small boulders in a gritty matrix. The pebbles are mostly small, ranging from a foot in diameter down to the size of peas. They are composed mainly of granite, greenstone, and other volcanics. Streaks of greywacke occur in the conglomerate. The prevailing dip is 80 degrees south. On the south side the conglomerate grades into a volcanic tuff. The conglomerate on Kabenung lake appears to be about 2,000 feet thick.

A better section was found on Desolation lake, just east of the preceding one. Massive greenstone cut by apophyses of the intrusive granite to the north and metamorphosed by them, is succeeded southward by boulder conglomerate. This conglomerate is crowded with boulders flattened to about half their original diameters. It appears to be about 300 feet thick and is followed by a similar thickness of greywackes. Beyond this are 500 or 600 feet of conglomerate, about 300 feet of greywacke, and then nearly 1,000 feet of boulder conglomerate. This gives place to a stratified arkose or fine porphyry tuff, coarser tuffs, and other prevailingly light-coloured volcanics.

The oblique section supplied by the creek that flows along the north line of township 29, range 26, was described in the section dealing with the distribution and structure of the Dore series. It shows a more pronounced change from bottom to top than the preceding sections. It commences as a pale-coloured, tuff-like conglomerate composed wholly of fragments of granitic material, overlying granite though not in visible contact with it. This alternates with felsitic beds, and changes gradually to a boulder conglomerate composed exclusively of crowded, well-worn granite boulders in a mica-schist matrix. In a southward direction, that is, towards the top of the series, the boulders become smaller, less numerous, and more varied in composition, and the matrix correspondingly more abundant and also finer grained until it becomes a fine mica-schist or metamorphosed greywacke. This, in its turn, passes by insensible gradations into a dense, nearly black rock, which is undoubtedly volcanic.

In other places east of this locality there is an alternation of greywacke and conglomerate near the top of the series, comparable with that found near Michipicoten Harbour and Dore river.

East of Magpie river the intrusive granite penetrates southward into the Dore series and in consequence the sediments are very greatly metamorphosed, the pebbles in the conglomerate being flattened to thin ribbons, and the matrix and greywacke members transformed into highly foliated garnetiferous mica-schists. The series dips southward at 60 degrees or more. The section consists from north to south of a well-bedded greywacke-like material intruded by granite and greatly metamorphosed, followed by about 900 feet of conglomerate. South of the conglomerate is a slaty, laminated schist, apparently a metamorphosed tuff, and beyond that other dark-coloured, basic volcanics.

THICKNESS

The Dore series between Dore river and the first great fault to the east is 9,000 feet wide and the dip ranges from 50 degrees south to about vertical. Leaving out of consideration irregularities in the dip, possible faults in the formation, and occasional intrusive dykes, and assuming an average dip of 75 degrees, the thickness of sediments and interbedded volcanics works out at about 8,400 feet. Determined in the same manner at Black Trout lake it is only 3,300 feet thick. At Magpie river the band has shrunk in thickness to about 400 feet and at Steephill falls to about 250 feet.

The northern band is estimated to be about 2,800 feet thick at Kabenung lake; 2,200 at Desolation lake; 1,100 in township 29, range 26; and about 1,000 feet thick east of Magpie river.

RELATIONS TO UNDERLYING AND OVERLYING VOLCANIC COMPLEX

The downward passage through the Dore series in the section from Dore river to Black Trout lake is characterized by a slow and gradational change from conglomerates and greywacke of distinctly sedimentary appearance into material which resembles scree material or coarse and fine volcanic tuffs. These tuffs or doubtful sediments rest upon, and have evidently been derived from, light-coloured granitic and porphyritic rocks. The downward change from undoubted sediments to these angular clastics is so gradual that probably no two geologists would draw the line of separation in the same place.

In the section between Black Trout lake and Magpie river there is likewise an easy upward gradation from undoubted porphyry tuffs into conglomerate or into the finely stratified slaty member of the Dore series. In the remainder of the V-shaped band the passage from the volcanics inside the V to the slaty member composing it is also not sharply marked.

The northern band of sediments shows a similar gradational passage into the volcanics underneath; that is, to the volcanics adjacent on the north side. The immediately underlying volcanics are not everywhere the same. A granite or coarse porphyry occurs in some places and green schist or mica gneiss in others. There is an abundance of hard granite boulders and pebbles in the Dore conglomerate which, unlike the volcanic inclusions, successfully withstood the squeezing to which they have been subjected (Plate III A). The conglomerate along the north side of township 29, range 26, contains little else but granite pebbles. Probably these came from some of the granite which lies just to the north; but it is difficult to prove this supposition, for there is also on the north side of the sedimentary band younger granite, which intrudes the sediments, and no means were found to distinguish younger granite from older. At the point closest to the granite where the Dore series could be found exposed —at an interval of several hundred feet—the Dore series is represented by a conglomerate of rudely-shaped boulders or fragments of granite and granitic porphyry in a matrix of feldspathic mica-schist.

The Dore sediments are much more sharply separated from the prevailingly dark-coloured volcanics which overlie them. A contact is exposed near mile-post 1, on the railway above Michipicoten Harbour. At that point there is a gradual change in 50 feet or less from a distinctly clastic, dark green material, which appears to be part of the sedimentary series, into a green schist which is undoubtedly volcanic and perhaps tuffaceous. At Steephill falls the slaty stratified member representing the Dore series graduates in 10 feet into a coarser and undoubtedly volcanic formation. On the north side of township 29, range 26, a fine, dark green phase of the Dore greywacke merges, in 50 feet or more, into a hard, fine-grained greenstone. Transition from sediments to volcanics takes place in a very much shorter distance than at the base of the series,

yet there is the same absence of any sharply-defined plane of separation such as marks most of the important Precambrian unconformities.

CONDITIONS OF DEPOSITION

The Dore series has the aspect of a land formation rather than one formed in the sea or in a lake. It has no sharply-defined erosional base. It varies enormously in thickness, and within short distances. The conglomerate of which it is largely composed attains a thickness of thousands of feet in some places. The series contains volcanic rocks apparently interstratified with the sediments. There is little assortment of materials, with a dearth of clayey and other fine-grained materials, and no known chemical sediments.

Erosion must have proceeded vigorously, disintegration of the rock formations into blocks and finer fragments greatly outstripping the processes of rock decay, for the Dore series is composed of conglomerates and greywacke in which the original feldspar grains are abundant and fresh (Plate IV B). Products of rock decay, such as shales and limestones, are absent. Early Precambrian sediments are characteristically coarse and poorly weathered, it is true—perhaps through lack of a protective cover of vegetation—but the Dore series is outstanding in these respects even among Precambrian sedimentaries.

Such vigorous erosion is found today only in glaciated territory or in regions of mountainous relief. In the case of the Dore series a continental glacial origin may be dismissed after brief consideration. There are no conglomerates that resemble boulder clay. There is no suggestion of an ice-smoothed basement. The rude tuff-like conglomerates made up of fragments of a single class of material—granite or granitic porphyry—derived from an underlying formation of the same rock, can hardly be glacial. They more nearly resemble the talus accumulations which form at the bases of cliffs and in steep-sided valleys. Towards the top of the series conglomerate and greywacke alternate in a manner which bears distinct resemblance to the interbedded stream gravel, sand, and silt found in the mountain valleys of British Columbia, reference to which has already been made. The extraordinary variation in thickness of the Dore series is also suggestive of land accumulations of sedimentary debris in regions of mountainous relief. A high relief and a steep slope are necessary conditions, in the absence of glaciers, for the transport of the boulders up to 30 inches which occur in the conglomerate. The volcanic formations in the Dore series also predicate volcanoes and the usual rugged topography of volcanic regions. In places, as between Steephill falls and Black Trout lake, the Dore series consists exclusively of volcanic ash and tuffs, probably water-assorted.

A fairly consistent feature of the thick parts of the Dore series is the gradual change from rude, tuff-like or breccia-like conglomerates at the bottom of the series to distinctly sedimentary alternations of greywacke and conglomerates towards the top. The conglomerates near the base consist almost exclusively of a single material—granite or pale-coloured porphyry—evidently derived from a subjacent formation of the

same kind. The upper conglomerates contain a varied assemblage of granite, greenstones, acid volcanics, iron formation, etc., just as evidently derived from a wide extent of country. In further evidence of the distances they must have been carried, these pebbles—at least such as have not been squeezed out of shape—are well-rounded (Plates II and III). It would appear that the Dore series had begun to accumulate by talus or scree formation and other processes of disintegration, with a consequent aggradation of the rugged topography, and that as aggradation progressed and the loose material increased in depth these materials were subjected more and more to transportation by the ordinary agents, streams, rain, and wind. Probably the better stratified parts were deposited in small bodies of water.

The writers are inclined to visualize Michipicoten district at the commencement of Dorean time as a region of rugged relief and waning volcanic activity. During early Dorean time this land surface, devoid of vegetation, was eroded rapidly, some deep-seated granite masses being uncovered to provide the great quantities of granite pebbles and boulders found in the Dore conglomerate. The rude granite and porphyry conglomerate and associated formations in the lower part of the series were formed nearly in place by rock disintegration, with a consequent aggradation or wearing down of summits and filling in of depressions on the surface of the country. As a lower topographic relief was developed stream deposition became more and more effective and a few stream expansions and small lakes may have existed. This normal process of wearing down of a country of rugged relief was at last terminated by renewed and long-continued volcanic activity that resulted in the post-Dorean volcanics.

PRE-DOREAN GROUP

DISTRIBUTION

The pre-Dorean formations are shown on the map as two strips of irregular width lying between the Dore series and the batholithic masses of granite which intrude even the post-Dorean group. Evidence has already been given to show that the two belts of Dore series are monoclinal in structure and represent a single, steeply tilted succession of the series. It has also been shown which side of the tilted series corresponds to the bottom. It follows that the formations adjacent on that side are older than the Dore series, unless they were placed there by intrusion or faulting. No other practicable method is known for identifying and distinguishing the pre-Dorean formations, for the volcanic schists of which they largely consist are not sufficiently different in appearance from the post-Dorean volcanics to be distinguished on lithological grounds. In the absence of a recognizable belt of Dore sediments no differentiation could be made between the older and younger volcanics.

Throughout the southwestern band of Dore series, and for a large part of the northern band the formations adjacent on the under side are in their normal relation to the sediments. The conglomerates near the base of the Dore series are composed of boulders and fragments of rock

materials identical with the underlying granitic porphyry, granite, green schists, etc. The sediments next those underlying igneous formations show no signs of contact metamorphism. The underlying formations are accordingly regarded as older than the sediments. East of Magpie river, however, the northern band of the Dore series is unmistakably intruded and severely metamorphosed by a younger granite mass. The pre-Dorean formations which once underlay the sediments in that part of the district have been destroyed.

A boundary can thus be drawn between the Dore series and the pre-Dorean, wherever the latter remains. The distal boundary of the pre-Dorean is much more difficult to establish. In some places the pre-Dorean rocks next the sedimentary series are greenstones and other volcanic schists. In other places they are granite, or a granite-like porphyry not easily distinguished from granite. In all cases, whether the pre-Dorean formations are volcanic schists or granite, at a distance from the Dore sediments varying from a few hundred feet to several miles they give place to an extensive batholithic body of granite. Now, east of Magpie river, the granite batholith is intrusive in the northern band of the Dore series and it is commonly believed that all the large granite areas in the district are of the same post-Dorean age. It, therefore, becomes necessary to distinguish between the older granite and granite porphyry which lie adjacent to the Dore series and which furnished it with pebbles, and the younger granite which intrudes the Dore series, before any boundary can be drawn between them. The writers have not made any serious effort to do this. They have been content to leave an uncoloured strip on the map, a geological terra incognita, between what they believe to be pre-Dorean schists and granite on one side and what is probably post-Dorean granite on the other side. A longer acquaintance with the two granites might reveal some criterion for telling one from the other, which escaped their casual observations; but anyone familiar with Precambrian batholithic intrusives is likely to regard with misgiving the undertaking of mapping them separately.

DESCRIPTION

The Dore sediments are underlain in large part by a complex series of schistified volcanic flows and tuffs. These occur thinly along the lower edge of both bands of the sediments except within the V-shaped parts of the southwestern band, which they fill. They are green or grey rocks with an imperfect schistosity and are folded to much the same extent as the Dore series. In composition they range from rhyolite to basalt, but the greater part, judging from their dingy grey-green colours, are intermediate between these extremes. Tuffs and ash rocks are common. There is perhaps a larger proportion of light-coloured porphyries and porphyry tuffs than in the post-Dorean volcanics, but the lithological differences between the post-Dorean volcanics and the upper part of the pre-Dorean are not great enough to distinguish one from the other. The lower part of the pre-Dorean is more distinctive, however, consisting principally of highly stratiform dark-coloured mica-schists. Fine exposures were found on Catfish lake, where the mica-schists dip at angles as low as 25 degrees.

Occasional traces were found of angular fragments like those in volcanic tuffs, but with this exception there is little to indicate the nature of these schists.

The pre-Dorean volcanics in the northern part of the map-area consist mainly of green and grey schists. In places they are stratified or even delicately laminated; in other places there are coarser tuffs and flows of fine, pale-coloured porphyry. There should be some banded iron formation associated with the pre-Dorean volcanics, for pebbles of iron formation occur in the Dore conglomerate. None was found, however.

In addition to the volcanic schists, the pre-Dorean group, as it is loosely constituted in this report, includes rock formations of granitic character. Northwest of mile-post 2 on the railway near Michipicoten Harbour the Dore series overlies a pale grey granite or granite porphyry. Close to the contact this rock is somewhat sheared and has some resemblance to a coarse-grained volcanic porphyry, but at a greater distance it assumes a strictly granitic aspect. The rock is almost white on weathered surfaces, quite coarse-grained and consists of feldspar and quartz, with infrequent small flakes of biotite. This granite furnished almost all the boulders and fragments for the lower conglomerate members of the Dore series; hence there is no doubt that it is older than the sedimentary series. How far it continues northward is not known. Although granites extend uninterruptedly in that direction for many miles most of these are presumably the later, post-Dorean intrusives, and no attempt was made to differentiate them from the pre-Dorean granite.

Nearer to Dore lake the Dore conglomerate was found exposed within 200 feet from coarse biotite gneiss. The conglomerate shows no more than its usual regional metamorphism, a condition which suggests the gneiss to be older than the Dore series, for wherever a distinctly intrusive granite is found in contact with the sediments the latter are changed to coarse mica-schists.

Northwest of Black Trout lake, near the fault indicated on the map, the pre-Dorean mica-schist gives place, first to a rather fine-grained, light grey porphyry, and then to coarser and coarser rocks of the same type, until a grey type of distinctly granitic appearance is reached at about 1,500 feet from the lake shore. This granite is apparently pre-Dorean. Immediately across the ravine which coincides with the fault is a bright red granite, easily distinguished from the grey type, which is assumed to be post-Dorean.

There is less direct evidence of pre-Dorean granite in the northern part of the map-area, but the extraordinary abundance of granite boulders and pebbles in the lower part of the Dore conglomerate implies that an older granite must have existed nearby.

Although the present areal delimitation of the older granite and its lithological distinction from the younger, post-Dorean, granite have not yet been accomplished, there seems to be adequate evidence that such an older granite exists. This is a matter of some scientific interest. Heretofore, granitic intrusions of only two widely different ages have been definitely identified in the Precambrian of northeastern Ontario[1]. One of these

[1]*See* Geol. Surv., Can., Map 155A.

intrusions, the Killarney granites of the north shore of lake Huron, has recently been proved to be late Precambrian in age, and intrusive even in the Cobalt series and the supposedly Keweenawan diabases. The other, which is widespread through northeastern Ontario, and known variously as the Laurentian, the Algoman, or simply as the pre-Huronian granite, is older than, and furnishes a basement for, the oldest Huronian sediments, but is intrusive in the Keewatin. Existence of a still older granite has been suspected for a good many years by geologists who found granite pebbles in pre-Huronian conglomerates, but the pre-Dorean granite of Michipicoten district appears to be the first announced in situ representative of this third period of granitic intrusion, that greatly antedates the pre-Huronian, or Algoman. The younger of the two granites in Michipicoten district—that which invades and metamorphoses the Dore series—is evidently the pre-Huronian or Algoman. It occurs more or less continuously all the way to Lake Huron and Sudbury districts where it is known to underlie the Huronian sedimentary series. Moreover, in Michipicoten district, it is intersected by diabase dykes which are regarded as part of the Keweenawan basic intrusions. Between this younger granite and the pre-Dorean granite lies a space of time required for the deposition of thousands of feet of post-Dorean volcanics, the deposition of the Dore sedimentary series, and an interval of erosion of unknown but not inconsiderable duration representing the unconformity beneath the Dore series.

POST-DOREAN VOLCANICS

On one side of the upturned bands of Dore sediments lie the pre-Dorean volcanics and granitic rocks. On the other side is a vast and extraodinarily complex assemblage of post-Dorean volcanics, sediments, and iron formations. The iron formations and a few of the sedimentary formations are mapped separately and will be described at considerable length in these pages; but only casual study was made of the preponderant volcanic group. There were a great many extrusions of lava and the geology of the assemblage was afterwards complicated by severe folding, faulting, and almost every conceivable variety of metamorphic change. Given plenty of time, it is quite possible to work out the succession and structure of these volcanic formations locally, but to do so for the whole map-area would involve many years of work of little utility. In the three seasons of field work the present writer obtained only a general conception of the composition and structure of the group.

COMPOSITION

The group is composed mainly of extrusive formations of fine grain and characteristically dull colouring. The shades of grey and green prevail, and the hills composed of these rocks are a uniform dreary grey-green. Basalts or greenstones are abundant. There is also a large share of pale-coloured porphyries and other acid lavas. In fact there is probably a fairly complete range from one extreme to the other of the lime-alkali series of igneous rocks. Rocks rich in alkaline minerals are not known to be present.

Flows of lava are common and, in several observed cases, are of great extent. There is, for example, a flow of ellipsoidal greenstone at Goudreau, which, even in its folded condition, occupies 5 square miles. It attains the coarseness of grain of ordinary granite in places, and, judging by the topographic relief carved in it, must be many hundreds of feet thick. Apparently, however, the flow rocks are exceeded in volume by pyroclastic formations. These range from coarse tuffs composed of volcanic fragments from 6 inches and more in diameter down to ash rocks too fine-grained for the particles to be distinguished by the unaided eye. There is also much variety in the manner in which these pyroclastics were deposited. A majority are unstratified and composed of angular fragments that appear to have fallen upon a land surface, but others were as evidently deposited in water, and have in varying degrees the aspects of conglomerate, greywacke, and slate. It is, in fact, just the most pronouncedly sedimentary of these waterlaid volcanics which are mapped separately under the designation of local sedimentary deposits. Coleman and Willmott called these sediments the Eleanor slates.

The post-Dorean group probably includes a considerable share of intrusive formations, but these are difficult to distinguish from coarse-grained flows. One of these intrusives, a highly magnesian rock, known as "mica dyke", contains narrow veins of asbestos. This rock intrudes the ore-body of Magpie mine.

A few of the flows, tuffs, and intrusives in this post-Dorean complex deserve individual description.

Ellipsoidal Greenstone

This is probably the most distinctive and widespread flow rock in Michipicoten district. It underlies many square miles of country near Michipicoten Harbour. Another extensive area occurs around Goudreau and it is also abundant near Loonskin lake. The Goudreau flow, which is like the others, but larger, must be hundreds of feet thick, for there are large hills carved in it. It consists largely of massive greenstone from medium to coarse in grain, representing the main flow of lava. At many places the massive lava merges into fine-grained ellipsoidal or pillow lava, which no doubt represents the surface portion of the flow. Associated with both are smaller amounts of highly schistose, fine-grained material which are believed to represent beds of volcanic ash. Massive greenstone, pillow lava, and ash rocks are all dark green and of the composition of basalt.

The ellipsoidal phase is well developed on the north side of the small dumb-bell-shaped pond which lies in mining claim AC 14, a mile west of mile-post 176 on the Algoma Central railway. A fine section is also exposed in a rock-cut at mileage 181. At both these places the lava is composed of rudely globular or ellipsoidal masses of greenstone ranging in diameter from 6 inches to 2 feet. These are packed closely together, their surfaces of contact being flattened or dinged in much the same manner that loaves of dough would be piled together. At mileage 181, where a fresh surface is exposed, the ellipsoids are firmly coherent, and the angular interstices among the ellipsoids are filled with whitish, crystal-

line carbonate; but in the other locality mentioned above, the interstitial filling is dissolved out and the pillows are weathered more or less free from one another. A few small ones were loose or had fallen out.

The rock-cut near mile-post 181 offers an unusually fine chance to examine the ellipsoids in detail, for a good many have been broken open. The interior of each ellipsoid is fine-grained, hard, and quite free of schistosity. Within an inch of the periphery, however, it shows signs of alteration, and this change grows more pronounced from there to the surface. The result is a shell about 1 inch thick, of darker colour, and softer consistency than the core. This shell contains many small scales of black mica, especially in its outer part, arranged so as to produce a slight schistosity concentric to the core. The angular spaces among the pillows are filled with a coarsely crystalline carbonate, through which are scattered tiny six-sided "books" of biotite. The carbonate is probably a mixture of the carbonates of lime and iron, and possibly also of magnesia, for it weathers to a rusty brown colour. There is a remarkably close resemblance between this carbonate and the carbonate or "crystalline limestone" member of the Goudreau iron formation.

A thin section made from the core of an ellipsoid proves it to be a much decomposed basalt. The section consists of 75 or 80 per cent secondary hornblende, 5 per cent magnetite, and the balance of quartz and feldspar. The hornblende is the common secondary variety showing blue-green pleochroism. It forms irregular grains and fibres. The magnetite is in scattered crystals and less regular grains. Quartz forms over 10 per cent of the section. It is in fairly large grains and also part of a fine mosaic, the other component of which is probably feldspar.

A section from the micaceous rim of the same ellipsoid is composed of at least 80 per cent biotite, 5 per cent magnetite, and a little carbonate, the remainder being a clear mineral of low refringence thought to be zoisite. All these constituents except part of the magnetite are in irregular grains, and all are almost certainly secondary minerals. The mineral supposed to be zoisite forms a minute mosaic of irregular grains. Towards the interior of the micaceous rim this material grows more abundant, as if it may have been an intermediate product in the process of change which transformed the original basaltic material into the micaceous rim.

Alteration of the ellipsoids is confined chiefly to the micaceous shell. It is just as pronounced at the bottom of a 25-foot rock-cut as it is near the top. It cannot be ascribed, therefore, to weathering from the surface, especially as the readily soluble carbonate interstitial fillings are also fully preserved. Moreover, the mica which occurs in the shell and in the carbonate fillings is not chlorite, the usual product of weathering, but a brown biotite of primary igneous aspect. There is more reason to regard the alteration as a result of the action of solutions and other exhalations from the lava during its cooling and crystallization. These exhalations not only produced the altered shell enclosing each ellipsoid, but must also have filled the inter-ellipsoidal spaces with carbonate, for the books of brown biotite scattered through the carbonate are optically

identical with the biotite in the shell, and presumably originated in the same way.

It will be shown a few pages later that an enormous amount of secondary carbonates are distributed through the volcanic rocks of the schist complex and the opinion will be advanced that these carbonates probably came from the volcanic rocks themselves. Farther on, the great bodies of siderite in the iron formations will be ascribed a volcanic origin. The ellipsoidal greenstones are interesting in this connexion inasmuch as they afford fairly direct evidence that large quantities of carbonates were given off by the basaltic lavas.

Ottrelite Porphyry

The mineral ottrelite is not very common and, according to the best authorities, is at home only in metamorphic rocks. In Michipicoten district a mineral of the same optical character was found in a comparatively unaltered volcanic rock. This appears to be a new habitat for ottrelite. The rock in which it occurs is of further interest in that it directly underlies one of the principal iron formations. It forms a prominent range of hills south of the Nichols Chemical Company's railway spur at Goudreau, extending from the Algoma Central railway east to Goudreau lake.

In most places the rock is massive and moderately coarse grained, and looks more like an intrusive than a lava flow, but at some places on Goudreau lake there is a coarse tuff phase. It is pale grey, sprinkled rather plentifully with rectangular crystals, up to one-tenth of an inch across, of a black mineral which was taken in the field to be hornblende, but on microscopic examination corresponds to ottrelite. These rectangular, black crystals distinguish the rock from all the other porphyries seen in the district.

The texture is strongly porphyritic. Phenocrysts of ottrelite, feldspar, and quartz, oriented in all directions, are distributed through a much finer groundmass of quartz and feldspar, partly altered to sericite. No second generation of ottrelite was seen in the groundmass. Ottrelite crystals make up from 5 to 15 per cent of the rock. Quartz and feldspar phenocrysts are much less abundant, or absent. In fact, there are all gradations from a quartz porphyry carrying a little ottrelite to an ottrelite syenite porphyry.

The ottrelite is pale bluish green in transmitted ordinary light. Sections normal to the c-axis are irregular; those parallel thereto are rectangular, the basal plane being represented by a straight edge, whereas the prismatic edges are frayed. The largest rectangular sections are 2 by 1 millimetres, with the long side parallel to the basal plane. These sections show polysynthetic twinning lamellæ like plagioclase, which extinguish at angles up to 14 degrees. The pleochroism is: a=green, b=bluish green, c=yellowish green.

The mineral was referred for independent examination to Mr. Eugene Poitevin, chief of the Division of Mineralogy, who reports it to be a species of chloritoid corresponding fairly closely in optical behaviour to ottrelite. It forms platy individuals of monoclinic character elongated normal to the c-axis. There is a good basal cleavage and an imperfect cleavage

normal to the b-axis. The mineral is polysynthetically twinned normal to c. It is optically positive with $a=\alpha$, $b=\beta$, and the angle between c and γ 11 degrees. The refractive index of β is $1{\cdot}708 \pm 0{\cdot}005$ and 2 V is 45-70 degrees. The pleochroism is: α, green; β, light bluish; γ, light greenish yellow. Microchemical tests indicated manganese to be present. Though the percentage of manganese in the mineral is too small to be estimated closely the low index of refraction of β (1·708), in comparison with 1·73 for ottrelite and 1·75 for sismondine, suggests that the mineral is higher in MgO and lower in FeO and MnO than these species.

This mineral was also found in a light-coloured porphyry near the west side of township 28, range 25. It occurs also in streaks in the siderite of the southern of the two iron formations just west of mileage 176, Algoma Central railway. These streaks, which contain over 25 per cent of ottrelite, may be vestiges of an ottrelite-bearing rock which has been replaced by carbonates.

In some of the above-mentioned occurrences it is a little difficult to decide whether the ottrelite is a primary constituent of the volcanic rock, or of secondary origin. The crystals are full of inclusions of the groundmass of the rock, and in cases where the groundmass is schistified the lines of schistosity seem to continue through the ottrelite. This may be illusory, however, and due to some of the groundmass underlying the ottrelite in the thin sections, for on the other hand the ottrelite crystals are oriented in various directions with no regard to the schistosity. In some of the specimens of porphyry examined the ottrelite is in good crystals, fresh, and without inclusions of the groundmass. On the whole there seems excellent ground for believing it to be a primary constituent of the porphyry.

Spherulitic Greenstone

On the southeastern shore of Cross lake, township 30, range 26, there is exposed a rock which, upon casual inspection, would readily pass for conglomerate. As exposed at the water's edge it consists of abundant smooth pebbles and small boulders, from 1 to 8 inches in diameter, embedded in a dark green schist. The matrix, however, is more basic than any ordinary sedimentary material and, on microscopic examination, proves to be a green schist composed largely of actinolite. The boulder-like inclusions when broken proved, in every instance, to be composed entirely of actinolite grown in long blades from the periphery towards the centre. Apparently the rock was originally a basic lava full of great vesicular cavities which became filled with actinolite grown from permeating solutions.

"Mica-Dyke"

The siderite ore-body of Magpie mine is intruded from beneath and bifurcated by a great mass of rock which was subsequently badly sheared and decomposed, with a consequent abundant development of silvery talc. On this account it was called "mica-dyke" by the mine officials, who regarded it with great disfavour. In addition to the main mass various small dykes, from 1 to 4 feet wide, intersect the ore-body. The rock is

highly magnesian and in the large, sheared mass smooth, almond-shaped, or pebble-like masses of carbonate (probably magnesite), as much as a foot long, are found rather frequently.

The same rock was found at various other places in the map-area, usually little schistified but always badly decomposed. A large and extremely coarse-grained body occurs along the west side of Baldry lake. The rock when massive, as it is here, weathers to an exceedingly harsh, sandpapery surface and somewhat rusty colour, by means of which it is easily recognized. A similar mass is exposed along the east side of Kapimchigama lake, and another on the islands in Eleanor lake. This last mass is seamed in places with narrow veins of bright green asbestos.

The rock is everywhere so decomposed that its original composition must largely be inferred from the secondary mineral constituents. Some of the more basic phases contain areas of serpentine, probably secondary after olivine, and a rhombic pyroxene which decomposes to colourless fibres having the optical characteristics of talc. Feldspar is not present in this basic type, but in the rock found on Baldry lake it is in association with mica and forms up to one-third of the rock. The feldspar is usually very much replaced by carbonates.

ALTERATION OF THE VOLCANICS TO CARBONATES

On first consideration of the rocks of the Keewatin schist-complex one is impressed by the degree to which they have been schistified and by the amounts of secondary micas—chlorite, paragonite, sericite, etc.—which have been developed. A less conspicuous feature, but one which is even more widespread and interesting, is the alteration of these rocks to carbonates. The carbonates are disseminated in such a way that they are not readily perceptible in the field, but it is difficult to find a rock in the schist-complex which does not reveal under the microscope at least several per cent of carbonates. About one hundred thin sections of these rocks have been examined. Of these, scarcely any contain less than 2 or 3 per cent of secondary carbonates. The majority carry from 5 to 40 per cent and a few as high as 60 per cent. There even came under observation a number of rocks, composed of carbonate, and 10 per cent or less of quartz, chlorite, and other silicates which, judging from their field relationship, had once been ordinary igneous rocks. A case in point is a siderite mass which is cut through by the railway at Leg lake, on the Michipicoten branch; this body, which is about 90 per cent carbonate, fades in the most gradational manner into greenstone. It will also be shown later in this report that the siderite member of the iron formation is in large part ordinary volcanic rock which was replaced more or less completely by carbonates.

This alteration of the volcanics to carbonates is not a recent change due to weathering by surface agents. It appears, rather, to have affected the whole complex. Diamond-drill samples of rock were obtained from a depth of over 200 feet on the Holdsworth claims, near Hawk Junction, and these samples are carbonated to much the same extent as specimens taken at the surface. Carbonation seems, also, to have taken place in

early Precambrian time, for although all varieties of rocks in the schist-complex are altered, the late Precambrian diabases are slightly or not at all carbonated. The younger diabase, to be referred to later, is free of any trace of secondary carbonates. Even the early Precambrian granite gneiss is not affected.

Besides the carbonate which is finely disseminated through the volcanics occasional large masses are encountered, like that at Leg lake, which consist mainly of carbonates. Most of the iron formations also include a carbonate (siderite) member ranging in thickness from a few feet to over 100 feet. The interstices in the ellipsoidal greenstone formations are filled with carbonates. In addition the schist-complex is traversed in many places by veins of carbonate. Veins of this sort can be seen near the railway at Loonskin lake. It is probably within the truth to say that 10 per cent of the whole volume of the schist-complex consists of carbonates.

This condition has been commented upon by Leith, working on the south side of lake Superior, and by M. E. Wilson and other workers in the Canadian field. These geologists are agreed that carbonation extends to the greatest depths in the schist-complex yet reached by drilling or in mines, and that it took place in Precambrian time. They are of the opinion that it was caused by heated carbonated waters that accompanied the successive volcanic eruptions. With this opinion the present writers agree. They also believe that the iron formations of Michipicoten district were produced in large part at the same time, and by the same replacement action of carbonate-charged waters on the volcanic rocks.

It is not easy by microscopic study to ascertain the composition of the carbonates disseminated through the volcanics. They appear to consist in large part of the carbonate of iron (siderite), for on exposure the tiny areas of carbonate weather to a rusty colour and, in extreme cases, the whole surface of the rock becomes coated with limonite. If the carbonate member of the iron formations be representative of all the secondary carbonates in the schist-complex, the latter must be mixtures of the carbonates of iron, lime, magnesia, and manganese. Analyses of the iron-formation carbonate show these minerals in the proportions of about 66, 13, 15, and 7 per cent respectively. The rock specimens examined with the microscope show that the feldspars are much more changed to carbonate than the dark minerals, and it is noteworthy that the carbonate members of the iron formations are commonly replacements of light-coloured, feldspathic volcanics.

IRON FORMATIONS

The iron formations are the source of all the iron-ore and pyrite deposits in the map-area and have an intimate relation to the genesis and distribution of these deposits. On this account the description of these formations is deferred to Chapter IV.

LOCAL SEDIMENTARY DEPOSITS

Interstratified with the post-Dorean group of volcanic formations is a considerable proportion of clastic sedimentary deposits. A few of the larger and more persistent bands of these sediments are shown on the accompanying geological map, No. 1972, so as to give some indication of the structure of the complex, but a great many other bands were found which are not mapped. Indeed, it was soon ascertained how impracticable and useless it would be to try to map them all. In the first place no precise distinction can be made between what are worthy of being called sediments and what are only more or less stratiform volcanic tuffs. Again, most of the sedimentary bands are mere streaks a few feet or yards wide, which fade imperceptibly on either side into volcanic formations. Like all the other formations comprising the schist-complex they are severely folded and dip nearly vertically. They are seldom traceable lengthwise for any considerable distance, owing to the drift cover. In a few instances where rock exposures were abundant and the sediments were followed for considerable distances—up to half a mile—they were found to thin or to disappear altogether.

These sediments are all somewhat alike, no matter how thick and continuous, or in what part of the map-area they occur. They are entirely clastic and include fine conglomerates and greywacke, either without conspicuous bedding planes, or, in many instances, stratified in regular laminæ a quarter inch or less in thickness.

The best-developed conglomerates were seen at the south end of Eleanor lake (the Eleanor formation of Coleman); east of Mildred lake; and near the small lake lying north of mileage 21 on the branch of the railway between Magpie and Hawk Junctions. At these and all other places observed the conglomerate pebbles are abundant, well rounded, and not over 2 inches and usually less than one inch in diameter. They consist entirely of rock types found in the post-Dorean group and never of granite. The small size of the pebbles and the absence of granite pebbles make it easy to distinguish these conglomerates from the Dore conglomerate, which is a boulder conglomerate carrying granite boulders in excess of any other kind. The conglomerate found east of Mildred lake is in places crowded with smooth, snow-white pebbles of quartz derived from an iron formation. In all these conglomerates the pebbles are held together by a grit or greywacke in which quartz particles are commonly rather abundant. Microscopic examination shows it to be invariably a coarse, quartzose phase of the greywacke which occurs in series with the conglomerate.

The greywacke member is prevailingly a dark grey-green rock. It consists, as seen under the microscope, of characteristically angular, unworn particles of quartz, feldspars, dark minerals, particles of rock, and dust too fine to be identified. The dark minerals are usually badly decayed, but the feldspar grains are fresher. In many cases a great deal of secondary carbonate is present. An average thin section of these greywackes resembles one of fine volcanic tuff both in mineral composition and in texture. The finely stratified greywackes are finer grained than the more massive phase, but otherwise unmistakably of the same derivation.

ORIGIN

The name Eleanor slate, or formation, was given to these sediments by Coleman and Willmott, apparently in the belief that the different bands then known belonged to a single extensive sedimentary horizon in the schist-complex. Although the sequence of formations in this complex is still very imperfectly known, there is little doubt in the minds of the present writers that the sediments occur at many different horizons. Some have been found only a few hundred feet above the Dore series, whereas others occur above iron formations which are certainly some thousands of feet above the Dore.

A few of these sedimentary formations are known to fade out completely along their strike, and all of them vary greatly in thickness in compartively short distances. They are composed altogether of materials like the neighbouring post-Dorean volcanics and iron formation. Some are only a few feet thick and the majority less than 200 feet thick. It is quite likely, therefore, that they are all local deposits laid down in restricted basins.

The laminated greywackes were evidently laid down in water, probably in tranquil standing water. The well-worn pebbles of the conglomerates are prevailingly elliptical in outline and not flattened, and may be the work of streams. Alternating with these sediments all the way up through the post-Dorean group are volcanic tuffs which were certainly not subjected to the same wear and tear as the sediments. To explain these scattered local accumulations, originally of gravel and mud, at intervals among a vast thickness of lava flows and tuffs, one is almost restricted to the idea that the region at the time of their formation was a land area, perhaps of rather rugged character, traversed by streams which transported the sediments and deposited them in small lakes. Such a condition would appear to have persisted throughout the accumulation of the post-Dorean group, and is in continuity with the condition conceived to have existed in Dorean time.

BATHOLITHIC INTRUSIVES

The boundaries of the accompanying map (No. 1972) were drawn so as to include practically all of the schist-complex, which is the mineral-bearing formation, and as little as possible of the granite gneiss, which holds little interest for the prospector, except in the case of small intrusions. Consequently there are only comparatively narrow areas of granite gneiss along the western, northern, and eastern sides of the map-area. These, however, are parts of granitic bodies which extend for great distances away from the map-area under consideration. Their total extent may be learned by references to Map 155 A, of the Geological Survey.

These batholithic masses of granite gneiss are quite like others so liberally distributed throughout northern Ontario and need little description in this report. The eastern contact of the granite gneiss with the older schist-complex is, however, somewhat unusual. As a rule the great batholiths in northern Ontario are coarse-grained right up to their margins and have

developed a broad contact-zone of coarsely crystalline amphibole rocks and other metamorphic products in the Keewatin schists. The unfaulted contact that extends from Hawk Junction towards Michipicoten Harbour does not show such intense metamorphism. The main mass of granite gneiss there is of ordinary coarseness, but the smaller advance masses, which were injected into the Keewatin, range in texture from granite to a dense porphyry difficult to distinguish from acid volcanics that properly belong to the schist-complex. Fine-grained apophyses of this sort were found as far within the schists as Loonskin lake. South of Wawa lake, also, it was found difficult to draw any definite boundary between schist-complex and granite gneiss, owing to the fine grain of the latter next to the schists and the gradual manner in which it grows coarser. Apparently the heating effects of the batholithic intrusive were considerably weaker than usual along this contact.

It is perhaps more than a coincidence that gold-bearing veins have been found at many points along this contact. A comparative study of the gold-bearing veins of northern Ontario, Quebec, and Manitoba has revealed that most if not all of these are connected in origin with granitic intrusions. An opinion is also growing that the veins are associated only with small, rather quickly cooled, intrusions and do not occur along the contacts of the great batholiths, where the contact effects were severe and prolonged, and probably dissipated the mineralizing solutions they may have given off. It is possible, therefore, that the unusually mild contact effects along the granite gneiss contact near Wawa lake afforded favourable conditions for gold ore deposition.

From this economic standpoint the small granitic intrusions within the Keewatin of the map-area are of more interest than the great batholiths. The most interesting of the small intrusives lies in township 28, range 26. It is an oval mass with a decidedly serrated margin, especially at the eastern end. The rock is massive, and very light grey, the only dark mineral observable in it being occasional small flakes of black mica. The interior of the mass is quite coarse grained, but at many places along the margin, especially along the north side, the rock becomes as fine grained as rhyolite. The surrounding Keewatin schists are not much recrystallized. It seems unlikely that the mass was hot enough to digest its way quietly into the older schists; on the contrary the chilled and serrated margin suggests entrance by pushing aside of the schists. If the serrations represent lines of forcible entry and fracturing of the schists their vicinities should have afforded favourable conditions for vein formation and should now be the best ground to prospect. In 1921, since the mass was mapped by the writers' party, a gold-bearing vein was found near the eastern tip of the intrusive, on what are known as the Murphy mining claims (now Goudreau Gold Mines, Limited).

The small granite mass at the fourth fall on Magpie river, also, seems to have been rapidly cooled. It consists in part of an ash-grey rock of fine grain through which are distributed clear six-sided crystals of quartz up to nearly a quarter inch in diameter. Unfortunately this mass is largely buried under stratified sand and only a part of its boundary can be seen.

The mass of granite near Pashoskoota lake, in township 29, range 26, although of small exposed area, does not show signs of rapid cooling. It is a speckled hornblende granodiorite of fairly coarse grain. The other small masses shown in the northern and western part of the map-area are also coarse grained and are probably just protruding parts of an underlying batholithic mass of large size which is continuous with the main granite gneiss areas.

The granite gneiss mass that extends across the northern side of the map-area has developed an extensive border of hornblende gneiss and other crystalline materials in the Keewatin, indicative of severe metamorphic effects.

AGE

All the small bodies of granitic rocks are intrusive in the post-Dorean part of the schist-complex, so also is the greater batholith on the east side of the map-area. There is no doubt, therefore, that they are younger than any part of the Keewatin schist-complex. The batholith on the north and northwest in places intrudes the post-Dorean schists, the Dore series, and the pre-Dorean schists. At such places it also is younger than any part of the Keewatin. In other places, however, the Dore conglomerate rests against a grey granite from which a share of its boulders was obtained. Some of these places—north of Michipicoten Harbour; in the vicinity of Black Trout lake; and probably in the northern part of township 29, range 26—have been described in the section that deals with the Dore series. These granitic rocks are older than the Dore series, but their relation to the pre-Dorean schists was not ascertained.

The granite gneiss in the northern and western parts of the map-area is, therefore, composed partly of rocks younger than the post-Dorean volcanics and partly of rocks older than the Dore series. No attempt was made to differentiate and map separately these two granites, and any attempt to do so will probably encounter formidable difficulties, owing to the similarity of the rocks. It is supposed, however, that the pre-Dorean granite is not extensive and that the main body of granite in the western and northern part of the map-area is younger than the Dorean and post-Dorean divisions of the schist-complex. Consequently the major part is mapped as post-Dorean; but the writers' uncertainty regarding the extent of the older, pre-Dorean granite is also expressed by an uncoloured strip that has been left between them.

LATE PRECAMBRIAN DYKES

All the early Precambrian formations are intersected by two sets of diabase dykes. The older set consists of quartz diabase and ordinary diabase; the younger and more numerous set, of a characteristically fresh diabase which occasionally contains olivine. It is rather important to be able to distinguish between them, for many of the older set coincide with faults that have displaced the older formations, including the iron formations, whereas the younger set are not associated with faults.

The older diabase is a dark green, fairly coarse-grained rock not in all cases easily distinguished from some of the more massive and coarse-

grained greenstones in the schist-complex. Its recognition is aided, however, by the fact that it becomes distinctly finer grained at the dyke edges, which are in knife-sharp contact with the older formations. The dyke rock is also more massive than most of the Keewatin rocks, although it is not free from schistosity. A few of these dykes, particularly one shown on the map in township 30, range 26, were mapped with care, and were found to be quite sinuous. This sinuosity is probably due to small movements since intrusion of the dykes, for they are slightly schistose in places.

Even from inspection of hand specimens it is evident that the older diabase is considerably decomposed, and microscopic study makes this plainer. The rock consisted when fresh of about equal amounts of augite and plagioclase with a small percentage of black iron ore and a few small patches of quartz and feldspar micrographically intergrown. It resembles in composition the supposedly Keweenawan quartz diabase of Cobalt district and the north shore of lake Huron. The augite is now almost wholly changed to hornblende and the plagioclase partly changed to a fine-grained aggregate of epidote and other secondary minerals. The iron-ore grains are partly changed to leucoxene.

Outcropping on the shore of Wawa lake are three wide dykes which, for lack of exact information regarding their age, are represented on Map 1972 by the same geological colour as this older series of diabase dykes. Lithologically, however, they are quite different. They are coarse-grained, black rocks consisting of about 80 per cent common hornblende, 10 per cent quartz, 5 per cent plagioclase, and lesser proportions of black iron ore, pyrite, etc. The hornblende appears to be a primary mineral. These dykes intersect the Keewatin schists and an oval body of quartz porphyry that is mapped as granite. They are cut by quartz veins carrying tourmaline which have been test pitted and are said to contain some free gold.

The younger dykes are easily distinguished from the older ones and from any other rock in the map-area. Although of the same dark green colour as the quartz diabase dykes they are free from any trace of schistosity, and the rock is perfectly fresh. Freshly broken surfaces are bright and exhibit slender, glassy crystals of feldspar. There are also present in all except very narrow dykes occasional white crystals of feldspar from one-quarter to over one inch in diameter. These weather into shallow pits on exposed surfaces and are so conspicuous that they can in some instances be seen from a distance of 100 feet or more. These large crystals are never found in dykes less than 5 feet wide or in the chilled edges of larger dykes, but are numerous in the interiors of the larger dykes. They are, therefore, believed to have developed after the molten magma had filled the dykes.

When examined with the microscope this younger diabase is found to be almost completely fresh. It consists mainly of stout, lath-shaped crystals of glassy labradorite embedded in irregular individuals of augite. The proportion of labradorite to augite is about 5 to 4. Black iron ore is an abundant accessory mineral. A little brown mica is also present. Although the rock is called olivine diabase, olivine is only occasionally present, but it is a regular constituent of the same rock in other parts of northern

Ontario. The large crystals of feldspar are plagioclase grown in concentric zones and varying considerably in composition from zone to zone. The outer part of these crystals is full of small crystals of augite, but the interior is free of such inclusions.

Unlike the older dykes the younger ones are extraordinarily straight. The only younger diabase dyke seen in the map-area which seems to have been bent since its intrusion is exposed along the railway just northwest of Loonskin lake. This dyke is curved and is shattered into blocks from a few feet down to an inch or so in diameter.

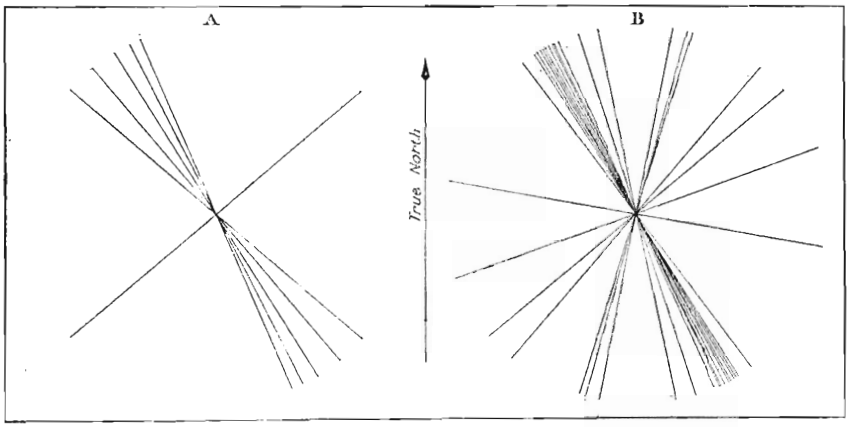

Figure 3. Diagram showing the courses of various older diabase and younger diabase dykes in Michipicoten map-area; plotted through common centres. A=older series; B=younger series.

There are certainly many more dykes of both sets than are shown on the accompanying map, for they were noted only incidentally to the mapping of the older formations. Younger diabase dykes are at least three times as numerous as those of the older group. Both sets strike in about the same direction. An endeavour has been made in Figure 3 to express this (by graphs) by plotting through two common centres the courses of a number of each set of dykes which were mapped with some accuracy. The figure shows that a majority of both sets strike about 30 degrees west of north.

AGE

Both sets of dykes intersect the granite gneiss and all members of the schist-complex. This does not fix their ages at all closely. The younger diabase dykes were not seen to cut across the quartz diabase dykes; but there seems very little doubt that they are the younger of the two series, perhaps much younger. They are perfectly fresh, whereas the quartz diabase dykes are considerably decomposed. They are straight and unsheared, whereas the quartz diabase dykes are bent and slightly sheared.

Evidence from outside the map-area indicates both sets to be late Precambrian. The older set is lithologically similar to the quartz diabase found on the north shore of lake Huron; at Cobalt; and at many other places in Lake Superior region. At these other points it intrudes the Huronian sediments and is correlated with the Keweenawan diabase of Michigan. Olivine diabase dykes remarkably like the younger series found at Michipicoten are also widespread through northeastern Ontario and are also very uniform in composition and freshness throughout this region. Along the north shore of lake Huron they intrude the quartz diabase and also the Killarney granite, the youngest of all the Precambrian formations. They apparently do not intersect the Palæozoic (Ordovician). Hence it is likely that the younger diabase dykes of Michipicoten district, like those in the Lake Huron district, were intruded at about the end of Precambrian time.

PRECAMBRIAN FAULTS

The whole Keewatin schist-complex is folded severely and in a manner too complex to be worked out in detail. The Dore sediments and the iron formations, however, give some indication of what has taken place. They are found dipping at angles seldom less than 45 degrees and usually close to the vertical. Their surface outcrops as shown on the map indicate the existence in the map-area of two major pitching folds, complicated by a great many minor folds of diminishing orders of magnitude. One of the major folds, a syncline, occupies the southern part of the map-area and pitches towards the northeast. The other, also a syncline, occupies the northern part of the map-area and pitches southeastward. These structures are partly eaten into and destroyed by the batholiths of granite gneiss. The whole complicated structure and the batholithic intrusions are believed to be the results of a process of early Precambrian mountain-building.

Long after this mountain-building operation, the map-area was slashed into parallel strips by an extraordinary series of faults. All these faults that were discovered are shown on the map. They all strike north or northwestward. As pointed out by Coleman, they are without exception left-hand faults, that is, an observer looking across the fault sees the opposite side displaced towards his left hand. In many cases the fault-plane is occupied by a dyke of the older (quartz diabase) type. The apparent horizontal displacement is usually extraordinarily large, amounting in one case to 12,000 feet.

The nature of these faults was studied with the best results in the case of this 12,000-foot fault, which crosses the Michipicoten branch of the railway near mile 3. The fault is expressed topographically as a straight and rather steep-sided valley which runs northwestward at right angles to all the other ridges and valleys in the locality, these latter coinciding with the strike of the tilted rock formations. The bottom of the fault valley is 200 to 800 feet wide and is largely floored with stratified silt and sand. The walls are rocky and rather steep. One part of the southwestern wall is a smooth and vertical face of granite about 50 feet high

and continuous in a perfectly straight line for over 200 yards. The amount of horizontal displacement was best determined by means of a small iron formation, one part of which occurs near the railway and the other about 12,000 feet northwestward up the fault valley. This iron formation originally lay parallel to the Dore series and extended in a direction about northeast. Now the two faulted ends are sharply curved around in the direction of the fault-plane, indicating that faulting must have taken place under compression, and that a real as well as an apparent horizontal displacement occurred.

In most cases these faults were not traced very far. The longest distance was in the case of the fault which follows McVeigh creek. It displaces the Dreany iron range a short distance beyond the northern edge of the map-area and is easily traceable south to Hawk Junction. It displaces the Goudreau pyrite range southward over 6,000 feet, and farther south the granite contact, which runs northeasterly, is displaced southward about 2 miles. Beyond Hawk Junction its existence cannot be proved because there is only granite gneiss on either side, and the depression which it probably follows is filled with sand. There can be little doubt, however, that a fault which runs so straight and has such an enormous displacement where last measurable must continue for a great distance southward. The remarkably straight, narrow, and deep canyon of Agawa river, through which the Algoma Central railway also runs, is in almost perfect alignment with this fault, and a valley can be traced all the way south to it from Hawk Junction. If this depression represents an extension of the McVeigh Creek fault the fault must have a minimum length of 75 miles. It is likely that the other faults are proportionately long compared with their horizontal displacements.

Most of these faults are represented at the surface by sharp ravines, all the more challenging of attention because they run at right angles to the valleys eroded along the strike of the folded rock formations. In cases where they are occupied by diabase dykes of the older set the dykes appear to have been more resistant to erosion and the depression is absent or faint. The association of these dykes with the faults probably means that faulting took place at, or not very long before, intrusion of the diabase. The faulting may, therefore, have been a manifestation of the earth movements in Keweenawan time which, 150 miles to the south, culminated in the building of the Killarnean mountains.

CORRELATION

In northeastern Ontario and in the Lake Superior region generally the Huronian sedimentary formations, especially the Bruce and Cobalt series, are the most reliable means of correlation within the Precambrian[1]. None of the Huronian sedimentary formations occurs in Michipicoten map-area. In their absence the best basis for classification of the formations present is furnished by the group of volcanics and sediments known as the Keewatin. The Keewatin is found through the Lake Superior region and is easily distinguished from all other Precambrian subdivisions by the exceptional

[1] *See* Geol. Surv., Can., Map 155A.

thickness and variety of the volcanic rocks of which it is chiefly composed. Both in northeastern Ontario and south of lake Superior it forms part of an ancient basement upon which the Huronian formations were deposited. No volcanic group comparable with it in magnitude has been found within or above the Huronian. The Keewatin is, therefore, distinctively pre-Huronian in age and one of the oldest of known Precambrian subdivisions.

There is little doubt that the thick group of volcanics and sediments in Michipicoten map-area corresponds to the Keewatin elsewhere in the Lake Superior region, and it may accordingly be accepted as pre-Huronian or early Precambrian.

In this area it can be subdivided into three parts: Dore sedimentary series, a post-Dorean volcanic group overlying the Dore, and a pre-Dorean volcanic group underlying the Dore. All three divisions are pre-Huronian.

It is possible that the pre-Dorean division is much older than the Dore series. This division has been found, just beneath the Dore series, to consist in part of schistified volcanics and in part of granitic rocks, both of which have yielded large quantities of boulders to the Dore conglomerate. Possibly the granitic part represents batholithic masses of granite which were intruded into an ancient crust of pre-Dorean schists, and it may also connote a process of mountain-building in pre-Dorean time, like all later batholithic invasions. If so, there must have been a great amount of erosion before Dorean time to have laid bare these granite batholiths, which would presumably be deep-seated intrusions. In such case the unconformity between pre-Dorean and Dore series would represent a great interval of time and would separate the pre-Dorean division widely in geological time from the Dorean and post-Dorean divisions. Possibly this is the case, but the evidence collected to date is much too scanty to serve as a foundation for so important a conclusion. Very little is yet known about the extent of the pre-Dorean granite, its manner of intrusion, or its relation to the pre-Dorean volcanic schists. Moreover, although the Dore series is of imposing thickness in most places, there are other places, such as in township 29, range 24, where it shrinks to a formation not larger than, or essentially different in appearance from, some of the local sedimentary deposits which occur throughout the post-Dorean division. Local sedimentary formations, in some cases several hundred feet thick, but in all cases representing brief and circumscribed episodes of sedimentation, have been found interbedded with the Keewatin volcanics at many places in northeastern Ontario. The Dore series may be just an exceptionally large deposit of the same sort.

Though part of the granite gneiss in Michipicoten district is pre-Dorean, probably much the greater part is intrusive in the post-Dorean volcanics, and hence younger than these. In northeastern Ontario two periods of granite intrusion later than the Keewatin are known. One, of great extent, called the Algoman or pre-Huronian granite gneiss, was intruded before Huronian time and constitutes part of the basement upon which the Huronian (Bruce series) sediments were laid. The other, known as the Killarnean, is intrusive in even the youngest Huronian sediments. The Killarnean granites appear to be confined to a region of Huronian mountain-building which, so far as can be ascertained, did not extend far

north of lake Huron and not so far as Michipicoten district. The Algoman granite gneisses, on the other hand, are widespread in northeastern Ontario. Hence, the granite gneiss of Michipicoten map-area that invades the post-Dorean volcanics is much more likely to be Algoman, or pre-Huronian, than Killarnean.

The two series of diabase dykes which intersect the Keewatin and the granite gneiss are believed to be late Precambrian. Both series escaped the extreme mountain-building deformation that affected the Keewatin. The older series is similar in composition to the quartz diabase intrusions of Cobalt district, the north shore of lake Huron, and the Lake Superior region generally, which are usually regarded as Keweenawan. The younger set, in their remarkable freshness and other peculiarities of composition, closely resemble similar dyke rocks scattered throughout northeastern Ontario which intersect all the Precambrian formations, even the Killarney granite, though they are not known to cut any of the Palæozoic strata.

Both series of dykes cut the post-Dorean granite gneiss, a circumstance that supports the opinion that the granite gneiss is pre-Huronian rather than Killarnean.

PLEISTOCENE

The mantle of sand and other loose material which lies upon the Precambrian solid rocks consists of two well-defined parts. Below an elevation of about 1,085 feet above sea is a thick deposit of stratified sand, silt, clay, and fine gravel that was laid down in an ancestor of lake Superior which stood as much as 485 feet higher than the present lake. Above 1,085 feet is a much thinner cover of till, gravel, and sand deposited by the Pleistocene ice-sheet and by streams flowing from the ice-sheet. The lake deposits occur near lake Superior and in tongues that extend up the valleys of Magpie and Michipicoten rivers for the full length of the map-area. The glacial deposits are found farther inland, at higher levels.

GLACIAL LAKE DEPOSITS

The following measurements and descriptions of the terraces at Michipicoten are submitted as a small contribution to the data needed to elucidate further the history of the Great Lakes. It is known that from Glacial time onward the Great Lakes have stood at successively diminishing levels, have diminished in area, changed in shape, and had various outlets, depending primarily upon the manner of retreat of the ice-sheet and upon a slow northwestward tilt of the region. The traces of subsidence left in the form of terraces around the Great Lakes are numerous and fragmentary, and the rate and amount of tilting of the earth's surface are small quantities. It is clear that these quantities cannot be determined until many exact measurements have been made at various places of the positions and elevations of the terraces. The authors of this report are not immediately concerned with the history of the Great Lakes. Their object is simply to make available to more devoted investigators of the problem a quantity of data which it was possible to secure at little expense in the course of other field studies.

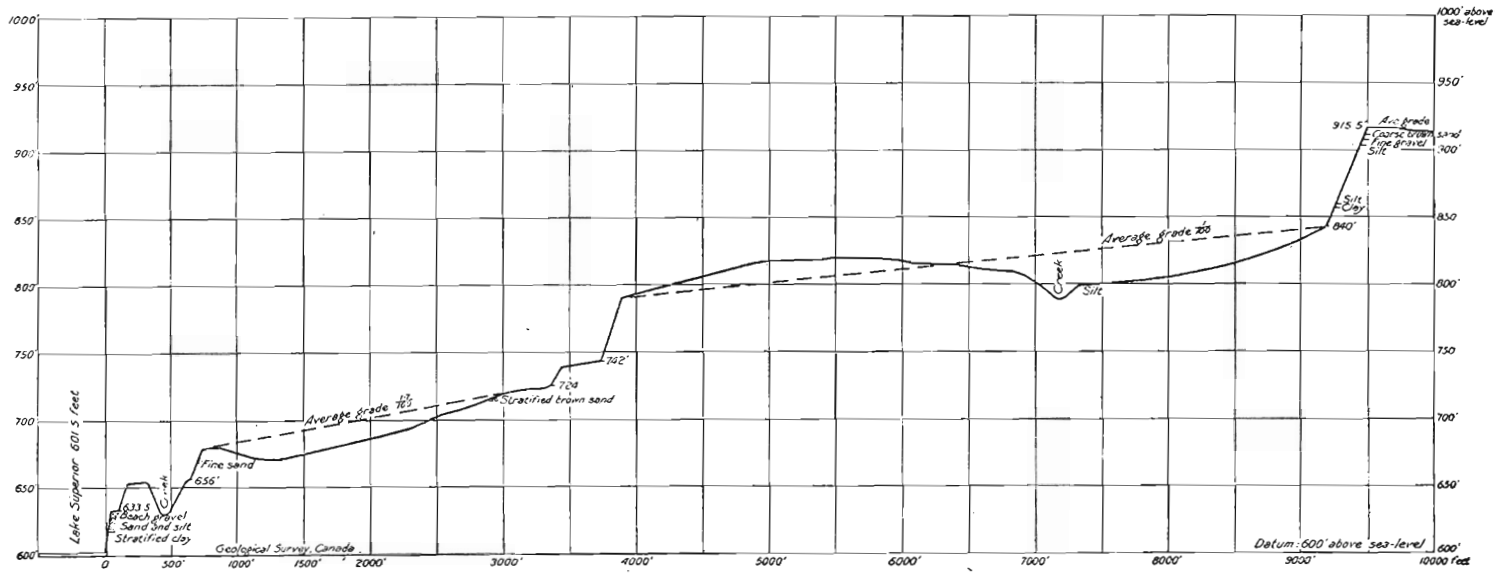

Figure 4. Profile of surface of terraced Pleistocene lake-beds as measured along wagon road between The Mission and Wawa lake. Vertical scale ten times horizontal scale.

The lake deposits challenge an observer's interest more strongly than the glacial deposits. The relationships of the two can also be studied with most ease by commencing with the lake beds, although they were formed more recently than the glacial deposits and entirely from them.

Magpie and Michipicoten rivers both occupy broad and deep valleys in the solid rock surface, which converge and unite at lake Superior. If lake Superior were raised 400 feet Michipicoten bay would reach inland with undiminished width for over 5 miles up this depression, and long arms would extend for miles farther up the valleys of the Magpie and Michipicoten, besides which other more irregular arms would be created along Firesand creek, and Wawa lake. Apparently this did occur in late Pleistocene time, and into the sheltered bay so formed the two rivers dumped enough sediment to fill it, or to change it from a deep rock-bottomed bay to a shallow sandy one. While this was taking place, as it is yet, lake Superior lowered in intermittent stages, and while doing so excavated the sediments into artificial-looking terraces, and carried the excavated material lakeward with its receding shoreline. The two rivers have aided in the work of excavating and shifting the sediments lakeward by digging deep and tortuous trenches through them and dumping the excavated material farther out in the lake.

Recently the forests that clothed and protected these abandoned bay deposits were burned clean, and now the whole series of terraced deposits lie in plain view unchanged since the lake withdrew, except for the destruction worked by the rivers and some slight wear of the ancient shore-cliffs under the action of gravity. The late Pleistocene lake deposits are probably better preserved and exposed in this predecessor of Michipicoten bay than anywhere else along the north shore of lake Superior (*See* Map 1972, in pocket).

Elevations of Terraces. The Algoma Central railway traverses the lake beds from Michipicoten Harbour for 15 miles and affords an excellent base for measuring the elevations of the terraces. At intervals of about 3 miles along the railway the Geodetic Survey of Canada has established precise level bench-marks, and the Hydrographic Survey has a level gauge on the dock at Michipicoten Harbour. During 1920 the senior author ran various series of levels over the terraces, starting from one or another of these bench-marks and employing an Abney hand-level mounted on a jacob-staff. The results obtained from the longest of these traverses, from The Mission along the wagon road to Wawa lake, are represented in Figure 4, and the remainder are given below.

The common channel of Michipicoten and Magpie rivers from The Mission to lake Superior is principally shallow and sandy, with banks rising about 4 feet to a small flat terrace. Commencing at the river's edge at The Mission, however, the bank rises sharply to the level of the first considerable terrace, on which the Indian village, called The Mission, is built. The essential profile features of this and succeeding terraces are shown in Figure 4 and on the table, page 45.

Although the terrace on which The Mission stands is designated as No. 1 in the table, because there is a single, steep, and recently cut bank

from it to the river nearby, there are really two, if not more, lower gravel beaches to be seen on the road which leads from The Mission across Magpie river to the shore of lake Superior. These lower beaches were not measured, but probably correspond to beaches at 612 and 623 feet elevation which Coleman[1] measured at Brûlé harbour.

Number of terrace	Height of shore-cliff in front	Height from base of shore-cliff in front to base of shore-cliff in rear	Extreme elevation above sea-level of base of shore-cliff in rear	Character and gradient of terrace along section line
	Feet	Feet	Feet	
1	30·7	32	633·5	Very narrow
2	18·7	22·5	656	Narrow, trenched by stream
3	22	68	724	Wide and uneven; average gradient 1·7 per cent
4	14	18	742	Narrow
5	45·8	98	840	Wide and uniform; average gradient 1 per cent
6	75·5	About 160	About 1,000	Very wide and uniform; average gradient to Wawa lake 0·3 per cent
7	?	?	About 1,085	Wide and uniform; average gradient along railway 0·2 per cent

Terrace No. 6, which may appropriately be called the Wawa terrace, and is the largest and highest of all, was traced from the shore-cliff fronting it on the wagon road to Wawa station. In this distance it is very uniform. Between Wawa station and Wawa lake it stands at an average elevation of about 963 feet (965·8 feet at the Geological Survey bench-mark at Wawa lake). North of Wawa station along the railway it rises in two slight terraces and fades out against the rising rocky country at about 1,000 feet above sea-level. To find the relationship of this terrace to the next above, it would be necessary to trace it up the valley of the Magpie from the railway bridge near mile 7. This was not done, for this stretch of country is forested and observation of topographic details is not easy. Consequently the nodal boundary between these two terraces was not located.

The seventh topmost terrace was followed from mile 13 on the railway northward to near mile 15 where it terminates either against rocky hills, or in one place west of mile-post 15, against a wave- or stream-cut bank 38 feet high, composed of bouldery material which appears to be a glacial morainic deposit rather than lacustrine. It is difficult to determine just where one type of deposit ends and the other begins, but the change takes place at an elevation within a few feet of 1,085 feet above sea, which appears in the Michipicoten map-area to have been the highest level attained by Lake Algonquin.

The level plain of stratified sand at Hawk Junction stands about 1,040 feet above sea and is evidently part of the uppermost terrace. There is

[1] *See* "Glacial and post-Glacial Lakes in Ontario," University of Toronto Studies, No. 21, page 25.

also an extensive plain of stratified sand along Magpie river, in township 28, range 26, which is probably an extension of this terrace. The sand-plain there stands about 1,030 feet above sea along the river and gives place away from the river at higher elevation to rolling hills of drift.

Coleman, who also measured the terraces north of The Mission, believes the terraces below 656 feet to have been formed during the Nipissing stage of the Great Lakes, and the higher terraces to belong to the older Lake Algonquin.

A comparison was attempted between the terraces north of The Mission and those which occupy the much narrower valley that the railway follows down to Michipicoten Harbour, but without much satisfaction. The terraces in this valley have been greatly dissected by stream action, and although various terraces are visible it is not easy to find and measure the original bases of the shore-cliffs. One such change in slope was located at 959 feet above sea, near bench-mark 697 of the Geodetic Survey. This old shore-line is not at the same elevation as any of those near The Mission. However, it is part of a shore-cliff which at 974 feet above sea flattens out into the Wawa terrace.

Composition of the Lake Beds. The present shore of lake Superior between Michipicoten Harbour and The Mission, where not of bare rock, has a beach and shelving bottom of sand, fine gravel, or shingle. The first river-cut cliff of 30·7 feet at The Mission consists upward of about 16 feet of finely stratified clay, 10 feet of silty sand, and 4 feet of beach gravel, all horizontally stratified. No fresh sections are visible in the second or third shore-cliffs except at one place near the top of the third, where a few feet of stratified brown sand can be seen. Elsewhere the surface is composed of loose, silty sand, apparently free from pebbles or boulders. The fourth and fifth cliffs are very similar. On the fifth terrace, however, just beyond the creek shown in Figure 4, a pit has been dug at the road-side exposing a section of 4 feet. This consists altogether of silt and silty sand, showing a peculiar type of ripple-mark (Plate VI A). The ripples are about 4 inches from crest to crest and are placed exactly one above another in successive strata.

The sixth shore-cliff shows a few feet of clay overlain by silt at 860 feet, and at the top between 900 and 915 feet is 6 feet of silt, overlain by 4 feet of fine gravel and by sand and gravel in alternating layers 4 to 30 inches thick, to the crest. Elsewhere the prevailing material is loose, yellowish brown, silty sand without intermingled pebbles.

The writers were informed that the piles that support the ore-dock in Michipicoten Harbour were driven in clay, and clay occurs at various places near the lake, within 10 or 15 feet of water-level. At elevations between 750 and 950 feet above sea (150 to 350 above the lake) along the railway there are several fine fresh sections of cream-coloured silt of flour-fine consistency. Near the top of the Wawa terrace (974 feet) is some reddish-brown sand fairly solidly cemented by iron oxide.

At one place on Magpie river about three-fourths of a mile west of mile-post 13 on the railway a recent slide in the steep river-bank exposed a fairly continuous section from the water's edge at about 920 feet above sea, to the level top of the same plain at about 1,060 feet. The section is as follows, elevations referring to sea-level:

	Feet above sea
Obscured by slide material	920— 940
Very fine stratified sand, free from pebbles and showing ripple-marks of large amplitude arranged exactly one above another in the successive layers (Plate VI A)	940— 950
Similar, but with a slight admixture of clay	950— 965
Obscured	965— 985
Sand, slightly coarser than any lower in the section	985— 990
Similar sandy material, with wide ripple-marks, not arranged exactly above one another as below, but irregularly, some of the parting planes crusted with iron oxide	990— 995
Similar, but with some interbedded clay	995—1,005
Fine sand, with occasional stiff clay partings	1,005—1,015
Fine, ripple-marked sand	1,015—1,030
Obscured	1,030—1,050
Well-rounded pebbles and boulders up to 5 inches in diameter, crowded together, with interstices filled with silty sand and small pebbles. (To top of sand-plain, seventh or topmost terrace)	1,050—1,060

From the lake up to the top of the sixth terrace at Wawa, with the exception of the modern beaches at lake-level, the prevailing materials are sand and silt apparently quite free from intermingled pebbles and boulders. The first considerable amount of gravel seen is at an elevation of about 980 feet, a quarter mile north of Wawa station. There the Wawa plain rises in two low terraces (beaches?) composed of gravel up to 2 inches in size.

The seventh terrace, extending from mile 13 northward to near mile 15, is covered with boulders, apparently to a considerable thickness. In the river bank section just described the boulder bed is at least 10 feet thick. At mile 13 these boulders are not over 6 inches in diameter. Northward they gradually increase in size until at mileage 14⅔ they reach 3 feet in diameter and are crowded together, with a mixture of fine gravel and sandy material filling the interstices. The surface of this bouldery plain is quite even.

The occasional fresh sections thus seen at various parts of the terraced area indicate a general lakeward and downward change from boulders to sand, silt, and clay. Apparently the bulk of the lake beds was deposited when the lake stood at about its maximum height, for only traces of clay were found anywhere above 620 feet. No doubt additional material was added as the lake sank, but the principal work during subsidence was an excavation of the material already deposited into terraces, and transport farther lakeward of the excavated materials. The terraces are thus mainly cut terraces rather than built terraces.

There is a strong gravel beach along the present lake shore, and another on the terrace at The Mission (No. 1 of table, page 45), but no others of any of the higher shore-cliffs were seen, although they were looked for. It seems very likely that beaches do exist on these higher terraces, but have perhaps been covered up by the downward creep of sand and silt from the shore-cliffs above. If gravel beaches do exist at the base of each of the higher shore-cliffs, concealed under several feet of sand and silt that have crept down, it will mean that the elevations given for the bases of the cliffs in the table, page 45, as representing the elevations of the former shore-lines, are too great in each case by the thickness of this cover of sand and silt. In no case, however, is this cover likely to be more than 5 feet (*See* Figure 4).

It is somewhat puzzling to understand where the beach gravel at lake Superior came from. No pebbles of considerable size were found in the higher terraces until the upper part of the sixth shore-cliff was reached, at an elevation of 980 feet, and 6 miles in a direct line from lake Superior. It would seem necessary to assume that occasional stones are scattered through the deposits of sand and silt and that these have been carried lakeward and have accumulated in the beaches.

The heavy coat of boulders on the surface of the seventh terrace is taken to imply proximity to an ancient shore, and the upper limit of submergence. These boulders probably were carried there by ice as well as water and were concentrated into a bed by the extraction and renewal from among them of the finer sand and silt by the receding lake water. The junction of this highest terrace with the still higher glacial deposits is not well defined, nor marked by any beach where seen by the senior author.

Hawk lake, Wawa lake, and the line of smaller ponds between are rather remarkable features. Hawk lake and the small ones lie in a plain of stratified sand and silt about 1,040 feet in elevation. Wawa lake lies in the Wawa plain, which at the western end of the lake is 965 feet in elevation. A narrow, rocky ravine separates Wawa lake from the others. The small lakes between it and Hawk lake are without outlets, and at least one of them is paved with rounded boulders of large size. There seems to be a channel-like depression in the sand-plain, leading from one to another, as if they were once part of a river bed.

GLACIAL DEPOSITS

Above the glacial lake beds, that is, above an elevation of about 1,085 feet, the solid rocks are very unevenly covered by a sheet of glacial material. A large share of the Precambrian bedrock is bare or very thinly and discontinuously covered by till composed of boulders embedded in rather sandy, light-coloured soil. No true boulder clay was seen in the map-area. At a few places, notably in the northwestern part of townships 27 and 28, range 26, this till is much thicker and forms rolling hills having somewhat the topographic aspect of a terminal moraine. Similar gravelly hills occur just north of Hawk Junction.

Other parts of the high-level deposits have been partly assorted by water action, perhaps of glacial streams and lakes. At Goudreau, 1,220 feet above sea, is a plain of stratified sand and gravel which is probably a glacial outwash deposit. The sand-plain contains a few, small, kettle-shaped ponds without outlets, and immediately to the north is a series of rough hills of bouldery material that was taken to be a terminal moraine. The plain at Goudreau continues down the valley of McVeigh creek for over a mile at about the same level. Sections along the railway consist largely of well-smoothed boulders from 8 inches in diameter downwards. This material is roughly stratified.

Although this deposit is stratified and its surface is notably level it is not believed to belong to the post-Glacial lake deposits. It is nearly 150 feet higher than the highest terraced lake deposits near lake Superior, and much undoubtedly morainic material occurs at lower levels.

Similar coarse gravel deposits occur along the Magpie mine branch of the railway at high levels. There is one ridge of gravelly drift near the Magpie River crossing at mile 6, the base of which is only about 1,000 feet above sea-level. It was probably submerged when Lake Algonquin stood highest, but, being in a narrow arm, withstood erosion.

CHAPTER IV

ECONOMIC GEOLOGY

IRON FORMATIONS

The iron and sulphur ore deposits, which are the chief mineral asset of Michipicoten district, are closely related to the iron formations. The iron formations are, in fact, the source of all these deposits, and on that account they are described here with the ore deposits instead of in the chapter on general geology.

It is perhaps prudent at the outset to avoid confusion on the part of the reader by stating that the following pages will deal solely with a type of iron formation peculiar to the Keewatin and almost entirely with the representatives of this type which occur in Michipicoten district. Such a restriction is required because the term "iron formation" has been applied in the Lake Superior region with equal propriety to a variety of lean, extensive accumulations of iron minerals which occur at various horizons within the Precambrian and which are not identical in lithological characters or modes of origin. Many of these, such as the Mesabi and Gogebic ranges in the United States, the Animikie range near Port Arthur, the Savant range in western Ontario, and some of those east of lake Nipigon, are sedimentary deposits, the iron minerals being immediately associated with argillitic or arenaceous material and the iron formation being in series with conglomerate, greywacke, or quartzite. The iron formations of Michipicoten district, to which attention is restricted in the following pages, should not be confused with these sedimentary iron formations. The Michipicoten iron formations are probably analogous to the Vermilion iron formation of Minnesota, the Timagami, Woman River, Moose Mountain, and many other ranges that occur within the Keewatin of Lake Superior region.

The Keewatin iron formations, as they are commonly called in Ontario, or the Helen formation as they were more locally named in Michipicoten district by Coleman and Willmott, have long been, and in a large measure are still, a puzzle to geologists. They seem to have no equivalent among modern rock formations, and no present-day counterpart of the process by which they were formed has been recognized. They are regularly and conspicuously stratified and were consequently once thought to be sedimentary formations of the same general nature as quartzite. More prolonged study, particularly with the help of the microscope, has compelled an abandonment of this opinion in favour of an origin by chemical precipitation. Van Hise and Leith, studying similar formations in Minnesota and Wisconsin, concluded that the Keewatin iron formations and even some of the later sedimentary ones (Mesabi) originated from volcanic waters, and in the case of the Mesabi much was

done by these geologists to reveal the particular conditions of formation. Coleman also concluded as early as 1901 that the Michipicoten iron formations were closely related in origin to the lavas with which they are interstratified. "At intervals the volcanic activity would naturally diminish, and during such periods chemical sediments were precipitated from the waters, which seem to have been heavily charged with carbonates of lime and iron and also with silica."

The stratigraphic relations and structure of the Keewatin iron formations have been as enigmatic as their manner of origin. The iron formations of Michipicoten district, as elsewhere, are almost all nearly on edge and are seldom traceable for more than a mile or two. They lack the criteria to be found in most sedimentary formations for distinguishing between top and bottom of the strata and there is little help to be had from the volcanic formations that invariably occur on each side. On such scanty evidence as could be found, the earlier investigators in Michipicoten district concluded that these steeply inclined formations, or "ranges," were closely compressed synclinal folds. Since no other formations were ever found in the hearts of these supposed folds it was further concluded that the iron formations all lay at the top of the schist-complex (Keewatin) and represented a single geological horizon. Such, however, is not the case.

The present writers were fortunate in studying the iron formations after several of the more valuable ranges had been diamond-drilled and otherwise explored in search of ore, and when important evidence which had not been available to earlier investigators had thus been laid bare. Through this new evidence was discovered a means of distinguishing top from bottom in most of the iron formations. This discovery proved to be the key that enabled it to be shown that the steeply tilted iron ranges are not tight synclinal folds, but in nearly all instances simple monoclinal structures. It became further evident that instead of a single iron formation horizon at the top of the schist-complex, there are many iron formations interstratified with the volcanic formations at various horizons throughout thousands of feet in the schist-complex. Finally, evidence was obtained that leads to a more precise conception of the origin of the Keewatin iron formation.

STRATIGRAPHY

Nearly all the iron formations in Michipicoten district stand about on edge. They consist in part of quartz, and on that account have resisted erosion so much better than the volcanic formations on either side that they constitute well-defined ridges, or "ranges" that stand as much as 250 feet above the general level of the country. There is little information to be gained from the attitudes of these ranges to indicate which side of the iron formation is the top.

The iron formation at Goudreau is fortunately an exception to this rule. It is so little folded that it seldom dips more than 70 degrees and in some places not more than 15 degrees. There is no doubt which side is the top. When the Goudreau formation was studied in 1918 a large

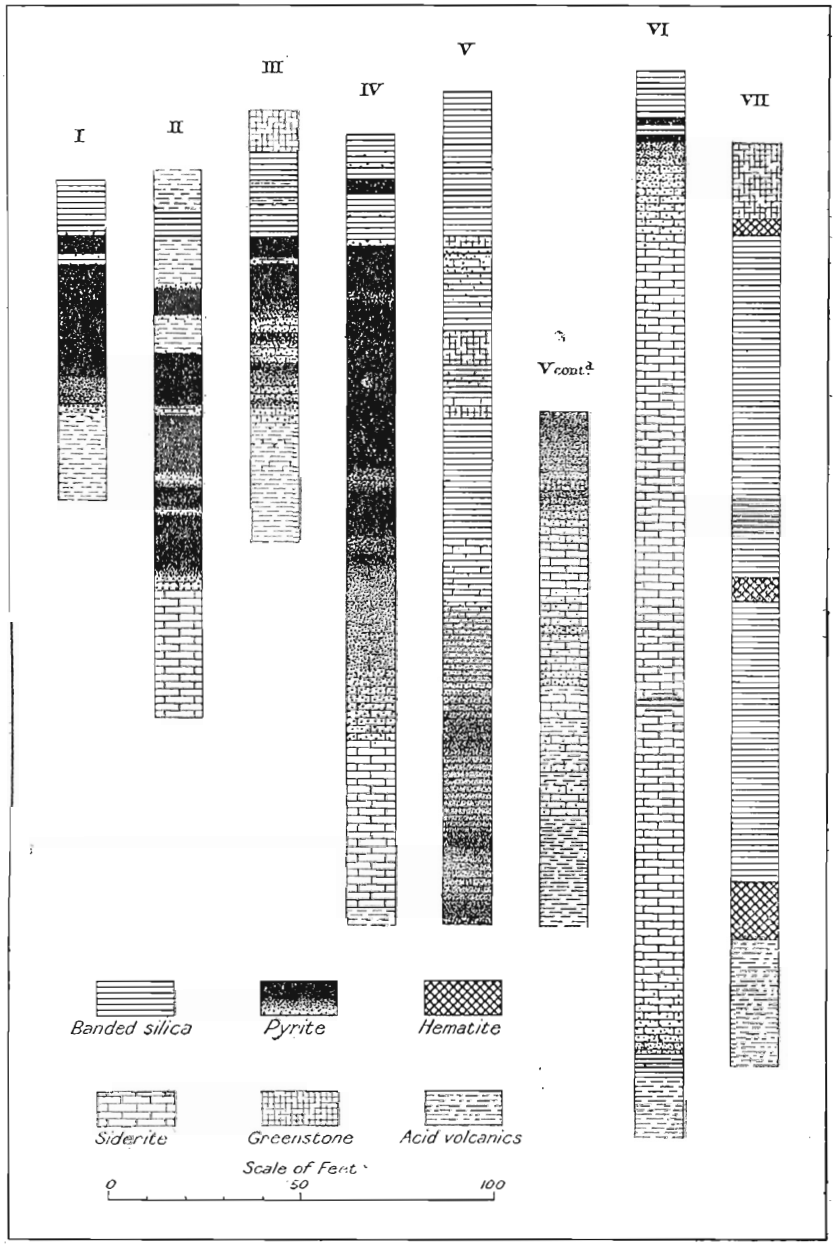

Figure 5. Diamond-drill sections of iron formations showing the stratigraphic arrangement of banded silica, pyrite, and carbonate (siderite or sideritic limestone). The drill logs have been corrected so as to show true thicknesses in each case: I, hole No. 15, C deposit, Nichols Chemical Company's property near Goudreau; II, hole No. 8, Morrison No. 2 property, south of Goudreau; III, hole No. 16, Morrison No. 3 property, east of Goudreau; IV, hole No. 8, Morrison No. 1 property, east of Goudreau; V, hole No. 1, Bartlett range, between 950 feet and 30 feet; VI, hole No. III, Helen range; VII, hole No. 17, Josephine mine, between 450 feet and 850 feet.

amount of surface trenching and diamond drilling had been done, affording an exceptionally good chance to examine the iron formation in section. It was soon noticed that cross-sections from all parts of the formation, though differing in thickness and successional details, are alike in their main stratigraphic features. The volcanic formation just above the Goudreau iron formation is prevailingly an ellipsoidal greenstone. The upper part of the iron formation in sharp contact with the greenstone is composed of white quartz and resembles a granular quartzite. It is either in fairly thick layers or in layers an inch or less thick that alternate with somewhat thinner red layers composed of a mixture of quartz and siderite. Locally this banded silica member of the iron formation is lacking, and in other places a little pyrite intervenes between it and the greenstone; but when the whole exposed formation is considered there is no escaping the fact that the banded silica is aggregated at the top of the iron formation and constitutes the uppermost member. The banded silica member gives place downward to a pyrite member. There are usually a few minor alternations of banded silica and pyrite just beneath the main body of banded silica, but these eventually give place to a main zone, or member, composed of pyrite and some pyrrhotite, with a variable admixture of carbonate. The sulphides are most concentrated immediately under the banded silica and tend to become more and more diluted with carbonate in a downward direction. By this gradual displacement the pyrite member gives way to a carbonate or siderite member, composed of the carbonates of iron, lime, magnesia, and manganese in variable proportions. In some places lime carbonate predominates and the carbonate member is then a coarse crystalline limestone; more commonly iron carbonate is the chief component, forming a fine-grained siderite that weathers red. This carbonate member, like the pyrite and silica members, varies greatly in thickness and may locally be almost absent; yet its prevalence throughout the iron formation and its stratigraphic position with respect to the other members is unmistakable. The carbonate member grades downward into an acid, light-coloured volcanic formation.

The stratigraphy of the iron formation at Goudreau may be summed up as follows: (1) a basic lava flow constitutes the cover of the iron formation, or its hanging-wall where the dip is high; (2) in sharp contact beneath this lava is a banded silica member; (3) in sharp, partly alternating contact below the banded silica is a pyrite member which grades downward into (4) a carbonate member; (5) there is a gradational passage from the carbonate member into an acid volcanic formation that forms the floor, or foot-wall of the iron formation. A more detailed idea of this succession is conveyed by Figures 5 and 6, which show cross-sections of iron formations in various parts of the map-area, and Figure 9 which represents an ideally simplified iron formation.

The steeply tilted iron ranges in other parts of the map-area were afterwards studied to see whether they possess the same stratigraphic arrangement. Some exceptional cases were found. Thus the Magpie mine formation lacks the banded silica member, and the pyrite member is rudimentary. The Dreany range has only a rudimentary pyrite member and apparently no carbonate member. Most of the very small iron

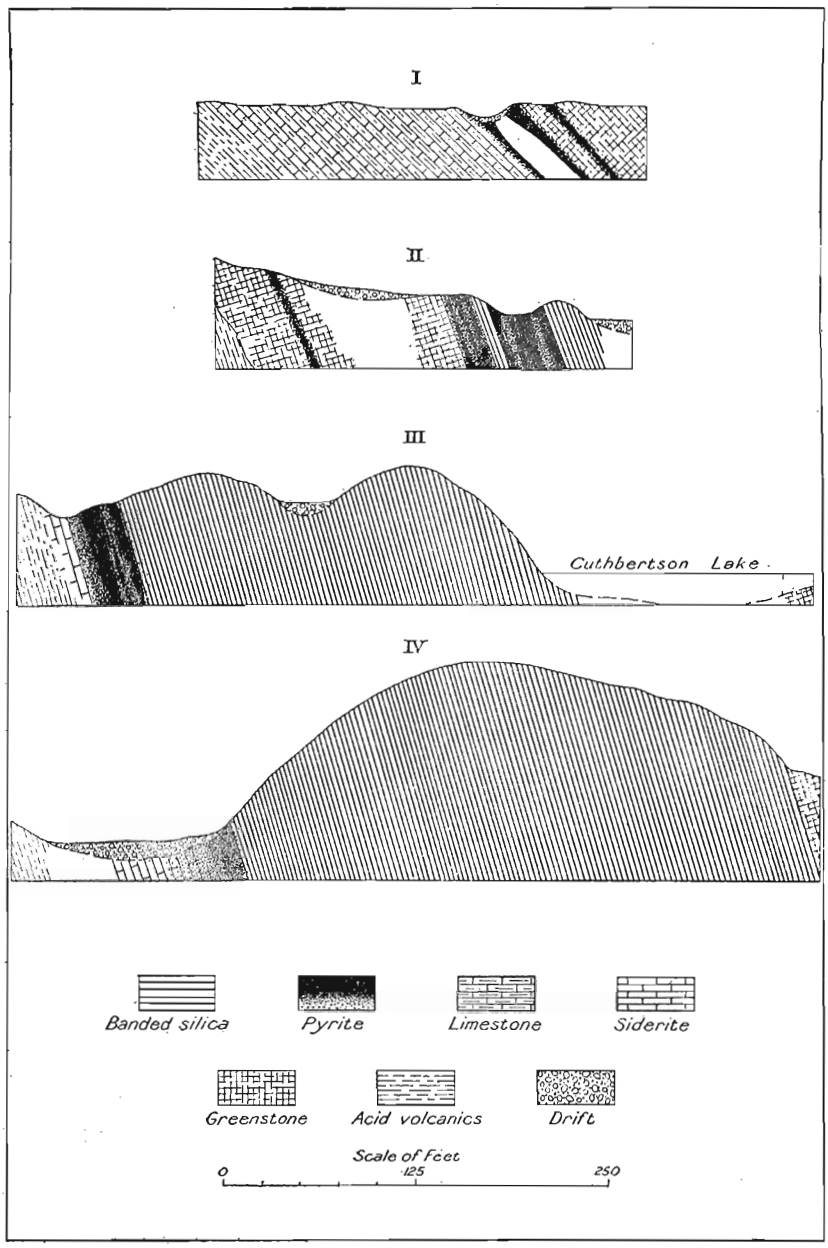

Figure 6. Cross-sections of iron formations showing the general stratigraphic arrangement of banded silica, pyrite, and carbonate and the characteristic topographic expression of each. I, near middle of mining claim J.L. 10, township 27, range 26; II, along east boundary of mining claim A.C. 39, township 27, range 26; III, near east end of Cuthbertson (Long) lake, township 28, range 24; IV, near middle of Bartlett range, township 28, range 25.

formations consist only of banded silica. But a satisfying majority of the larger ranges have all three members arranged in the same order as at Goudreau.

In a few instances beds of banded silica are to be found within, or even at the bottom of, the carbonate member. A thin bed occurs at the bottom of the Helen range locally, and beds of banded silica alternate with carbonate to the bottom of the Goetz range in townships 29 and 30, range 24. These beds are in all cases, however, greatly inferior in size to the main banded silica member at the top of the iron formation.

Wherever possible this means of distinguishing top from bottom of the iron formations by their stratigraphic arrangement was checked by applying other methods. This could not be done in all cases, since the formations with which the iron formations occur are nearly all volcanics, but wherever independent criteria could be applied they corroborated the evidence of the iron formation. The following tests were applied:

(1) Consider first the great iron formation which extends in a series of faulted segments across the map-area from Mildred lake northeastward to the main line of the railway between Mildred and Baldry lakes. This range is paralleled just to the north by a belt of sediments which includes a conglomerate composed mainly of small pebbles of banded silica. These pebbles evidently came from the iron formation. Such being the case, the iron formation must underlie the conglomerate and its original top must now face northward. A section southward across the iron range should, therefore, consist of banded silica, followed by pyrite and by carbonate, which is actually the case. The succession is, therefore, similar to that of the iron formation at Goudreau.

(2) The Dreany iron formation in the northeastern part of the map-area, and those formations near Kabenung lake, are so close above the Dore sedimentary series that they must lie in the same fold, and in the same attitude—that is, dipping southward or southeastward, with their tops facing in that direction. A section from south to north should, therefore, show basic lava, banded silica, pyrite, carbonate, and finally acid volcanics. Such is the case. At Brant lake not far east of Kabenung lake two diamond-drill holes had been drilled northward at 45 degrees dip through the second and third iron formations, counting from the south. Both holes and the neighbouring outcrops show a northward succession through the second iron formation of basic lava, banded silica, brown iron ore (the oxidized product of an original siderite band), and finally acid volcanic tuff. One of the holes also shows some pyrite next the banded silica. The dip of the iron formation is 57 degrees southward. Again, therefore, the succession is the same as at Goudreau.

(3) A more speculative test was applied to the iron ranges east of Loonskin lake and in the central part of township 28, range 25. These lie more or less parallel to the great broken range which extends from Mildred lake northeastward to the main line of the railway. This broken range has a total exposed length of over 7 miles and averages several hundred feet in thickness. If the width of this formation before folding was at all commensurate with its length, it is likely that instead of continuing downward indefinitely the folded formation would return towards the surface

in one or more folds, the truncated outcrops of which would constitute other more or less parallel ranges. If that happened, each adjoining pair of ranges would have to lie face to face and back to back alternately; that is, if the sequence in one range in a given direction were banded silica-pyrite-siderite it would be siderite-pyrite-banded silica in the ranges on either side. Now this is actually the relationship between the broken range east of Loonskin lake, the main 7-mile range, and the third range in the middle of township 28, range 25.

These are all the tests which could be discovered and applied to ascertain whether the sequence found in the iron formation at Goudreau obtains in the same vertical order in all the other iron formations of the district. Wherever these tests could be applied they point to a single conclusion: that the iron formations of Michipicoten district, when most fully developed, consist from top to bottom of:

(1) A banded-silica member, overlain sharply by a volcanic formation prevalently of basic composition.

(2) A pyrite member or zone, which grades downward into

(3) A carbonate (siderite) member or zone, which passes gradationally into an underlying volcanic formation usually of acid composition and usually pyroclastic.

STRATIGRAPHIC DISTRIBUTION IN THE SCHIST-COMPLEX

Once provided with the aforestated criterion for distinguishing the top of an iron formation from the bottom it is possible to work out the main fold-structure of the Keewatin schist-complex in which the iron formations occur and to determine roughly at what horizon or horizons in the schist-complex these iron formations lie. Brief consideration of the accompanying geological map (No. 1972) will show that all the iron formations represented on it are in the post-Dorean volcanic group. Judging from the structure of the underlying Dore series and the occasional bands of clastic sediments and iron formations in the post-Dorean group, this post-Dorean group has a depositional thickness not less than 10,000 feet and more likely a multiple of this amount.

Now, the small iron formation near mile 3 on the railway north from Michipicoten Harbour, which is broken in two by the great fault marked on the map at this point, lies within 350 feet above the top of the Dore series. Allowing for the dip, it lies in the post-Dorean group, 300 feet from the bottom. East of Kabenung lake there are four iron ranges parallel, very close together, and so related to acid tuffs on the north and basic lava on the south that they must be considered as four distinct iron formations originally deposited one above another, with intervening volcanic strata. The lowermost is about 700 feet stratigraphically above the Dore series and the uppermost about 1,000 feet higher in the post-Dorean. The iron formation nearest the Dore series in township 29, range 26, is 525 feet stratigraphically above the Dore series and another one parallel and farther away is between 1,800 and 2,000 feet above the same sediments. There are two iron formations about a mile south of Goudreau, both of which are evidently high up in the post-Dorean volcanics since they are remote from the nearest Dore sediments. These two formations lie parallel 600 feet apart and with their top facing northward. As they dip almost

vertically it seems clear that the one to the north was laid down 600 feet higher up in the volcanic group than the southern one.

It seems, therefore, that the various exposed iron formations are not parts of a single formation that occurs at one geological horizon, but that they are individual deposits distributed at a great variety of horizons throughout the post-Dorean group. No iron formations were found in the pre-Dorean group, but their presence there is indicated by pebbles of banded silica in the overlying Dore conglomerate.

SHAPE AND SIZE

It has been shown in the two preceding sections that the many bands or ranges of iron formation in the map-area are not all parts of a single formation occurring at a single geological horizon in the Keewatin. On the contrary there are many iron formations, which are distributed at different horizons throughout the whole vertical range of the post-Dorean schist-complex, and presumptively also in the pre-Dorean. It is now worth while to compare these iron formations in respect to shape and size.

The Goudreau iron formation alone lies in such shallow folds that its form can be almost completely determined. Before it was folded it was a tabular or very thinly lenticular formation about 175 feet in greatest thickness, at least 5 miles long, and at least 1 mile wide. Every other iron formation in the map-area is steeply folded and its edge outcrops as a band of notably uniform width, and of great length as compared with the width. The great faulted band that extends northeastward from Mildred lake is about eighty times as long as wide. Diamond-drill exploration of this range, the Helen, Magpie, and other ranges, indicates that the iron formations maintain this proportion in depth. It seems reasonably certain, therefore, that the iron formations before being folded into their present positions were horizontal stratiform bodies comparable in shape to a pancake.

The smallest one seen is exposed in a rock-cut in the railway spur that runs from Goudreau to the Nichols Chemical Company's plant. It is a lenticular body of banded silica about 1 foot thick and 5 feet long, enclosed, apparently, within a greenstone lava flow. Of course, only a section of this iron formation is visible, but an impression was gathered from a study of all adjacent rock outcrops that the exposed section is fairly central and that the whole body is only a few feet in any dimension.

The largest iron formation in the map-area is exposed in a series of faulted, offset segments that begin at Mildred lake and extend northeastward to, and possibly across, the main line of the railway. This dislocated band is over 7 miles long and maintains in that distance a thickness of from 100 to 550 feet. It stands on edge, with the top facing northwestward. Now, if the original width of this formation had been at all comparable with its length, other limbs of the folds into which it would have been thrown might be expected to appear at the surface as nearly parallel iron ranges, face to face and back to back alternately with the dislocated band just mentioned. It has been shown that two such parallel ranges do exist. On the east side of Loonskin lake about 6,000 feet

southeast of the 7-mile band is another series of short ranges that seem to represent the dislocated fragments of a once continuous band of iron formation. These fragments are on edge, with their tops facing southeastward. They have been found over a length of 4½ miles. On the opposite side of the 7-mile band and 9,000 feet away from it is a third dislocated series of ranges 4½ miles in aggregate length, and nearly as thick as the 7-mile band. The top of the belt faces southward. The orientation of these three belts and their resemblance in size and composition, strongly suggest that they are simply three parallel outcropping limbs of a single huge folded iron formation, the structure to the southeast of the middle or 7-mile band being a truncated arch, and to the northwest of that band, a trough. If this interpretation be correct, the original iron formation must have been a sheet over 7 miles long, at least 4 or 5 miles wide, and up to 550 feet in thickness.

Between this great iron formation and the pygmy one seen on the railway spur at Goudreau, there are in the map-area other formations of various intermediate sizes. In fact the completeness of the gradation in size of these gives further support to the dimensions here ascribed to the two extreme cases.

BANDED SILICA MEMBER

Some conception has now been deduced of the composition, size, and distribution of the iron formations. Before inquiring into the manner in which they originated it will be necessary to consider them in greater detail.

The uppermost, or banded silica member, is the most constant part of the iron formations. It is lacking in the Magpie and in parts of the Goudreau iron formation, but in all the others it is present in large proportion. Most of the small iron formations consist altogether or nearly altogether of banded silica; and in all the large ones banded silica greatly exceeds the pyrite and siderite. It reaches a thickness of 675 feet in the Helen formation in a total of 900 feet, and of 400 feet in a total of 550 feet in the great 7-mile range east of Mildred lake.

In the Helen and Goetz ranges subsidiary beds of the banded silica member are found in, or even at the bottom of, the carbonate member.

The commonest and most characteristic phase of the banded silica consists of laminæ of nearly pure silica alternating with other laminæ of silica mixed with siderite or some other iron compound. A very good example may be seen in the tunnel which the Algoma Steel Corporation has driven through the banded silica member of the Helen iron formation. Beautiful specimens which can be picked from the rock pile at the mouth of the tunnel consist of layers of pure white, granular quartz, half an inch thick, alternating with greyish or pink layers of siderite about half as thick. The siderite layers soon weather red, producing a brilliant, striped coloration. In the Dreany formation white or grey layers alternate with iridescent blue-black ones, owing to the fact that in the latter magnetite takes the place of siderite. This magnetite may be of the same generation as the siderite (primary), but the ready manner in which siderite at the Helen tunnel changes to red iron oxide suggests that the magnetite may

rather be secondary after siderite. Near Brant lake, in township 30, range 26, the siderite layers are converted, evidently by metamorphic action, into layers of bright green iron silicate (grünerite). All the banded-silica members of the Michipicoten iron formations are characteristically light-coloured, and particularly so where pyrite is abundant. The Goudreau formation is snow-white in many places. In other parts of Ontario darker colours are more prevalent. The Timagami iron formation, for example, is striped in brilliant red and blue-black owing to the presence of hematite and magnetite, instead of siderite. In spite of these colour variations, however, the close relationship of the different varieties is easily apparent.

Casual inspection of a large outcrop of well-banded silica gives the impression that the layers composing it are as regular and persistent as the strata in a finely bedded argillite (Plate VIII A). But, when a single layer of silica is traced it is commonly found in a few feet or yards to taper, often rather abruptly, and disappear, or to unite with another layer (Plate VII A). Another good photographic illustration of this feature is also given by Parsons.[1] The banded silica formation is thus not a succession of equally continuous layers, but of comparatively short overlapping layers and lenses.

Neither is the lamination uniform in respect to the thickness of the layers. Even in the same formation, and within no great distance horizontally the silica layers may change from thin laminæ to beds 2 or 3 inches or even as much as 18 inches thick (Plate VII A). In the Morrison No. 1 property northeast of Goudreau there is an unstratified mass of snow-white quartz many yards thick, and apparently of no great lateral extent.

Brecciation of the banded silica (Plate VII B) is a comparatively common local feature. The fragments are so slender in some cases that they could hardly have been made after the formation had cemented to its present extraordinarily hard condition. Portions above and below the breccia appear also to be undisturbed, as if brecciation had, perhaps, taken place during the time of deposition.

The banded silica is commonly a firm, brittle formation of about the physical consistency of vein quartz. As a result, it has withstood erosion better than the other rocks in the schist-complex, and where it is of considerable thickness forms high, well-defined ridges that make prospecting of the iron formation easy. The Goudreau formation is somewhat exceptional. It contains much rather loosely granular silica, though in this respect there is much variation even in the same section; for example, the upper bed shown in section II, Figure 5, can be reduced to sand by rubbing two pieces together, whereas the next one, 30 feet lower down, is hard and glassy.

The siliceous layers consist almost entirely of irregular interlocking quartz grains about as large as fine sand grains. Repeated microscopic examination of these grains by many observers, and on samples from many localities in Lake Superior region, has failed to reveal any dust

[1] Ann. Rept., Ont. Bureau of Mines, 1915, pt. I, p. 207.

rims or other signs of derivation from sand. There are usually a few shreds of secondary colourless mica scattered through thin sections of the rock. The iron-bearing layers are quite sharply defined from the silica layers. They consist of the same granular quartz grains mixed with about half as much carbonate (mostly siderite); a few irregular grains and crystals of pyrite occur with the siderite, and also, in some cases at least, a smaller percentage of octahedra of magnetite. The carbonate is a mosaic of small, irregular grains. In the Dreany formation magnetite entirely takes the place of the carbonate.

At 848 feet in the drill-core from the hole No. 105 in the Helen range is a layer 18 inches thick of a black carbonaceous material which soils the fingers slightly. This layer contains scattered lumps of pyrite and has banded silica on either side of it. Coleman found similar material at the Eleanor range. He says:[1] "The black graphitic slate forming a thin sheet just under the iron range proper west of the Helen mine and at other points in the region seems closely related to the granular silica, being composed of the same material with a large admixture of carbon which smears the fingers. The grains of silica are, however, much more variable in size than in the rock described above (banded silica, grains of which measure from 0·018 to 1·25 millimetres in diameter). As the carbon is opaque thin sections are unsatisfactory. The slate generally contains rounded masses or crystals of pyrite, which weather out leaving curious cavities, looking like bubble holes, lined with a thin white layer of quartz more coarsely crystalline than usual in the rest of the slate."

The contact of the banded silica with the volcanic formation overlying it is not often visible. At many places the two rocks were found exposed to within a few feet of each other, but only in two places was the contact seen. At both these places the contact can be defined within an inch. In one case the volcanic material is a schist. In the other case it is a massive, ellipsoidal greenstone, which for a few inches away from the banded silica has been bleached almost white. The nature of this bleaching was not investigated, but evidently the hot greenstone was the active cause of it. In the few cases where diamond-drill cores revealed a contact with volcanic rock it is knife-sharp.

Apparently this upper contact of the iron formation with the volcanic rocks is clean cut. The volcanic formation is, therefore, probably the younger, and was deposited upon the iron formation. Volcanic rocks are occasionally found interbedded with the banded silica. In some cases a few thin beds of banded silica at the top of the iron formation alternate with the volcanic rock, and in diamond-drill core No. 105 at the Helen mine, there are several thin layers of altered volcanic rock intercalated in the lower part of the banded silica. Several beds of greenstone occur in the core from hole No. 1, Bartlett range (Figure 5). These intercalated bands of volcanic rock are sharply defined from the banded silica. There is no gradation from one substance to the other that would imply chemical replacement of the volcanic rock by silica, but the volcanic rock is commonly replaced by carbonate, often to such an extent as to be difficult to

[1] Ann. Rept., Ont. Bureau of Mines, 1901, p. 183.

recognize. These bands of volcanic material were probably deposited during the formation of the banded silica.

The volcanic that overlies the iron formations is very commonly though not always an ellipsoidal greenstone. This is true of the Goudreau iron formation and parts of the formations near Loonskin lake. A thin iron formation exposed on the shore of lake Superior not far east of Michipicoten Harbour appears to lie between two flows of ellipsoidal greenstone; at least, there is massive ellipsoidal greenstone on either side except for about a yard of softer, fissile green schist immediately next either contact with the iron formation. In other cases the volcanic rock overlying the iron formation is of more acid character. In the case of very large iron formations such as that which extends from Mildred lake northeastward the overlying rock is not everywhere of the same character and may consist of more than one formation.

PYRITE MEMBER

Beneath the banded silica member of the iron formations is usually a more or less well-defined zone or member composed largely of pyrite. This part of the iron formation is an important source of pyrite ore and was in all likelihood also the source from which the secondary pyrite deposits in Michipicoten district were derived. In the iron formation at the Helen mine it is represented by a zone from 5 to 60 feet thick, either of fairly massive pyrite or of grains of pyrite distributed through a groundmass of siderite, so as to constitute from 10 to 35 per cent of the whole. In the Goudreau iron formation it attains a thickness of 120 feet and the pyrite is concentrated to form a massive yellow ore as much as 90 per cent pure. These two examples are cited as representing the extremes, between which there are all gradations in thickness and concentration (Figure 5).

In any given iron formation the pyrite member varies from place to place in thickness and degree of concentration. Apparently in all cases the pyrite is most highly concentrated immediately beneath the banded silica member and tends to become leaner in depth. The contact with the banded silica is fairly sharp, but for some distance above the main pyrite member there may be alternations of pyrite and banded silica (Figure 5). The lower boundary, on the other hand, is indefinite. There is an easy gradation from material composed mainly of sulphides into one composed of carbonate with a sprinkling of sulphide grains. The gradation is not regular; vaguely defined patches of carbonate, or even of volcanic schist, are scattered through the pyrite member, like the vestiges of country rock in a replacement deposit.

Range pyrite, as it is called, is thus really a mixture of sulphides and carbonates (siderite). It is characteristically granular and rather easily pulverized, the individual crystals being about as coarse as ordinary sand grains. The granular ore, however, is apt to be traversed by veinlets of harder and much more lustrous pyrite, evidently of secondary derivation. In a microscope preparation of lean ore the pyrite is seen to be in irregular grains and good crystals clustered together or distributed singly through a

groundmass of finely crystalline carbonate. Associated with the pyrite are a small proportion of pyrrhotite and an even smaller proportion of grains of magnetite.

The analyses of range pyrite given in the accompanying table, although incomplete and carried out only with the object of determining the commercial value of the ore, nevertheless indicate its chemical characteristics. About 10 per cent of each sample is magnetic, and consists of pyrrhotite and magnetite. Arsenic, manganese, and zinc are regular constituents, though in small amounts. The proportion of arsenic is too small to ascertain in what combination it exists, but it is probably in the form of arsenopyrite. A sample of siderite mixed with sulphides from mining claim KW 34, on the Brooks iron range, given the authors by Mr. A. Hasselbring, contains fine tabular crystals of arsenopyrite up to half an inch long. From 0·03 to 0·20 per cent of copper was obtained in eleven analyses of drill-core. Lead has not been analysed for, as far as known, though the very common association of this metal with zinc affords some reason for thinking that it may be present in small amount.

Samples from the C Deposit of Goudreau Range, Analysed by the Algoma Steel Corporation

—	Ia	Ib	IIa	IIb	IIIa	IIIb	IV	V	VI	VII
Fe	.....	57·84	.....	58·02	.....	57·04	.....	43·49	41·40	43·32
S	38·48	2·43	34·31	3·18	33·47	2·70	35·93	26·37	26·57	30·45
As	tr.	.....	0·01	.....	0·01	.....	.....	0·01	0·02	0·03
P	.....	0·014	.....	0·010	0·010	0·103	.....	.....	.....	.....
Mn	.....	1·10	.....	0·64	.....	1·31	.....	.....	.....	1·25
Zn	.....	.....	.....	.....	.....	.....	.....	1·08	1·48	0·74
Cu	.....	.....	.....	.....	.....	.....	0·12	None	None	.....
Ni	.....	.....	.....	.....	.....	.....	0·52	.....	.....	.....
Insoluble siliceous material	.....	4·56	.....	1·36	.....	2·40	.....	1·02	4·40	.....
Magnetic portion	12·15	.....	9·56	.....	10·52	.....	.....	.....	.....	.....

I. From carload of lump ore from Rand Consolidated Company's pit, mining claim AC 50, Goudreau; (a) as received; (b) roasted. Analysed by H. A. Leverin, Mines Branch, Ottawa.

II. From carload of lump ore from Nichols Chemical Company's pit, mining claim JL 15, Goudreau; (a) as received; (b) roasted. Analysed by H. A. Leverin, Mines Branch, Ottawa.

III. From carload of fines from Nichols Chemical Company's pit, mining claim JL 15, Goudreau; (a) as received; (b) roasted. Analysed by H. A. Leverin, Mines Branch, Ottawa.

IV. Average of six drill-core samples of range pyrite from hole No. 3, mining claim JL 15, Goudreau. Analysed by Algoma Steel Corporation, Sault Ste. Marie, Ontario.

V. Average sample of range pyrite from drill-core from mining claim JL 21, Goudreau. Analysed by H. A. Leverin, Mines Branch, Ottawa.

VI. Average sample of range pyrite from railway cut, mining claim Y 454. Analysed by H. A. Leverin, Mines Branch, Ottawa.

VII. Sample of range pyrite from iron range in northwest corner of township 27, range 25. Analysed by H. A. Leverin, Mines Branch, Ottawa.

One-half per cent of nickel was found in the only sample among the six that was analysed for this constituent, but ten drill-core analyses by

the Algoma Steel Corporation of samples from the C deposit of the Goudreau range yielded 0·02 to 1·10 per cent of nickel, with an average of 0·38 per cent. All the analyses show more iron than is necessary to satisfy the sulphur, even after allowance has been made for the pyrrhotite. Some of the surplus iron is in the form of magnetite, but probably the greater part forms siderite.

Traces of gold have been found in a sufficient number of the iron formations to suggest that the association is not an accidental one. A trace of gold is reported to have been found in the Barton iron range. The small iron range at the southwest end of Loonskin lake was originally taken up for gold and analyses of the pyritous part does show a trace of gold. The Emily gold mine on Dog lake is in an iron formation, and the ore includes a carbonate, pyrite, and pyrrhotite, and, it is said, a little free gold. The gold seems to accompany the pyrite member of the iron formation.

CARBONATE MEMBER

The third, and lowermost, member of the iron formations consists essentially of a mixture of carbonates, with a sprinkling of pyrite, and vestiges of volcanic rock. Just as the pyrite member is the ultimate source of all the pyrite deposits, so this member is either directly, or by conversion into secondary ore deposits, the source of all the iron ore deposits in Michipicoten district.

The carbonate member is present only in the larger iron formations. It reaches a maximum thickness of 240 feet in the formation at the Helen mine. In other ranges it varies in thickness down to nothing. It is a common experience in diamond-drill operations to find wide variations in thickness within short distances, even in the same iron range. In its space relation to the banded silica the carbonate member may be likened to the water remaining under thick ice in a shallow pond of uneven depth (Figure 9).

As described above, the passage from the pyrite member into the carbonate member is gradational. The bottom of the carbonate member is also indefinite. It gives place downward through poorly-defined alternations of carbonate and volcanic rock into continuous volcanic rock. This rock is in nearly all cases an acid variety, and in many cases at least a tuff. The change into the volcanic foot-wall is as a rule complete in less than 10 feet, but may require a considerably greater distance.

In all except the Goudreau iron formation the carbonate member is a siliceous siderite carrying scattered grains of pyrite. It is a close-grained, pale grey or pink material easily mistaken in the field for a decomposed rhyolite or other acid lava, because the admixed silica renders it considerably harder than ordinary siderite. It weathers, however, to a rusty brown limonite. Locally, and especially towards the bottom of the iron formation, the carbonate contains vaguely-defined patches of schist more or less completely replaced by carbonate. These are best seen in diamond-drill cores and vary from indistinct traces to well-defined volcanic rock.

The carbonate member of the iron formation at Goudreau is in places a siderite similar to that found elsewhere; but for the most part

it is a coarsely crystalline limestone, which recalls in a general way the Grenville limestones of eastern Ontario. It is a pale grey or pale brown rock carrying a few scattered grains and bunches of pyrite. Parts of it are uniformly grey, but other parts become speckled with brown on weathered surfaces, suggesting an admixture of iron carbonate. The rock surface at Goudreau is heavily drift-covered, so that the iron formation cannot be seen continuously for any considerable distance; but in one place the crystalline limestone was found to pass gradationally into the finer-grained siderite.

Chemical and microscopic examination of the carbonate member shows that it is really a mixture of the carbonates of iron, magnesia, lime, and manganese, and possibly also zinc carbonate, through which are sprinkled grains of quartz and pyrite, and also the remains of volcanic rock and ordinary rock-forming minerals. Under the microscope, at magnifications of about 100 diameters, the body of the carbonate appears as a fine mosaic of irregular grains of carbonate, and through this groundmass are scattered occasional irregular grains of quartz, irregular grains and good crystals of pyrite either separate or in clusters, a few grains or octahedra of magnetite, and shreds or vague patches of chlorite and other rock-forming silicates more or less corroded and replaced by carbonate. There is great variability in the proportions of carbonate, sulphides, and silicates. There is also apparently a considerable variability in the proportions of the four carbonates present. Usually siderite predominates, the carbonates of lime and magnesia are roughly equal, and manganese carbonate is least abundant. No analysis of the crystalline limestone phase of the Goudreau iron formation is available, but, judging from its appearance and manner of weathering, iron carbonate is subordinate to the carbonate of lime.

—	I	II	III	IV
FeO	.....	.....	.....	33·80
Fe_2O_3	.....	.....	.....	2·50
Fe	35·11	34·30	35·61	.....
Mn	2·86	2·21	2·09	0·35
CaO	8·40	5·48		3·25
MgO	4·17	5·51	11·83	5·24
Al_2O_3	3·04			3·29
		3·40		
SiO_2	9·20		7·28	20·87
S	7·43	.....	1·44	.....
P	0·019	.....	0·016	.....
Loss on ignition (CO_2)	21·50	32·24	31·56	28·75
H_2O (at 100°C.)	.....	.....	.....	0·04
FeS_2	.....	.....	.....	1·53
Total	.....	.....	.....	99·82

I. Sample of pyritic siderite from diamond-drill hole, mining claim SSM 1777, Goudreau. Analysed by the Algoma Steel Corporation, Sault Ste. Marie, Ontario.

II. Sample of raw siderite ore from Magpie mine. Analysed by W. K. McNeill (*See* Ann. Rept., Ont. Bureau of Mines, 1915, pt. I, page 202).

III. Average of siderite ore in Helen deposit above tunnel. Analysed by Algoma Steel Corporation, Sault Ste. Marie, Ontario.

IV. Sample of diamond-drill core 376 to 389 feet below surface, Helen mine. Analysed by A. H. A. Robinson for Ontario Bureau of Mines.

The following additional analyses express the constituents in terms of the carbonates present:

—	I	II	III
$FeCO_3$	78·57	74·07	53·20
$MgCO_3$	12·84	8·75	11·57
$CaCO_3$	4·09	0·79	9·79
$MnCO_3$	.....	.....	4·60
Insol. (quartz, pyrite, and rock matter)	4·38	14·76	3·40
FeO, Fe_2O_3	.....	.....	11·90
Total	99·88	98·37	94·46

I. Sample of siderite from hill east of Helen hematite mine. Analysed by A. P. Coleman, for Ontario Bureau of Mines.
II. Sample of siderite from west end of Boyer lake, Helen range. Analysed by A. P. Coleman.
III. Sample of siderite from Magpie mine. Analysed by W. K. McNeill, for Ontario Bureau of Mines.

There is abundant and unmistakable evidence that the carbonate (siderite) member of the Michipicoten iron formation is ordinary volcanic rock of the Keewatin schist-complex which has been converted more or less completely into carbonates by a process of chemical replacement. This evidence is chiefly available at the Helen mine and at Goudreau, many drill-cores from which have been accurately taken and carefully preserved. The evidence of replacement lies mainly in the fact that vestiges of the original volcanic rocks, in all degrees of alteration to carbonate, are to be found distributed throughout the carbonate and pyrite members. The volcanic rock immediately underneath is also partly altered to carbonate and there is prevalently a gradation, through from 5 feet upwards, from what is regarded by the drillers as foot-wall (rock) to the first lean ore. Almost any drill-core through an iron formation will show from the base upwards one or more sections of 25 feet or less in which there is an almost imperceptible gradation from good carbonate (siderite) into material easily recognizable as much carbonated volcanic schist, and just as gradually back to normal siderite ore. Camera-lucida drawings illustrating stages of replacement in one of these vestiges of the original volcanic material are shown in Figure 7. In general the vestiges become fainter towards the top of the carbonate member and on this account it is somewhat difficult to determine whether the entire siderite and pyrite members are replacements. Apparently they are, for well-defined traces of volcanic materials were found to within 30 feet of the banded silica in the iron formation at Helen mine, and intercalations of schist partly altered to carbonate were found in the banded silica member itself.

Corroborative chemical evidence of the origin of the siderite and pyrite members by replacement of volcanic rocks is given in Figure 8. The Algoma Steel Corporation took average samples of every 10-foot section of the drill-cores from the siderite member at the Helen range. These samples were analysed for iron, silica, and sulphur. Now, the iron content is rather closely proportionate to the carbonates in any sample, the only factors to disturb this ratio being additional iron from the pyrite and from unreplaced vestiges of volcanic rock. Except for these unimportant

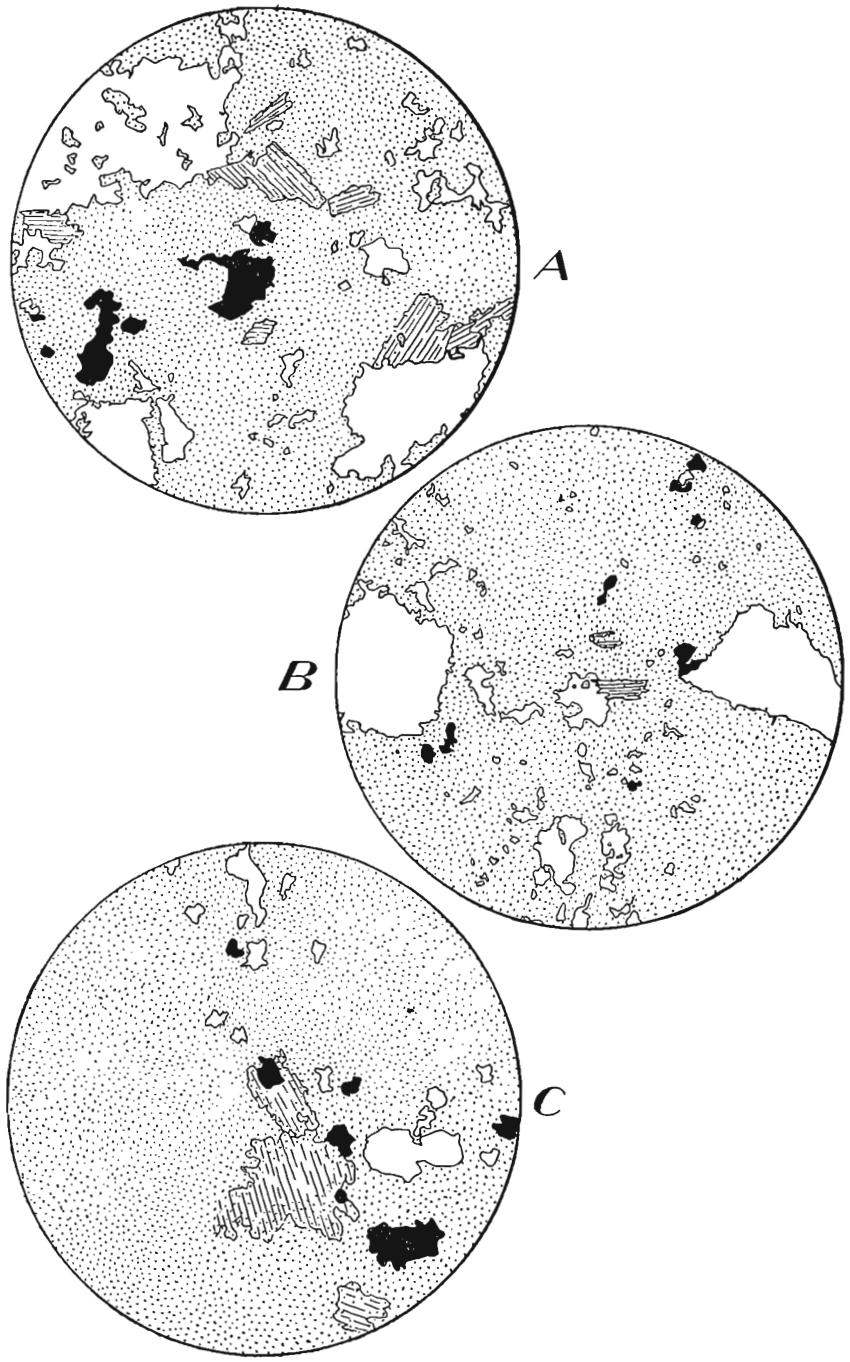

Figure 7. Camera-lucida drawings of microscopic preparations of a series of samples from 217 to 224 feet, diamond-drill core No. 109, Helen range, showing the gradation from rich siderite ore into a lean phase containing unreplaced volcanic rock matter. (A) Clastic volcanic rock, highly carbonated, from 217 feet. Magnified 170 diameters. (B) Same material, still more carbonated, from 219 feet. Magnified 150 diameters. (C) Good quality carbonate ore, from 224 feet. Magnified 185 diameters. Black=pyrite; lined areas=ferromagnesian minerals (biotite, hornblende, chloride); clear areas=quartz; stippled areas=carbonates.

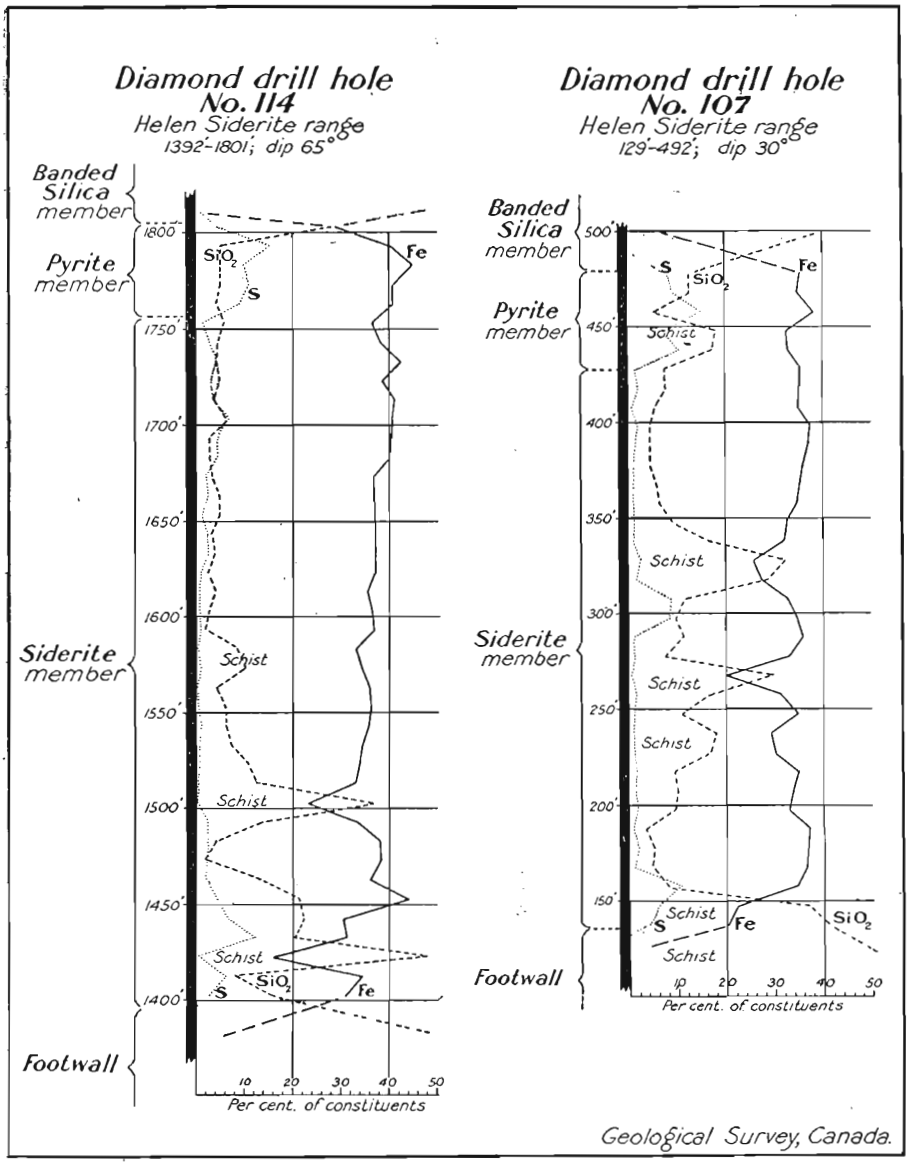

Figure 8. Curves showing the percentages of iron, silica, and sulphur in the cores from diamond-drill holes 114 and 107, in the iron formation at Helen mine. The curves correspond respectively to the amounts of carbonates, unreplaced rock matter, and of pyrite, and indicate that the entire carbonate and pyrite members of the iron formation are replacements of volcanic schists.

factors, which are for the most part small, a curve representing the content of iron also indicates the content of carbonate. Likewise, the silica content is a fairly accurate index of the amount of unreplaced rock matter in the carbonate body, the only disturbing factor being veinlets of quartz, which fortunately are small and infrequent. The sulphur content is, of course, an exact index of the pyrite content. In Figure 8 the percentages of iron, silica, and sulphur are plotted to form curves which thus also represent approximately the percentages of carbonate matter, unreplaced rock matter, and pyrite in the drill-cores. The peaks in the silica curve should correspond with vestiges of rock matter in the drill-core and should, therefore, also coincide with a lowered carbonate content and with corresponding depressions in the iron curve.

The curves for the two drill-cores selected, from holes 114 and 107, show that vestiges of rock matter occur here and there from bottom to top of the carbonate member. Hole 114 is the more usual case. In it the remnants of unreplaced rock matter are commonest and most pronounced near the bottom and become fewer and fainter towards the top of the carbonate-pyrite member. In hole 107, however, quite strong traces of rock matter are found to within a short distance of the top. Most of these vestiges were visible in the drill-cores and wherever they were so observed the word "schist" has been written in Figure 8 for the purpose of showing how closely ocular and chemical testimonies agree.

The sulphur curve has been included partly to indicate in how small a degree the iron curve is affected by the pyrite present, but chiefly to show how distinctly, even in the Helen range, the pyrite is concentrated in a "pyrite member" at the top of the carbonate member and immediately underneath the banded silica.

Under the microscope abundant evidence of the replacement of the rock-forming silicates by carbonates is seen in the frayed remnants of these silicates, which are riddled with carbonate particles. Apparently the carbonate solutions to which replacement was due reacted more readily with feldspars and even with quartz than they did with iron-bearing silicates, for in scarcely a single instance does feldspar remain in the siderite. The patches of volcanic rock still to be found in the siderite are all dark rocks. Confirmation of this opinion is to be found in almost any part of the Keewatin schists of the map-area. Nearly all of these contain secondary carbonates, even up to 60 per cent of the rock mass, and in these the feldspars are among the first mineral constituents to be replaced.

The occasional pyrite grains which are scattered through the carbonate member, and constitute about 5 per cent of it, appear to have replaced some of the more highly ferruginous silicate minerals of the original rock. Drill-cores of the Helen siderite deposit contain curious rod-shaped individuals of pyrite. On comparing a number of these it was found that there were gradations from some consisting entirely of pyrite, to others consisting partly of pyrite and partly of a dark altered mineral, probably hornblende (Plate V A, B). There seems to be little doubt that the dark mineral was a constituent of the original volcanic rock and that the rods of pyrite are pseudomorphs after it.

Once the process of replacement has been recognized various fainter traces of the original volcanic rock can be found, the significance of which would otherwise be missed. Certain of the rock-forming minerals have better resisted conversion into carbonate than have others, and corroded vestiges of these remain scattered sparingly through the siderite. Chlorite shreds are fairly common. The most tell-tale mineral of this sort, however, is ottrelite. An ottrelite-bearing rock forms the base of the iron formation at Goudreau and also occurs in association with iron formations at some other places in the map-area. The ottrelite crystals appear to have been little affected by the carbonate solutions and are found singly and concentrated in streaks in the siderite ore.

The chemical analyses of siderite given above, although commercial and not well adapted for the purpose in hand, nevertheless show fairly well the rude similarity in composition of the siderite to a volcanic rock, and also the variable proportions of its constituents. All the ordinary constituents of an igneous rock are present except the alkalis, which though not sought by the analyst in any case are probably present. The varying proportions of alumina and silica probably correspond to varying residues of the original volcanic rock.

To obtain a more precise idea of the composition of the carbonate member a careful chemical analysis was made, by M. F. Connor, of a composite sample taken at intervals between 217 and 224 feet from the core of diamond-drill hole No. 109, Helen range. Optical examination of the material showed it to consist, as usual, of carbonates, unreplaced vestiges of original volcanic rock, and a sprinkling of sulphides. The sample was first digested in hydrochloric acid so as to bring into solution all the carbonate and sulphides and as little else as possible, leaving an undissolved residue of rock matter. The two parts were then analysed separately, as shown in columns I and II below, and these results combined in column III.

—	I Part soluble in HCl	II Insoluble part	III Total
SiO_2	.....	13·91	13·91
Al_2O_3	0·20	3·43	3·63
FeO	28·62	.....	28·62
Fe_2O_3	2·93	0·35	3·28
TiO_2	trace	0·09	0·09
MnO	1·73	trace	1·73
CaO	4·34	.....	4·34
MgO	5·56	0·17	5·73
Na_2O	.....	0·94	0·94
K_2O	.....	0·45	0·45
CO_2	27·06	.....	27·06
P_2O_5	0·23	.....	0·23
Fe	5·08	.....	5·08
S	3·35	.....	3·35
H_2O-	0·10	.....	0·10
H_2O+	1·30	.....	1·30
Zn	.....	.....	.....
NiO	trace	.....	trace
BaO	trace	.....	trace
Total	80·50	19·34	99·84

The composition of the whole sample, given in column III, corresponds in its general features with the foregoing commercial analyses of siderite; the sample may, therefore, be regarded as normal, slightly lean, siderite ore. Mr. Connor's analysis, however, discloses much regarding the physical composition of the siderite which the commercial analyses do not. It corroborates the evidence of the microscope that the insoluble part is a residue of ordinary volcanic rock that survived complete chemical replacement by carbonates; for the constituents in column II comprise all the ordinary constituents of an igneous rock, and if they be calculated to a total of 100 per cent, they will be found to correspond in a general way with the proportions found in igneous rocks: viz., SiO_2, 72; Al_2O_3, 17; Fe_2O_3, 1·80; TiO_2, 0·5; MgO, 1; K_2O, 2·3; Na_2O, 5·0 per cent. The alkalis, potash and soda, are confined to this insoluble part. Manganese, on the contrary, is confined to the soluble parts and was presumably introduced by the carbonating waters. The small amount of phosphorus present is also in the soluble part. Zinc probably occurs in the iron formations as a sulphide, for as much as 1½ per cent of it has been found in the pyrite member, whereas Mr. Connor found only a trace in the carbonate. Iron, magnesia, and lime are almost entirely soluble and there is about enough carbon dioxide to satisfy all four bases. The soluble part of the sample is, therefore, evidently a mixture of the carbonates of iron, magnesia, lime, and manganese, and about 8½ per cent of sulphide of iron. Curiously, Mr. Connor ascertained this sulphide to be mainly pyrrhotite (8·31 per cent) with but little (0·12 per cent) pyrite, whereas the pyrite member of the iron formation is characteristically made up of about 90 per cent pyrite and 10 per cent pyrrhotite.

There are several otherwise puzzling features of the carbonate (siderite) member of the iron formations which are quite comprehensible when the siderite is regarded as a replacement deposit. The drillers who explored the iron formation at the Helen mine encountered in the siderite thicknesses of what they styled greenstone. These appeared in very erratic fashion. A considerable thickness of "greenstone" would be found at a certain horizon in one hole and would be absent in an adjacent hole or would appear in different thickness at a different horizon. They are too poorly defined to be regarded as dykes, and, owing to their erratic occurrence, they can not be correlated as volcanic flows, even if it were possible to overlook their gradational passage into good ore. The logs of these drill-holes also include certain sections of "lean ore" equally erratic in their occurrence. A re-examination of some of the drill-cores in 1920 showed that these patches of "greenstone" and of "lean ore" are really vestiges of the original volcanic rocks which were not completely altered to siderite (Figure 8). The presence of alumina and the other common chemical constituents of igneous rocks in the siderite is also readily explained as coming from unreplaced vestiges of the original igneous rocks.

As a matter of fact the process of replacement is exemplified in almost every formation in the Keewatin schist-complex. Scarcely any of these rocks are free from secondary carbonates and examples containing up to 20 or 30 per cent of carbonates are common. A few thin sections were examined that contained as much as 60 per cent, and a few lenticular

masses were found, notably one at Leg lake, near mileage 23 on the railway, which were changed almost completely into carbonates. Siderite is a prominent component of this secondary carbonate, as it is in the iron formations. The carbonate member of the iron formation may be said to differ from these ordinary rock alterations only in being more complete and on a more extensive scale, and in being associated with banded silica and pyrite.

In the replacement origin of the siderite there probably lies also an explanation of the fact that the volcanic formation underlying the iron formation is usually an acid rock, and also a tuff. A loose porous tuff would be much more readily permeated and altered by carbonate-bearing waters than a flow or other compact formation. An acid feldspathic rock, it has been shown, also reacts with carbonate solutions more readily than a basic rock.

SUMMARY DESCRIPTION OF IRON FORMATION

In order to provide a satisfactory basis of proof for the various conclusions reached regarding the nature of the iron formations it has been necessary up to this point to deal with each feature at considerable length and in the order in which these conclusions were actually reached during the field investigation. It may now be in the interest of clearness to give a briefer and purely descriptive résumé of a typical Michipicoten iron formation.

This description is embodied in Figure 9, which represents the authors' conception of an iron formation as seen in cross-section. The iron formations, as originally deposited and before they were folded, were approximately horizontal sheets or thinly lenticular bodies, ranging in size from a few yards in horizontal dimensions and one foot in thickness to 7 or 8 miles horizontally and 1,200 feet in thickness. They lie between volcanic formations. The underlying volcanic is prevalently, though not in all cases, an acid tuff. The overlying one is commonly, though not in all cases, an ellipsoidal greenstone. The iron formation, where fully developed, consists of three zones or members—the banded silica, pyrite, and carbonate (or siderite) members—arranged in that order downwards. There is great variability in the proportionate thicknesses of these members and one or two of them may be even lacking. Usually, however, where all three are present the banded silica constitutes as much as three-fourths of the total thickness.

The pyrite and carbonate members together represent a portion of the Keewatin volcanic complex adjacent to the original surface of the ground which has been transformed by chemical replacement, in varying degrees of completeness, into carbonate and pyrite. In consequence, they include incompletely changed vestiges of the original volcanic of all sizes and degrees of alteration, and the boundary between the carbonate and the volcanic beneath is vague and gradational. In general, replacement becomes increasingly complete upwards. The carbonate member is a mixture of the carbonates of iron, lime, magnesia, and manganese, together with a small percentage of pyrite (and pyrrhotite) disseminated through it

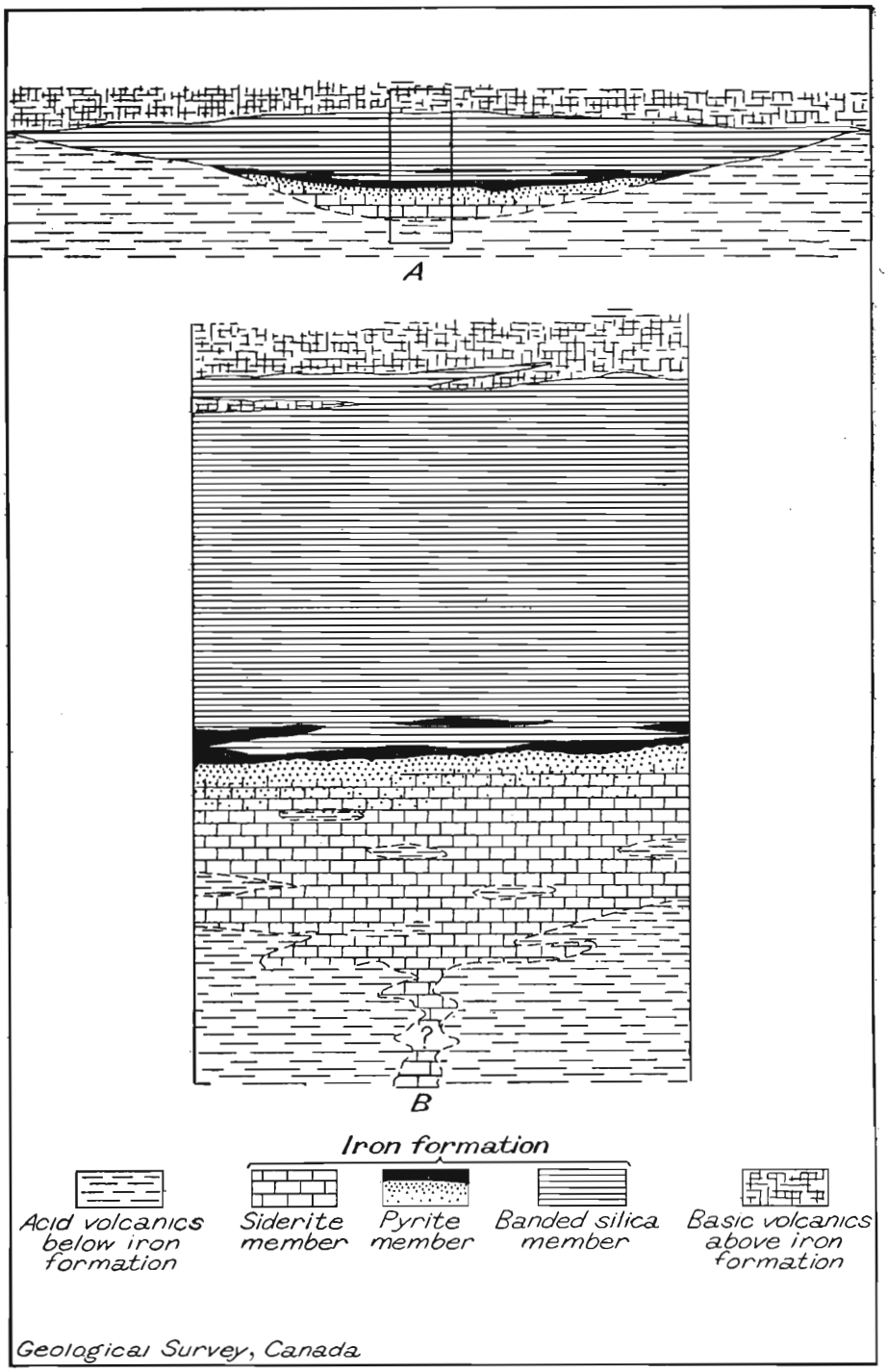

Figure 9. Diagrammatic vertical cross-sections of a typical unfolded iron formation to show stratigraphic arrangements and relationship to adjacent volcanic formations. A=entire cross-section, with thickness exaggerated about ten times. B=enlarged and more detailed representation of part of A indicated by the small rectangle.

and also scattered vestiges of the original volcanic rock. The pyrite member represents a concentration of pyrite and pyrrhotite at the top of the carbonate member, somewhat comparable in arrangement to the layer of cream over milk. Like the carbonate, the pyrite is most concentrated towards the top and grades downward into the carbonate.

The banded silica member has sharply defined contacts both below with the pyrite member and above with the overlying volcanic. There may be, however, minor alternations of banded silica with pyrite or with the volcanic rock near its boundaries; and subsidiary layers of silica, in a few cases, are found within and at the base of the carbonate member. The overlying volcanic is presumably younger than the iron formation, though this relationship has not yet been proved. The banded silica is essentially a stratified formation, but the component laminæ are lenticular or otherwise discontinuous instead of being continuous laterally like the strata of a normal sedimentary deposit. Laminæ of finely granular silica alternate with laminæ of siliceous carbonate (siderite). Magnetite or hematite takes the place of siderite in many cases, and may be the result of oxidation of the siderite.

Iron formations occur at various horizons through a stratigraphic range of thousands of feet in the post-Dorean volcanic group. They have not been found in the pre-Dorean volcanics, but their presence is indicated by pebbles of banded silica in the Dore conglomerate. The iron formations were folded closely in early Precambrian time and now the steep truncated limbs of these folds appear at the surface as linear bands or " ranges ".

ORIGIN OF THE IRON FORMATIONS

The carbonate and pyrite members of the iron formations have been shown to be chemical replacements of volcanic rocks. The banded silica member is also a chemical deposit and its constant association with the other members and the intimate interbanding in it of silica and siderite indicate that all three members were formed at the same time and by the same chemical agent.

It is an unavoidable conclusion that the chemical agent was mineralized water, and the extraordinary thoroughness and depth to which carbonate replacement occurred suggests that the active solutions were either concentrated or hot, or both. There are three other features which imply the action of hot or warm solutions. In the first place the iron formations occur interstratified in a great series of volcanic formations—lava flows, tuffs, volcanic ashes, and intrusives. At the time of their formation the region must have been the site of prolonged and intense vulcanism and it is altogether likely that heated waters were common. In the second place the pyrite and carbonate members of the iron formations contain a small but apparently ever-present percentage of pyrrhotite, which, as far as known, is formed only at high temperatures. Finally, the extraordinary variety of metals present in the carbonate and pyrite—gold, nickel, copper, zinc, manganese, iron, etc.—is strongly suggestive of an igneous source for the solutions that deposited them.

The pyrite and carbonate members, being replacements of volcanic rocks, were necessarily formed underground. It seems equally certain that material as extensive and as finely stratified as the banded silica could have been formed only at the surface. The contact between the banded silica member and the pyrite-carbonate members must, therefore, represent the surface of the ground at the time the iron formation was produced.

There is a variety of evidence that the heated mineralized waters responsible for the iron formations did their work on land and not in the sea or in any large stable body of water. Exponents of a submarine origin of iron formations have stressed the association of the iron formation with ellipsoidal greenstones and the opinion that an ellipsoidal structure is due to subaqueous deposition. It has never been adequately established, however, that submarine or even aqueous conditions are necessary for the development of an ellipsoidal structure in lavas, and certainly there is little evidence to be found in Michipicoten district to support the theory. On the contrary, the whole Keewatin group of lavas and coarse clastic sediments appears to be a continental, and mainly a land, deposit. If a sea or other considerable body of water had existed there would undoubtedly be a much greater proportion of sediments mixed with the volcanics and they would be normal sediments instead of boulder conglomerates and greywackes. As elaborated in Chapter III, Michipicoten district appears to have been a land area of mountainous or submountainous relief and great volcanic activity at the time the Keewatin schist-complex was accumulated. Such stratified sediments as occur with the volcanics are small local deposits that were, probably, laid down by streams or in small lakes.

The iron formations bear out this conception of land conditions. They occur in great numbers at many horizons in the volcanic complex and in all sizes from patches a few yards in diameter to large ones 7 miles or more in diameter. If these iron formations had been formed in a sea or other large and persistent body of water they would not have formed small local bodies but would, rather, be confined to one or a few horizons and to be coalescent in one or a few widespread sheets.

There is also a mechanical difficulty involved in depositing an iron formation such as that at the Helen mine in any large body of water. It would be impossible to deposit carbonate, pyrite, and banded silica in that order of superposition unless deposition of one was complete before deposition of the next began, and this would predicate a change in the composition of the mineralizing solutions from carbonate-bearing to sulphide-bearing and finally to silica-bearing, and would even require, in such ranges as the Goetz, several repetitions of this change. On the contrary, it is evident from the intimate interlamination of siderite and silica that carbonate, pyrite, and silica were being laid down at the same time. There is no difficulty in reconciling contemporaneous deposition of the banded silica, pyrite, and carbonate with a superposition of these members one upon another if the carbonate and pyrite are regarded as having formed just below the surface of the ground by chemical replacement and the banded silica as having been precipitated from solution upon the same surface.

The strikingly-banded character of the banded silica has no doubt had much to do with the belief that the iron formations must have been deposited in a body of water of some sort; but this conclusion seems to require some restriction. A close inspection of the banded silica reveals that the individual laminæ are not uniform and laterally continuous. Many of them are lenticular and the banded silica member is in part at least an imbricated succession of discontinuous layers and lenses. Irregularities of this sort might occur in a clastic sediment laid down in flowing water, but they are not easy to explain in the case of chemical precipitation in a standing body of water.

Attention has also been directed to the conspicuous breccias which occur in the banded silica and which appear to have been formed while the banded silica was still being deposited. Brecciation of this sort is more suggestive of exposure to destructive atmospheric agencies than of the tranquil and uniform conditions which obtain under a standing body of water.

The banded silica contains laminæ of siderite in some cases and of magnetite or hematite in other cases. It is almost certain that the iron was supplied in the first place by the mineral solutions as siderite and later converted into the oxides. This change was apparently not caused by dynamic or contact metamorphism, for under these conditions the siderite, in the presence of silica, is converted into an iron silicate (grünerite or actinolite) after the habit of all carbonates. The conversion of siderite into an oxide probably took place by oxidation either at the time of formation of the banded silica or at some time when it was still exposed to the atmosphere, and this oxide—probably limonite—was later converted into the more compact form of hematite or magnetite.

The three features, irregular lamination, brecciation at the time of deposition, and early conversion of siderite into iron oxide, suggest flowing water and exposure to the air rather than deposition under the seal of a large body of standing water. Apparently the iron formations were formed by ascending heated mineralized waters at many loci in a land area of great volcanic activity. These loci ranged in area from a few yards to 7 or 8 miles in major horizontal extent, and they are to be found throughout the vertical range of the volcanic complex. The heated waters were mineralized with carbon dioxide, iron, silica, and sulphur compounds at least. They permeated the volcanic rocks and converted them to a maximum depth of nearly 250 feet into carbonates and sulphides. In so doing they were protected from atmospheric oxidizing influences. At the surface they probably spread out in depressions and by evaporation and cooling precipitated their content of silica and such carbonate as was not deposited below ground. It is not absolutely certain that the banded silica deposits were formed above ground, but the stratified arrangement of the silica and iron compounds forming them, and their great horizontal extent as compared with their thickness, seem to require this postulate. In some cases these waters may have collected in pools and even extensive ponds, but the lenticular banding, brecciation, and substitution of hematite or magnetite for siderite in other cases seems to imply during part of the time thin and irregular flow over a surface intermittently exposed to the air. In some

such manner hundreds of feet of banded silica were built, and in one of several conceivable ways a laminated structure resembling fine sedimentary bedding was imparted to it. Eventually the iron formation thus formed in a valley or other depression was covered by a flow of ellipsoidal greenstone or other lava, terminating the process at this place, only to have it begun again in some other place at the new surface.

The subordinate beds of banded silica, which in a few cases are found within the carbonate member or at its base, and the subordinate alternations of banded silica and pyrite or carbonate seen in many of the iron formations seem on first consideration to contradict this theory of origin of the iron formations. However, in a region of active vulcanism and rugged topography, it is quite likely that layers of lava or rock debris would become spread over the growing iron formations from time to time, only to be covered up by later deposits of banded silica and converted into pyrite or carbonate by the mineralized waters, thereby producing minor repetitions or complications in the succession of banded silica, pyrite, and carbonate.

The conditions here visualized have probably a close modern counterpart in the volcanic regions of Iceland, Alaska, and Yellowstone park, where geysers and hot springs are depositing silica at the surface and no doubt causing extensive chemical alteration in the rocks through which they ascend. It seems well within the realm of probability that the loci of the Michipicoten iron formations were in early Precambrian time the scene of volcanic hot spring activity on a grand scale.

This conception offers a simple and apparently an adequate explanation for: (1) the formation of the banded silica member by chemical precipitation; (2) formation of the pyrite and carbonate members by replacement of volcanic rock; (3) the shape, irregular lamination, and local brecciation of the banded silica; (4) the occasional substitution in the banded silica member of oxides of iron for siderite; (5) the presence of pyrrhotite, a supposedly high temperature mineral.

According to this explanation the original surface of the ground was the boundary between the banded silica member and the pyrite-carbonate members. It, therefore, explains simply how all three members could have formed simultaneously and yet be deposited in three distinct zones, one above another. In still another respect the surface of the ground seems to have exercised a potent influence upon the character of the iron formation, for in all known instances the pyrite member has its greatest concentration just beneath this former surface and diminishes in concentration downward, and the carbonate member behaves in like manner.

Do the composition and stratigraphic arrangement of an iron formation accord with the theory of origin by ascending heated volcanic waters? Approximate compositions of the pyrite-carbonate member of an iron formation and of the volcanic rocks from which the pyrite-carbonate member was formed by chemical replacement are given, respectively, in columns I and II, following:

	I	II
SiO_2	9·00	60·00
Al_2O_3	3·00	15·00
FeO	32·00	7·00
Fe_2O_3	1·25	2·00
FeS_2	8·00	1·00
CaO	6·00	5·00
MgO	7·00	5·00
Na_2O	.....	2·50
K_2O	.....	2·00
CO_2	31·00	
Mn	2·00	0·50
Zn	0·50	
CuNi, etc	0·25	
	100·00	100·00

Brief consideration of these compositions reveals that to convert II into I, the ascending hot water would require initially to be charged with iron, sulphur, carbonic acid, and lesser proportions of manganese, zinc, copper, nickel, etc., in some state of combination. Lime and magnesia were probably present. During passage through the volcanic rocks iron, sulphur, carbonic acid, and the group of manganese, zinc, copper, etc., were deposited and silica, alumina, and alkalis must have been taken into solution, the water which finally reached the surface of the ground being essentially higher in silica and poorer in iron, sulphur, and carbonic acid than it was before its upward migration commenced. To be in the most soluble form iron would be combined with carbon dioxide as the bicarbonate, $FeH_2\ (CO_3)_2$, a compound which is stable only under considerable pressure and changes to the much less soluble carbonate, $FeCO_3$, when carbonic acid is allowed to escape. The volcanic waters were probably capable at any point of reacting with the rocks through which they permeated, but as the surface was approached, pressure diminished, escape of carbonic acid was facilitated, and iron bicarbonate commenced alteration to iron carbonate, a nascent condition would develop favourable to reaction with the adjacent volcanic rocks, and to their more complete replacement.

A similar relationship between the solubility of pyrite and concentration of sulphuretted hydrogen may explain the increasing upward concentration of pyrite in the iron formations. There is a remarkably similar arrangement of pyrite and silica in modern secondary pyrite deposits; e.g., that at Goudreau, described later in this report. These secondary deposits have been formed just below present ground-water level by sulphate waters that have leached from neighbouring iron formations. The waters which leach from the iron ranges carry large amounts of silica and iron sulphate and as they reach ground-water the sulphate is reduced and precipitated as granular pyrite, and the silica is thrown down above the pyrite as granular white quartz sand. As indicated by an analysis of mine water from the Helen mine, given on a later page, iron sulphate solutions appear to be able to carry in solution

much larger proportions of silica (as much as 80 parts per million) than ordinary water. When these solutions reach ground-water and the iron sulphate is precipitated as pyrite the remaining solution has less capacity for silica, which is then precipitated.[1] In the case of the Michipicoten iron formations, therefore, the banded silica member, found at the surface, may be due, first, to extraction of large quantities of silica from the volcanic rocks by ascending hot, acid waters, and to subsequent precipitation of this silica at the surface, by evaporation, and second, to the solution's capacity for silica having become lessened by loss of carbonic acid and sulphur compounds.

There are so many volcanic formations associated with the iron formations that it is difficult to determine which of these may have been the source of the thermal waters that gave rise to the iron formations. Ellipsoidal greenstones are more characteristically associated with the iron formations than other volcanics, but since they overlie and are, therefore, presumably younger than the iron formations they would appear not to be the causative agent. Nevertheless, as has been described in Chapter III, the ellipsoidal greenstone at Goudreau contains in the spaces between its ellipsoids a crystalline carbonate notably similar to the crystalline limestone member of the underlying iron formation. Moreover, this interstitial carbonate is of the same age as the greenstone, not a later introduction.

DESCRIPTION OF INDIVIDUAL IRON RANGES

Gros Cap and Vicinity

Some small bands of iron formation not represented on Map 1972 occur on Gros Cap peninsula, near Michipicoten Harbour. These were not examined by the present writers. The following descriptions were obtained from reports by Coleman, Willmott, and MacFarlane. On the west shore, near the south end of the peninsula, a band 150 feet in greatest width, consisting of rusty granular silica interlaminated with hematite, occurs in a band of chlorite schist. Another band of iron formation 60 feet wide is exposed on the southeast shore, and a third, still narrower, is situated just around the east point, near the beacon. The first two bands consist of light-coloured granular silica thinly interbedded with hematite, but the third contains magnetite and much pyrite along with the silica. These bands strike southeast (135 degrees) and dip 45 degrees to 50 degrees southwest. A similar band, which may be an extension of one of the above-mentioned, is visible on the west shore somewhat south of the portages across the neck of the peninsula.

As early as 1866, when MacFarlane explored the Lake Superior coast, the iron formations in the southern part of Gros Cap were being developed by J. W. Johnston, of Detroit. A shaft 64 feet deep was sunk in the iron formation on the southeast shore and test pits were made at other places. The ore in the dump consisted of granular silica interbedded with layers of compact hematite from ½ to 4 or 5 inches thick. A sample of

[1] Lenber and Merrill, Jour. Amer. Chem. Soc., vol. 39, 1917, p. 2630.

the hematite analysed by Sterry Hunt yielded: Fe_2O_3, 86·80 per cent; insoluble material, 12·75 per cent; P, trace; S, 0·092 per cent. About 25 feet of the total width of 60 feet contains a greater share of hematite than the rest, and mining operations were mainly restricted to this part.

The operations of 1866 were soon discontinued and in 1899 Coleman found the shaft full of water and the trench overgrown, but the dump could still be seen. Although the mine captain in charge of the operations in 1866 stated that the hematite extended across the full end of the shaft at the bottom, the surface indications and the history of operations do not indicate the Gros Cap iron ranges to be commercially valuable.

Just north of the peninsula (*See* Map 1972) are several narrow bands of iron formation, usually pyrite-bearing and associated with quartz porphyry schist, which dip southward.

A lenticular iron formation about 30 feet thick and 200 feet long, composed of white granular silica and some pyrite and other iron minerals, is exposed on the shore of lake Superior half a mile east of the Harbour. The iron formation is bounded on each side by coarse ellipsoidal greenstone, which is schistified for 2 to 4 feet next the contacts.

Another small iron formation, apparently of no value, was seen just south of the railway at Michipicoten Harbour.

Iron Formations near The Mission

A formation of banded silica and iron oxides about 15 feet thick, with greenstone on either side, outcrops on the north shore of the common channel of Michipicoten and Magpie rivers about a quarter of a mile from lake Superior. The formation being narrow, poor in iron at the outcrop, and heavily drift-covered inland, no attempt to trace it was made.

Another small iron formation was seen at the side of the road from The Mission to Grace mine within mining claim BY 80, known as Barton's claim. According to Coleman, there are two bands of iron formation at this place, one 6 feet wide, the other 4 feet wide, with 7 feet of green schist between. The bands strike at 165 degrees, are vertical, and can be traced southward from the road for 100 feet. The iron formation consists mainly of granular silica banded with darker layers containing a small percentage of iron oxides. It also contains pyrite in thin bands and irregular masses. A dyke of biotite picrite (probably similar to "mica dyke") crosses the iron formation. A 40-foot drift was run along the wider band of iron formation into the side of the hill, and a shorter drift was made in the smaller band. Some gold was said to have been found, but the amount was insignificant.

Gibson Claims

Late in 1922 Angus Gibson, of Sault Ste. Marie, Ontario, found a deposit of carbonates and brown iron ore in the northeastern part of township 29, range 23. This deposit lies just at the edge of the area geologically coloured on Map 1972, but some information about it has been obtained from others who have examined it.

According to an article in the *Canadian Mining Journal* of February 1, 1924, pieces of brown iron ore were first found in the bed of the west

branch of Firesand creek, and by tracing these upstream and examining the adjacent heavily drift-covered country for rock outcrops similar material was eventually found in place. Since then more intensive prospecting has been in progress. By the middle of September, 1924, when the latest information was obtained, a prospecting camp had been built 1½ miles south of the northeast corner of township 29, range 23, and a few hundred feet west of the line, a road had been built thence to the old road between Wawa and Hawk lakes, a large number of trenches had been made to bedrock across the iron-bearing formation, and three diamond-drill holes had been bored to depths of 50, 95, and 41 feet.

The camp is situated on a large sand-plain which extends south, east, and north, but not far towards the west the surface rises as much as 170 feet in a broad ridge where the underlying rocks are exposed in a few places. The iron-bearing formation lies in this ridge. It is described as a band of carbonate, at least several hundred feet wide and about on edge, that extends in a direction of 215 degrees from a point only a few hundred feet west of the camp. It has been traced for about one mile by means of exploration trenches. At the surface the carbonate is decomposed to a crumbly brown iron ore ranging in thickness up to several feet. According to the *Mining Journal* article, the best of the oxidized material contains 67 per cent of iron. Beneath it is a coarsely crystalline carbonate which is evidently the primary ore material and no doubt extends far downward. This carbonate is probably a mixture of the carbonates of iron, lime, etc.

Samples of the carbonate supplied by G. W. MacLeod, mining engineer, of Sault Ste. Marie, bear little resemblance to the siderite of the Helen and other iron ranges. They are much coarser and more nearly like the crystalline limestone of the Goudreau range. No banded silica is reported to be associated with the carbonate, but crystalline limestone is said to occur for as much as a quarter mile northwest of the iron-bearing carbonate band. It is doubtful, therefore, whether the Gibson deposit is a true iron formation, and its geological nature cannot be decided until more information is available.

The superficial zone of brown iron ore is not thick enough to constitute a commercial body of iron ore unless a deeper pocket, of the same character as the Helen and Josephine ore-bodies, be discovered. Whether such a pocket exists depends: (1) upon the presence of enough pyrite mixed with the carbonates to form, by oxidation to sulphuric acid, a strong solution for decomposing iron carbonate to iron hydrate; and (2) upon the existence of a natural preglacial depression in the carbonate formation in which this acid solution would be collected and held. There is on one of the claims a small marsh which may have served this purpose, though it may only have been formed by glacial action and not have existed long enough to produce a large body of brown ore.

Diamond-drill hole No. 1, situated on the northern edge of the small marsh, had been drilled vertically to a depth of 50 feet in September, 1924. In October, hole No. 2, located 20 feet southwest of No. 1, was down 94 feet at an angle of 70 degrees and a direction of 355 degrees; hole No. 3, situated about 500 feet southwest of No. 2, was down 41 feet at an angle of 63 degrees and a direction slightly north of west. The material

encountered in all these holes is said to be much alike, "largely limestone mixed with iron carbonate, the whole core being stained red from oxidation of the iron carbonate." The core from hole No. 2 is described as:

	Ft.	In.	Ft.	In.
Light-coloured crystalline limestone	1	–	5	–
Same, but stained reddish	5	–	9	–
Fair hematite	9	–	9	2
Core lost	9	–	10	–
Altered carbonate containing considerable iron	10	–	10	6
Crystalline limestone	10	6	15	–
Core badly broken; contains fair percentage of iron	15	–	16	6
Limestone with some altered iron carbonate	16	6	25	–
Same	25	–	80	–
Core lost	80	–	83	–
Same as 25 ft. to 80 ft	83	–	84	–
Core lost	84	–	85	–
Same as 25 ft. to 80 ft	85	–	93	–
Light-coloured crystalline limestone	93	–	94	–

The core of this hole sampled to a depth of 80 feet is reported to have yielded on analysis the results given in column I; and a sample of oxidized material from 17 feet across the surface, the results given in column II.

	I	II
Fe	25·60	55·5
SiO_2	1·98	1·00
CaO	14·58	0·96
Loss on ignition	24·58	12·16

Iron Formation Near Mile 3 on Railway from Michipicoten Harbour

A little south of the railway, where it is crossed by the great fault 3 miles from Michipicoten Harbour, there is an iron formation 15 to 20 feet wide, which dips about vertically. Traced southward it becomes narrower and apparently ends a few hundred yards in that direction. It consists entirely of white layers of silica about half an inch thick that alternate with dark grey layers of similar thickness composed of silica and magnetite. Although the fault-plane at the railway is in drift-covered ground the iron formation is presumably interrupted and displaced northwestward, for it could not be found on the east side of the fault. Search was accordingly made for its faulted extension east of the fault at the same distance south of the Dore conglomerate as it was found at the railway. The extension was found within a few yards of the granite which forms the opposite (west) wall of the fault, and was traced northward for 2,000 feet with the aid of a dip-needle. Although it was lost farther northward the iron formation probably continues northward and eastward, for up to the last outcrop seen it had gradually widened to 60 feet. The part east of the fault consists, like that on the west side, of alternating white and dark grey laminæ, the average iron content of which probably does not exceed 15 per cent. No pyrite or siderite was seen in the few natural outcrops, though these constituents may be present under the drift cover. If further exploration of this iron formation be undertaken its extension should be looked for eastward a few hundred feet south of the Dore series.

Goetz Range

The Goetz iron range lies in townships 29 and 30, range 24, about half a mile south of Magpie river. According to Coleman[1] it was discovered about 1906 by Messrs. Alois and George Goetz, of Sault Ste. Marie, Michigan. The whole range is included within ten mining claims, numbered Y 424 to Y 433, which belong to the discoverers.

The range commences a short distance east of Y 424 as a band only about a yard wide and increases steadily in thickness to 450 feet at the west end. It occupies the middle of a ridge which also gradually increases in height and steepness from east to west. At the west end the ridge stands precipitously about 150 feet above the flat sand-plain which bottoms the valley of Magpie river. This abrupt termination is about in line with a fault which crosses Black Trout lake and it was thought that the iron formation, since it has its greatest thickness at this place, might have been faulted southward. Accordingly, a dip-needle was used along Magpie river and the south boundary of township 30, range 24, in an endeavour to locate the faulted extension. The rocky country southwest of the river was also explored with some care, but no trace of an iron range was found. Seemingly, the Goetz range ends on the west in the same blunt manner as the Helen range. It is displaced, however, an horizontal distance of 250 feet, by a fault which crosses claims Y 429 and 432.

Shortly after the range was found the discoverers explored it methodically by digging cross trenches through the drift cover at intervals of about 60 feet. These trenches are now partly filled in except on the steep sides of the ridge. It could be seen, however, that the range, which dips 70 to 90 degrees to the south, consists of about 100 feet of banded silica, on the south side, followed towards the north by alternations of carbonate, silica, and volcanic rock. In 1906, when the trenches were fresh, E. S. Moore[2] measured a section along a trench situated apparently not far from the township line. He found, from south to north: banded silica of important thickness; impure carbonate; volcanic schist; impure carbonate; weathered granular silica; impure carbonate; banded silica with some interbedded volcanic rock; volcanic schists. This section is fairly representative of the range from Y 425 westward, where it is 200 to 450 feet thick.

According to the location of the range just south of the Dore series, the top of the now upturned iron formation should be on the south side. This is supported by the occurrence of the main body of banded silica on the south side, but on the other hand the recurrence of beds of granular silica within and beneath the carbonate member, together with the poorly developed pyrite member, tends to obscure the orientation of the iron formation.

The silica members of the formation vary considerably in appearance from place to place. In part they consist of granular white or rusty quartz without distinct banding, and other parts are fairly well banded, consisting of narrow white layers of quartz alternating with grey laminæ composed of a mixture of quartz and iron oxides, principally magnetite.

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[1] Ann. Rept., Ont. Bureau of Mines, 1906, pp. 181-183.

[2] Ann. Rept., Ont. Bureau of Mines, 1906, p. 182.

Near the west side of Y 428 and towards the south side of the range is a considerable thickness of pyrite mixed with carbonate and silica. The deposit is too low in grade to be pyrite ore. Elsewhere pyrite is uncommon and forms only small masses.

The siderite appears to be rather siliceous, but, as no samples were taken in 1919 for analysis, and as no analyses are given by Coleman and Moore, the quality of the material as iron cannot be positively stated. The bands of siderite are not over 30 feet thick and not likely to be seriously considered as sources of ore while much larger bodies, like the Helen, are available close to the railway.

A smaller iron formation, not over 25 feet thick, lies about 200 feet north of the main Goetz iron formation. It consists wholly of banded silica and seems to have no commercial value.

The volcanic formations on either side of the main iron formation are chiefly quartz-porphyry and other schists of acid or intermediate composition. The ellipsoidal greenstone so commonly found next the top of other iron formations is not present. Moore mentions a band of sedimentary material (Eleanor slate) on the north side of the range.

Helen Range

The Helen range, in the southwestern part of township 29, range 24, is more favourably situated with respect to the railway and lake Superior than any other large iron range in Michipicoten district, and contains the largest known body of siderite. The whole range and a considerable tract of country on either side is included in a group of mining claims owned by the Algoma Steel Corporation, of Sault Ste. Marie, Ontario.

The range lies along the crest and northern side of a broad and high ridge from its western end to mining claim JL 104. This ridge rises quite steeply from Talbot lake, but is divided into a sharp northern ridge and a broader southern area of high ground by a depression which contains Sayers and Boyer lakes. East of Boyer lake there is a single well-defined ridge that stands 350 feet above the country just to the north, and about 1,700 feet above sea-level. The highest point in claim R 732 affords a commanding view of the surrounding country, a bare hill near Magpie mine being visible in clear weather. Thence eastward the ridge becomes narrower and somewhat lower. At the east side of JL 104 it ends abruptly at a steep, narrow gully which extends northwestward to Walbank lake. The north side of this ridge is straight and steep, whereas the southern slope is gentler and irregular.

The gully at the east side of JL 104 evidently coincides with a fault-plane, for it is bottomed by a dyke of the older series of diabases, and the iron formation is not found on the eastern side in line with the main range but is displaced 1,500 feet northward. This eastern extension lies in comparatively level ground, so covered with drift that few exposures of the iron formation occur.

At its western end the Helen range forks into a broad northern part, which reaches Talbot lake, and a slender southern part, which Coleman[1]

[1] Ont. Bureau of Mines, 1902, pp. 167-168.

thinks may extend under the lake for a short distance. Neither fork appears on the west side of the lake and no indications were seen of any considerable fault in this vicinity, so the range is believed to end at Talbot lake. When the two forks unite, near Sayers lake, the iron formation has its greatest width, about 1,200 feet. Thence eastward it decreases in width to 40 feet at the last observed point east of Walbank lake. At the western side of claim R 732 it is crossed by two dykes of diabase and is faulted along both. The western dyke averages 50 feet in width and belongs to the older series of diabase dykes in the region. Most of the faulting at this place probably coincides with this dyke. The eastern dyke is 55-60 feet wide, and belongs to the younger series of fresh diabase. Between the dykes the iron formation has been turned almost at right angles with the iron range on either side and has been considerably sheared and recrystallized. At the east side of claim JL 104, where the deep gully brings the ridge to an abrupt end, the iron formation is again faulted towards the northwest for 1,500 feet. The faulted eastern extension was traced eastward for a short distance beyond claim DJ 55. It is less than 40 feet wide where last seen and evidently fades out entirely if it does not join the Eleanor range.

When it was realized, about 1912, that the old Helen hematite mine —which was a large pocket of oxidized siderite near the west end of the Helen range—would be exhausted in a few more years, its owners, the Algoma Steel Corporation, turned to the siderite in the range as a further source of iron ore. Between 1913 and 1917 the surface of the range was thoroughly explored by trenches dug through the drift and the iron formation was systematically bored, the drill-holes ranging in depths from about 500 feet to 2,444 feet (Figure 10). Between October, 1917, and October 4, 1918, further preparations for mining were made by driving an adit from the north side of the range into the siderite and branches thence east and west along the ore-body, at about 300 feet below the crest of the ridge (Figure 10). As a result of all this exploration the Helen iron formation is better known than any other iron formation in Michipicoten district.

The iron formation stands on edge, with its top towards the north. From north to south there appear: (1) a very thick banded silica member constituting from two-thirds to seven-eighths of the total thickness of the iron formation; (2) a faintly marked pyrite member not over 60 feet thick and consisting of siderite with not more than 50 per cent of pyrite; (3) a siderite member of variable thickness up to 240 feet. The country rock on either side consists of volcanic schists, those on the south, or under, side being more acid and containing more pyroclastic materials than the north, or upper, side. At most places a thin sheet of banded silica, 10 feet or so in thickness, lies near or at the bottom of the siderite. Almost all the diamond-drill holes were driven from the south side so as to avoid penetrating the very hard, banded silica member. These holes indicate that the iron formation dips towards the south from 70 degrees to 80 degrees; in other words it is overturned from 10 to 20 degrees.

The banded silica member is 1,000 feet thick between Boyer and Sayers lakes, according to Coleman's survey. Eastward from there it

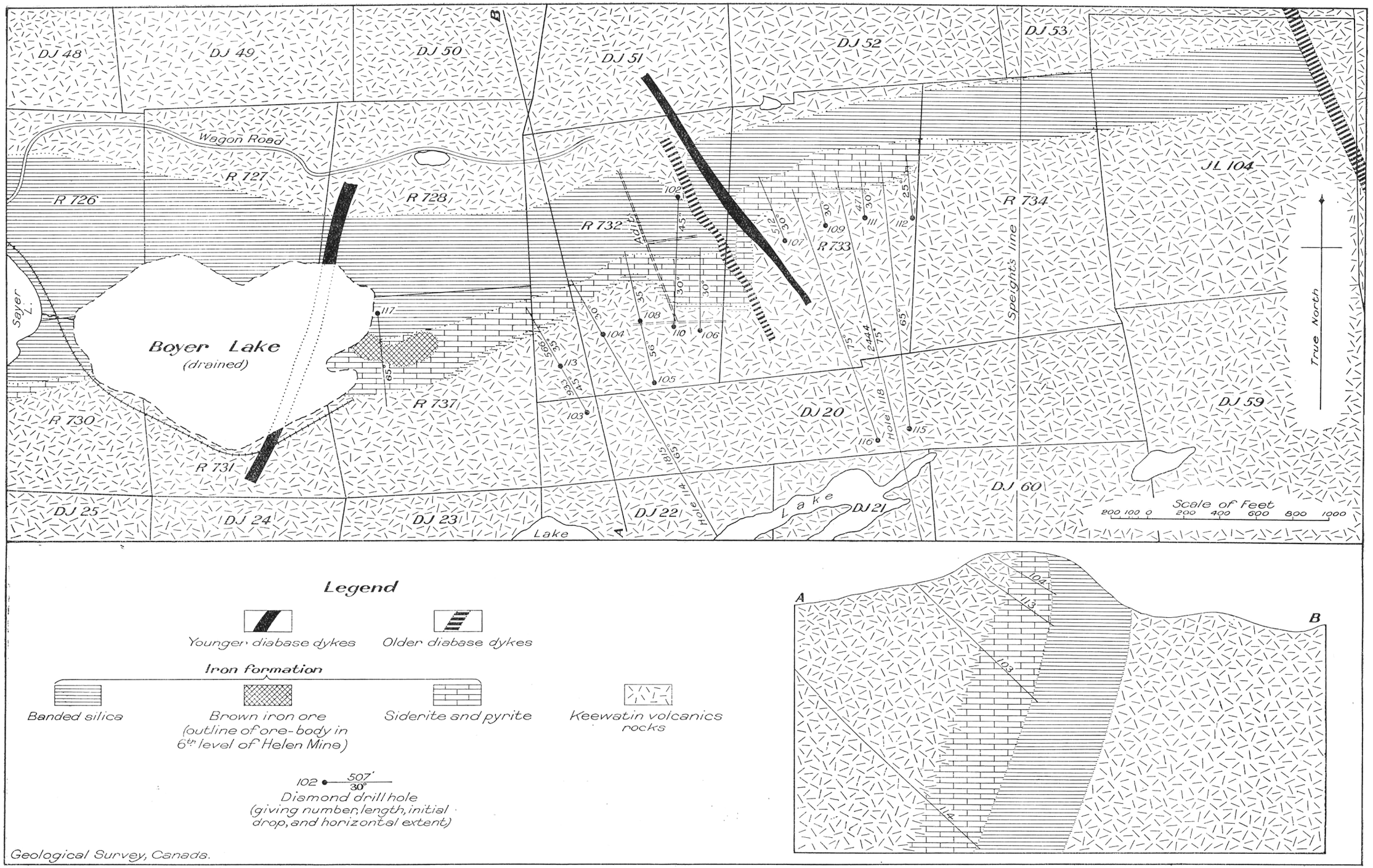

Figure 10. Plan and vertical cross-section of main part of Helen iron range.

becomes thinner, being about 450 feet near the adit, 300 feet east of the two dykes in R 732, 300 feet near the Walbank Lake fault, and about 40 feet wide east of DJ 55. In the newly-driven adit the banded silica consists of white quartz layers from a quarter to half an inch thick, alternating regularly with somewhat thinner pink layers composed of siderite mixed with silica. On exposure the siderite layers soon weather brown through oxidation to limonite, thus producing a striped rock of considerable beauty. North of Sayers lake the iron-bearing layers contain magnetite instead of siderite and are in various shades of grey. The formation is also more finely laminated and considerably brecciated. Between the two dykes east of the new adit the iron-bearing layers contain a bright green hornblende, along with magnetite. At other places a friable granular silica without distinct lamination is found. The siderite variety is probably the primitive type from which the others have been developed by different processes of metamorphism.

At places on the surface and in some of the drill-holes a sheet of the banded silica member 15 feet or less in thickness lies at the south side or base of the iron formation.

Just beneath the main banded silica member the siderite contains an inconspicuous but unfailing concentration of pyrite which corresponds to the more prominent pyrite member in other iron formations. The thickness of this pyrite member cannot be measured precisely owing to the gradational manner in which it passes downward into the siderite, but in the new adit it is between 5 and 10 feet thick and in the drill-cores attains 60 feet. Its presence in drill-holes 107 and 114 is shown in Figure 5. The sulphur content of the pyrite zone in six drill-cores ranges from 4·50 to 28·81 per cent as follows, the analyses, kindly supplied by the Algoma Steel Corporation, being each made on 10 feet of drill-core.

Hole	Approximate thickness of pyrite zone	Sulphur content
	Feet	Per cent
103	55	11·24 — 28·81
107	50	7·08 — 14·95
111	22	8·25 — 15·84
113	60	11·83 — 19·47
114	50	4·50 — 15·65
118	60	6·69 — 22·06

The pyrite is in the form of crystals and irregular grains disseminated through a groundmass of siderite. A small proportion of pyrrhotite is mixed with the pyrite. Concentration is greatest just under the banded silica member and diminishes at increasing distance away from it.

The siderite member extends from the west end of Boyer lake eastward to claim R 734, a distance of slightly more than a mile, beyond which it tapers out at both ends. In this mile the thickness varies from 50 to 240 feet. At the east end of Boyer lake it has been oxidized from the surface downward to form a pocket of brown iron ore 700 feet by 200 feet and 651 feet deep, which constitutes the old Helen mine, now worked out;

but the siderite, in all likelihood, continues underneath. Along its northern side the siderite becomes increasingly charged with pyrite for a thickness of 10 to 50 feet, forming the pyrite member, but ends abruptly against the banded silica member. On the south side it is bounded sharply by a thin sheet of banded silica, wherever the latter occurs, but elsewhere there is a transitional change into the acid volcanics, by diminution of carbonate and alteration of siderite and rock, which is complete in from 10 to 60 feet.

In appearance the Helen range siderite varies a good deal. Prevailingly it is a dense, light grey or pink rock speckled with bright grains of pyrite. It is much harder than pure iron carbonate, owing to the admixture of quartz grains and other rock-forming silicates, and is easily mistaken, on first acquaintance, for an altered acid volcanic rock, though the specific gravity is 2·90 to 3·00. Every drill-core, however, shows imperceptibly easy gradations from this relatively pure phase into lean phases consisting of siderite mixed with volcanic schist or even into slightly sideritized schist. These lean parts are of different thicknesses up to about 50 feet and no correspondence in position within the siderite member between the lean parts is found in the different drill-holes.

The lean parts in holes 107 and 114 are indicated in Figure 8, and as much difference in distribution was found in holes 103 and 113, one of which (113) is directly above the other. These lean parts seem undoubtedly to be vestiges of Keewatin lavas which were only partly replaced, chemically, by carbonates, and their occurrence from bottom to top of the siderite and pyrite members implies that these members of the Helen range were originally lavas. If they were intrusive dykes they would have well-defined edges and would pursue regular courses through the siderite. If they were lavas laid down on the surface of the siderite as it formed they should be found at corresponding depths in the different drill-holes. These replacement vestiges or "ghosts" of the original volcanic rock appear to be about as abundant towards the top (north side) of the siderite member as towards the bottom. Comparison of the analyses made by the Algoma Steel Corporation of the drill-cores, showing their contents of iron, silica, and sulphur for each 10 feet, indicate, however, that the siderite is slightly better in quality towards the top.

The varying quality of the siderite may be seen from the following analyses, supplied by the Algoma Steel Corporation.

—	I	II	III	IV	V
Fe	23·41	41·36	44·96	34·94	35·82
SiO_2	36·87	3·90	2·55	9·348	7·70
S	0·40	3·91	5·55	2·387	1·65
P	.....	.....	.....	0·013	0·012
Mn	.....	.....	.....	2·00	2·08
CaO, MgO, Al_2O_3	.....	.....	.....	.....	10·96
Loss on ignition	.....	.....	.....	31·83	31·55
Fe (roasted ore)	.....	.....	.....	51·40	52·33

I. Lean ore, mixed with schist, 1,492 to 1,500 feet, drill-hole 114.
II. Rich ore, from 1,700 to 1,710 feet, drill-hole 114.
III. Rich, pyritic ore, from 440 to 450 feet, drill-hole 113.
IV. Average of series of analysis of samples from No. 2 east and No. 2 west drifts from new adit (sulphur unusually high because the drifts run close to the north side [top] of the siderite body).
V. Average of drill-core analyses of ore-body beneath the level of the new adit and drifts (CaO, MgO, and Al_2O_3 by difference).

Between October 1917 and October 4, 1918, an adit 890 feet long was driven from a point on the north side of the Helen ridge and about 300 feet below its crest, penetrating through the banded silica member to the ore-body of siderite (Figure 10). A No. 1 east drift was run eastward 285 feet through banded iron formation and the west dyke of diabase, the intention being to extend it along the ore-body east of the dykes. No. 2 east drift and No. 2 west drift were run 263 feet and 244 feet along the northern edge of the siderite. The main adit is 12 feet by 8 feet in cross-section, each of the drifts is 8 feet by 8 feet, and all have an outward gradient of 0·6 per cent for drainage. It has been estimated from data obtained by diamond-drilling and surface exploration that the ore-body contains between 69,000,000 and 100,000,000 tons of ore in a depth of 1,700 feet, 11,000,000 tons of which lie above the adit and its drifts. The difference in the total estimates is due mainly to uncertainty regarding the past of the ore-body that lies between the two diabase dykes. The smaller estimate contains no allowance, whereas the larger one is made on the assumption that a wedge of ore of commercial quality will be found between the dykes, which diverge in depth. At the surface between the dykes the iron formation is turned almost north and south, the siderite member has a small area of exposure, and the siderite is partly altered to green hornblende (grünerite).

Eleanor Range

The representation of the Eleanor iron range on the accompanying geological map and the following description are based mainly upon an earlier map and report by Coleman.[1] This range attracted attention many years ago because of the rusty cliffs which rise almost vertically just east of the old portage road between Wawa and Eleanor lakes. It was taken up as one of the Johnston locations. Eastward from the road the range forms the backbone of a well-defined ridge about 200 feet high. At a distance of 2,200 feet it is cut off by diabase. The iron range is probably faulted northward and continues eastward since it is quite wide where it ends against the diabase, but no attempt has been made to find the continuation. The range is evidently also faulted along the course of the old portage road, for the iron formation is abruptly displaced southward 800 feet along a steep-sided gully, in the bottom of which the road is situated. Two small knobs of granular silica, possibly faulted fragments of the range, occur in the side of this gully. No description is given of the western part, which extends in the direction of the Helen range, but it is not unlikely that the range extends farther than represented on the map.

"A section going south from lake Eleanor shows greenstone, partly with ellipsoidal structure, partly massive-looking, very fine grained, and splintery. A little lake occupies a valley between the greenstone and the iron range, which rises as a steep ridge commanding the country. The north side of the ridge is granular silica interbanded with a small amount of iron ore to the width of 250 feet, followed by 25 feet of siderite somewhat interbedded with quartz porphyry schist, and then by 1,000 feet of the schist with little siderite."

[1] Rept. Ont. Bureau of Mines, vol. XI, p. 160.

"Associated with the granular silica and siderite are the usual thin sheets of black slate pitted with small cavities, once occupied by pyrite. The slate is not more than a foot or two thick and appears to underlie the other members of the iron range, resting between them and the quartz porphyry schist."

Evidently the top of the iron formation lies to the north, as in the Helen range. As seen in the cliff on the east side of the old road the formation dips almost vertically with a slight inclination southward. Years ago some trenches were made through the drift to expose the iron formation, but no diamond-drilling has been done.

Iron Formation at Mile 12

Close to mile-post 12 on the railway from Michipicoten Harbour rusty iron formation is exposed on the west side of the track. The exposure, which is not over 100 feet across in any direction, consists mostly of a breccia of white and dark siliceous material discoloured with limonite, but on the southwest side is a small quantity of pyrite mixed with siderite. An attempt was made to trace the formation away from this outcrop, but all the adjacent outcrops of rock are Keewatin volcanics, and dip-needle traverses across the drift-filled intervals revealed no exceptional magnetic disturbance. Apparently the iron formation is a small faulted piece of a range, not far away, which has not yet been discovered. The most likely place in which to seek the main part of the iron formation is about 1,000 feet south of the exposure at mile-post 12 and west of the fault indicated on the map.

Brooks Lake Range

The most extensive iron formation in Michipicoten map-area outcrops in a belt 7 miles long, commencing at the east side of Mildred lake and terminating again at the granite in the southeast corner of township 28, range 25. This belt is dislocated by faults into three parts, of which the westernmost, extending from Mildred lake to a point south of Baldry lake, is called the Brooks Lake range. The Brooks Lake range is contained within eight mining claims, KW 32 to 40.

The range is not well exposed at its eastern extremity in KW 40, but from the western side of this claim to Mildred lake it forms a pronounced ridge scarcely wider than the iron formation itself, with steep sides, and 150 to 250 feet high. The fault at the eastern end could not be precisely located, but probably lies close to the watercourse between Baldry and Loonskin lakes. Westward to KW 32 the iron formation is from 275 to 600 feet wide and is not interrupted except by two dykes of younger diabase, one about 100 feet wide, the other much smaller, which cross claim KW 35. In KW 32 the formation bends southward, narrows to less than 100 feet, and could not be traced farther. If it continue, it should swing parallel with the north side of the V-shaped band of Dore sediments, but a careful search revealed no trace of iron formation.

The iron formation stands on edge with its top facing northward. Volcanic schists of various kinds lie on the north side, followed by a banded-

silica member which occupies the ridge and constitutes nearly the whole thickness of the iron formation. Along the south base of the ridge there is a siderite member that ranges from almost nothing to 160 feet in width and apparently takes the form of a series of lenses. The siderite grades southward into volcanic schists, prevalently of light colour and acid composition. No distinct pyrite member was seen between the siderite and banded silica, but some of the siderite is heavily charged with sulphides. It seems very likely that a pyrite member, perhaps of considerable thickness and concentration, would be found if the range were drilled, for the central and eastern sections of this 7-mile iron formation show a well-defined pyrite member in places.

In 1911 W. M. Goodwin examined, for the Algoma Steel Corporation, the siderite bodies along the south side of the Brooks Lake range. He found a lens of siderite 100 feet wide and 500 feet long which crosses the line between KW 32 and 33. A second lens commences in KW 33, 350 feet from its eastern boundary, and extends eastward into KW 34 for a total length of 950 feet. It is 30 feet wide at the west end, 160 feet wide on the line between KW 33 to 34, 105 feet wide at 100 feet east of this line, and 30 feet wide for the last 300 feet at the east. One hundred feet east of this lens is a third one, 1,050 feet long and 60 feet wide, that extends for 300 feet into KW 35, where it merges into lean sideritized volcanics. Near the southeast corner of KW 35 is a fourth lens, about 50 feet wide, which is cut across by the diabase dykes shown on the map. On the east boundary of KW 39 the banded silica is followed by 140 feet of rather lean sideritic rock, and then by drift.

Ten years or so before the Brooks Lake range was mapped by the senior author in 1918, it had been well exposed by numerous trenches to bedrock across the ridge, but these trenches had partly refilled with earth, except on the steeper slopes. No diamond-drilling has been done and no analyses of the siderite are available.

A quarter mile or so north of the Brooks Lake range is a belt of sedimentary rocks—conglomerate and greywacke—which seems to have been taken up as an iron range, and is known as the Arnott-Wilkes range. Numerous trenches have been dug to bedrock across this belt, and near the northwest corner of SSM 1704 the rock has been prospected by a shaft and an adit just south of the sediments. The shaft was full of water when visited in 1918, so its depth and results could not be ascertained. The adit is driven about 20 feet southward on the side of a hill, which rises higher in that direction. It penetrates a greatly brecciated mixture of siderite, pyrite, and granular silica, the surface of which weathers to a porous black gossan. In the end of the adit is massive, blue-grey siderite, rather lean-looking and finely sprinkled with pyrite.

Long Lake Range (Ruth Mine)

The middle faulted section of iron formation next to the Brooks Lake section is known as the Long Lake range, or the Ruth iron mine. It is $1\frac{1}{6}$ miles long and extends from the south end of Baldry lake along the south side of Cuthbertson (Long) lake. The main part is included in mining claims KW 41 and 42 and Y 454 and 455, owned by Alois Goetz.

Along the south side of Cuthbertson lake the range rises steeply from the water's edge for about 200 feet, forming a broad-backed ridge. This ridge becomes lower and less conspicuous towards each end of the iron range. The iron formation is terminated at the southwest by a fault which evidently extends the length of Baldry lake. At the northeast it is cut off by a dyke of older diabase 140 feet wide which occupies another fault-plane. In KW 41 it appears to be offset 300 feet by a fault which strikes about 20 degrees north of west and it is crossed near the south end of this claim by a dyke of younger diabase 90 feet wide. The iron formation is 225 feet wide at the southwestern extremity, but a quarter-mile northeastward it thickens to 400 feet and from there on has a width of 400 to 700 feet. It stands on edge, with the top facing northwestward.

At the southwest end a banded silica member, composed of granular white quartz interbanded with narrower black bands containing iron oxides, rises from the edge of Baldry lake. It is about 200 feet wide and is followed by 30 feet of pyritiferous, blue-grey siderite coated with brown iron oxide. Another cross-section at the south end of Cuthbertson lake showed 400 feet of banded silica of the sort mentioned above, followed by 20 feet or so of siderite, beyond which is a light grey, fine-grained porphyry. The Keewatin rocks on the northwest side of the iron formation between Long and Baldry lakes are mostly ellipsoidal greenstones and other dark lavas, whereas those in the southeast side are prevalently light-coloured schists, distinctly fragmental in places. Another fine section is exposed in rock-cuts along the railway which crosses the iron formation at an angle of about 45 degrees. From south to north the section shows a pale grey feldspar porphyry schist which grades into 15 feet of lighter-coloured siderite. There follows a depression 35 feet wide filled with gravel cemented together with limonite. Beyond this is about 40 feet of pyrite, then some quartz banded with hematite, followed by 40 feet of pyrite mixed with siderite. This is succeeded by 200 feet of banded silica, an interval of limonite-cemented bouldery drift, and 150 feet more of banded silica of more granular, sugary texture. The next outcrop is a dark grey lava. This body of pyrite is thought to extend 1,000 feet or so southwest of the railway, for limonite and some pyrite can still be seen in the old trenches in that direction.

Coleman[1] tells of an opening one foot in diameter, situated on the hill-side overlooking Cuthbertson lake which leads downward into a cavern 25 feet deep and of unknown but probably not great width, that is thought to be a solution cavity.

It is said that an adit was driven into the iron formation years ago from a point near the water's edge on the southeast shore of this lake. This adit and the surface trenches, which can still be seen on the top of the ridge, are said to have revealed a siderite deposit 2,000 feet long, 200 feet in greatest width, and in most places 100 to 140 feet wide. This body was estimated by Mr. Alois Goetz to contain 3,000,000 tons of siderite above the adit, which is 150 feet below the surface outcrop. The owner reports the average composition of the siderite to be: Fe, 35·00; SiO_2, 8·00;

[1] Ann. Rept., Ont. Bureau of Mines, vol, XI, p. 173.

CaO, 5·08; MgO, 6·71; P, 0·012; S and Mn not determined. Owing to the proximity on the railway of a large body of pyrite and the prevalence of pyrite in the 7-mile belt of iron formation to which this belongs, it seems likely that the above siderite body would be found on further investigation to be pyritiferous. An analysis given on page 62 of the pyrite exposed along the railway, indicates it to contain 50 per cent of pyrite, though somewhat too low grade to be a pyrite ore.

In constructing the railway around Leg lake, just southeast of the Long Lake range, a rock-cut was made through a mass of siderite about 100 feet thick, situated between the two southern bays of the lake. This body, which is probably not of great size, contains no banded silica or pyrite. It appears to be a part of the surrounding green schists which has been converted more or less completely into carbonates by a process of replacement, for at its margin it grades in a distance of 30 feet from a massive siderite without visible admixture of volcanic schist into ordinary green schist. The siderite mass is intersected by small, lighter-coloured veins of purer carbonate. Though no sample was analysed a considerable part of the body looks as if it contained 30 to 35 per cent of iron.

Bartlett Range

At the east end of Long Lake range the iron formation is faulted northwestward 3,000 feet and from there extends eastward in a gentle curve for 3⅔ miles to the granite. The western half of this range is known as the Josephine property and will be described later as one of the secondary iron-ore deposits. The remainder, east of mining claim Y 453, is known as the Bartlett range, after Mr. James Bartlett who, with W. M. Goodwin, located it for the Algoma Steel Corporation.

The Bartlett range forms a fairly continuous steep-sided ridge up to 150 feet in height, that sinks only at the eastern end and at Kimball lake, the small sheet of water which occupies the second mining claim east of Y 453. It is faulted slightly in one place, but is intersected by numerous dykes of younger diabase. The iron formation stands on edge, with its top facing north. The dip varies from a few degrees less than vertical towards the south to a similar amount northward. In the two easterly claims the iron formation is only 80 to 150 feet thick, but the remainder is from 250 feet to 550 feet thick. The volcanic rocks on either side vary considerably from place to place, but the same types, mostly light-coloured, fairly acid rocks, are found on either side. Banded silica is the preponderant member, forming not less than two-thirds of the total thickness of the iron formation at any point and in some places nearly all of it. As in the Long Lake and Brooks Lake ranges, it is almost white, the amount of iron oxides interbanded with the quartz being subordinate. A siderite member appears to be fairly continuous along the south side of the range, and in the upper part of the siderite, next to the banded silica, there is a concentration of pyrite, quite distinct but not rich enough to form pyrite ore. The siderite appears to merge southward into Keewatin schists.

In 1912 the Algoma Steel Corporation stripped and diamond-drilled a part of the Bartlett range in the fourth and fifth claims from the east

end, revealing a band of siderite 2,000 feet long. Drill-hole No. 1 is situated in the fourth claim from the east end of the range, on the northeast corner of a small pond shown on the map and 90 feet south of the iron formations, towards which it was drilled at an angle of 55 degrees from the horizontal. Hole No. 2 is on the south side of the same pond, 350 feet south of the iron formation, and was drilled at an angle of 50 degrees. Hole No. 3, situated east of the pond, is about 400 feet south of the iron formation and dips at 53 degrees towards it. All three holes, after traversing the volcanic schists in which they start, pass through a band of high-grade siderite, 42 to 64 feet in true thickness, and then through 24 to 200 feet (true thickness) of leaner pyritic siderite before entering the banded silica member (cf. Figure 5, section V). Systematic analyses of each 10 feet of drill-core by the owners indicate the high-grade sheet of siderite to contain as large a percentage of iron as the Helen Range siderite, but considerably more sulphur. The lean pyrite part, similarly analysed, shows from 7·17 to 36·06 per cent of sulphur, or not sufficient to constitute a pyrite ore.

A quarter-mile south of Kimball lake is a thin iron formation lying parallel to the Bartlett range, which can be traced for about 1,500 feet. Where best developed it is only about 30 feet wide and is composed of granular white silica and a blue-grey sideritic material, impregnated with pyrite, which merges into the adjacent volcanic schist.

A mass of sideritized rock very much like the Leg Lake mass in appearance and relationship to the volcanics, occurs at the west end of Siderite lake, a pond situated partly on the second claim from the east end of the Bartlett range. The siderite seems to be of fairly good quality, but the mass is probably small.

Iron Formation Southeast of Loonskin Lake

Several small bodies of iron formation which may be fragments of a formerly more continuous belt occur roughly aligned along the southeast side of Loonskin lake. None of these fragments could be traced for more than a few hundred feet, however, and they do not seem to be of economic importance.

A small outcrop of granular silica mixed with pyrite occurs just south of the portage from the south end of Loonskin lake. Coleman states that this material was staked for gold and that an analysis of the pyritous material does show a trace of gold. A band of similar material about 20 feet thick is exposed on the shore of the lake one-third mile northeast from the portage. The vicinity is too thickly drift-covered to admit of tracing the iron formation away from the shore. A third outcrop of iron formation is reported to occur on a rather high hill which lies 1½ miles up the lake from the portage and a quarter-mile inland, but this exposure could not be found.

Iron formation is again exposed at the narrows half-way up the lake. Here it is around 60 feet thick and consists, next the water, of a body of pyrite and pyrrhotite about 20 feet thick succeeded inshore by a banded silica member composed of white granular silica interbanded with darker

iron-bearing layers. When examined in 1918 an adit had been driven into the iron formation from a point about 30 feet above the water's edge by John Holdsworth and John McEwen. The pyrite did not seem to be extensive and was scarcely pure enough to meet the requirements for a pyrite ore. The iron formation could not be followed northeastward more than 800 feet. On the southwest it ends abruptly at a dyke of older diabase, nearly 200 feet wide, which strikes northwestward and cuts off the Long Lake and Josephine ranges. As this dyke evidently coincides with a fault-plane, the displacement along which is 3,000 feet at Long lake, it is presumed that the iron formation on Loonskin lake is also faulted, and that part of it should be found on the southwest side of the dyke opposite McEwen lake. No particular search was made for it, in 1918, because the facts relative to the fault were not then known.

Two-thirds of a mile northeastward along the shore from Holdsworth's adit is another small band of white, granular silica which can be traced inland for a few hundred feet. Beyond this, in about the place indicated on the map, is a body of siderite which was prospected years ago by Dr. Robert Bell.

Brooks Ranges

A mile and a half north of the Bartlett range, in the middle of township 28, range 25, prospectors for the Algoma Steel Corporation have found three sections of iron formation, each about 4,000 feet long and in fairly close alignment, which are, probably, continuous with one another except for such faults as have displaced them locally. From east to west the three known sections are called Brooks No. 1, Brooks No. 2, and Brooks No. 3, respectively. All three parts stand on edge and appear to have their tops facing southward, but more detailed exploration is required to establish this point.

Brooks No. 1 is a strip of iron formation not over 125 feet wide and not of sufficient size to form the usual characteristic ridge. The eastern part is 50 to 125 feet wide and is reported by W. M. Goodwin to consist mainly of banded silica, with a narrower band of impure siderite along the south side. The siderite has a varying content of pyrite that in places is fairly pure. At 800 feet from the west end, the formation narrows to a few feet of black, slate-like pyritic material. At the westernmost exposure, situated in a swamp, the iron formation is 25 feet wide, and consists of banded silica, black and slate-like in places and carrying disseminated pyrite.

Although the iron formation probably continues towards Brooks No. 2, it is concealed by swamps and is probably not sufficiently magnetic to affect a dip-needle strongly. If it does connect with Brooks No. 2, there must be a fault along the creek where Brooks No. 2 begins, for a greenstone is exposed on the east bank of the creek directly opposite the east end of Brooks No. 2.

Brooks No. 2 is from 300 feet wide at its eastern extremity to 850 feet at the western end, and forms a high ridge, in which the iron formation has been exposed by trenching. At least four dykes of younger diabase cut across the iron formation, thus greatly reducing its possible commercial

value. The preponderant banded silica member consists of granular, white quartz interbanded with iron oxides and much stained with limonite. Along the north side is a strip of rusty-weathering carbonate. The Keewatin volcanics on the south side are green schists, those on the north side a pale grey schist.

The interval between Brooks No. 2 and No. 3 was not explored, but it is likely that the iron formation extends across it. Range No. 3 is from 30 feet to 100 feet wide, and does not form a ridge. It is faulted and also cut across by numerous dykes of diabase. No considerable amount of siderite or pyrite is exposed in the trenches that have been made across the iron formation.

In the northwest corner of township 27, range 25, is a narrow iron formation which, though now 3½ miles northeast of the Brooks range, was probably nearly in line with it before the great fault along McVeigh creek occurred. This range was found by John Holdsworth in 1919 after it had been exposed by the severe forest fires of that summer. It consists of two thin lenses, each about 3,000 feet long and 50 feet in greatest thickness. Both lenses consist of rusty granular silica on the north side, south of which is schist alternating with several lenticular beds of pyrite rich enough in places to be a pyrite ore, but not over 8 feet thick. Both lenses dip 50 degrees north. The western one is overlain by 30 feet of dark green tuff with ellipsoidal greenstone above and is underlain by a light-coloured schistose tuff. The eastern lens is within the light-coloured tuff and apparently about 100 feet stratigraphically lower in the Keewatin than the western one. A representative sample from the largest lenses of pyrite seen at the surface yielded 30·45 per cent of sulphur (*See* analyses No. 7, page 62.

Brooks, a prospector for the Algoma Steel Corporation, reported having found a wide iron formation 1½ miles north of Brooks No. 1 range, but this has never been more definitely located. The only iron formation material in this locality known to the writers is a thin band of sideritized schist accompanied by a small amount of granular quartz, shown on the accompanying map 1¼ miles directly north of Brooks No. 1.

A small deposit of iron formation also occurs near Candy mountain, a bare high hill which rises on the west side of McVeigh creek, 2 miles north of the southeast corner of township 28, range 25. W. M. Goodwin states in a report to the Algoma Steel Corporation that it is a small body and apparently not accompanied by any considerable amount of iron ore.

Eccles Lake Iron Formations

Map 1972 shows numerous small bands of iron formation in the southwest corner of township 28, range 26. This mapping is only a simplified approximation of the actual distribution of the iron formations. Apparently there were originally several thin iron formations not far apart stratigraphically, and these and the adjoining Keewatin volcanics were folded and faulted in complicated fashion. There are now left numerous remnants of various sizes, greatly contorted and lying in such a variety of attitudes that only detailed field work would locate them

all in their correct positions. They are commonly in folds that pitch steeply towards the northwest, and for this reason outcrop in sinuous bands. They appear to be too small and devoid of iron ore or pyrite bodies to warrant such study. The bands of iron formation seen during 1919 are from 3 inches to 20 feet wide. They consist entirely of hard, white or grey quartz interbanded with glistening black layers of magnetite, usually finely crumpled. Wider bands up to 75 feet are said to occur.

The small pieces of iron formation near Irene lake, 1½ miles farther north, are of the same character.

Magpie Mine

Up to the time of writing, the Magpie siderite deposit is the only siderite deposit in Michipicoten district that has been mined for iron ore. The deposit has a total length of 2,100 feet and strikes in a general northwesterly direction, but its course is highly irregular and it has been dislocated by minor faults, and probably also by folding, into four segments. The deposit stands almost vertically between an ellipsoidal greenstone on the northeast and a coarse tuff of acid composition on the southwest. It maintains a width of 40 to 60 feet.

The two segments at the northwest end and one at the southeast end are low grade and mining operations have, consequently, been restricted to the main, middle part. This section is about 1,400 feet long and averages 45 feet in thickness. It contains no banded silica and no distinct concentration of pyrites. The ore-body consists uniformly of siderite sprinkled with pyrite. The siderite gives place to the volcanics on either side within a distance of 2 feet. In these respects the Magpie deposit is unlike either the typical iron formation, such as the Helen, or siderite masses such as that at Leg lake. It has less appearance of being a replacement deposit than any of these; nevertheless, the siderite is similar in composition and appearance to that found in other iron formations.

An analysis of the siderite is given on page 64. The ordinary variety is pale grey or yellowish-grey, massive rock sprinkled with small, bright specks of pyrite. Towards the west end of the mine, however, the ore-body is crossed by a dyke of younger diabase 95 to 105 feet wide and the ore next this dyke is black, owing to the presence of small particles of magnetite. It also contains more silica and less carbon dioxide than the normal ore. The black variety is evidently due to the intrusive effects of the diabase, for at increasing distances from the dyke it grades into the ordinary grey phase.

The Magpie deposit was trenched, stripped, test-pitted, and diamond-drilled by the Algoma Steel Corporation in 1909, and in 1910 work was commenced on the 4-compartment shaft from which mining operations were afterwards conducted. A roasting plant for treatment of the raw ore was begun in 1911. Owing, however, to the fact that the roasting process was more or less experimental, and had to be modified as experience was gained, this first plant was torn down and a new one built,

which commenced operations in May, 1914, and was found to be successful. Electric power for lighting and operating the mine was secured from the hydroelectric plant at Steephill falls, supplemented when necessary from the Algoma Power Company's plant at High falls on Michipicoten river. A railway spur 9 miles long was constructed to the mine from Magpie junction so that the roasted ore could be hauled, down-grade, a distance of 26 miles to Michipicoten Harbour.

Except for occasional shut-downs the mine was operated from 1910 until 1921. The shaft was sunk to 400 feet and later to a total depth of 611 feet. Levels were run at 100-foot intervals eastward along the ore-body for 400 feet and for 1,000 feet west. Down to the third level the ore-body proved to be a simple tabular body interrupted only by the diabase dyke, but farther down it was found to be split obliquely by an intrusive mass and small dykelets of a basic magnesian rock, called mica-dyke because in most places it is decomposed and sheared to a silvery talc-schist. This intrusive increased the cost of mining operations to such an extent that it was finally decided to discontinue operations, a decision that was probably also influenced by the fact that a much larger and better situated body of siderite had been proved at the Helen range. Operations ceased on March 8, 1921, and will probably not again be resumed. Altogether about 1,500,000 tons of siderite had been mined out of a total quantity of about 2,250,000 tons estimated from diamond-drill explorations to exist in the ore-body.

The ore raised from the mine was broken into lumps 4 inches or less in diameter, from which pieces of mica-dyke and lean ore were picked by hand. The clean ore was fed into rotary steel kilns 125 feet long and 8 feet in diameter, inclined so that the ore would travel from end to end in four hours, and heated from the lower end by a burning jet of powdered bituminous coal. The ore after attaining a temperature of 1,100° C. was discharged into a concrete storage bin and allowed to cool. In this manner the carbon dioxide and sulphur were driven off. About 300 pounds of pulverized coal—obtained from a mine in Virginia owned by the Algoma Steel Corporation—and 2,800 pounds of siderite were required to produce one ton of finished ore. An extended and detailed description of the roasting plant is given by A. Hasselbring.[1] Excellent photographs of the plant may also be seen in the Ontario Bureau of Mines report for 1915, and in "Iron Ore Occurrences in Canada" by Lindeman and Bolton, Mines Branch, Department of Mines, Ottawa.

The finished ore was a nodulized brown material, free of water, consisting mainly of the oxides of iron. The average composition of the product made in 1916, was:

	Per cent
Fe	50·10
SiO_2	9·14
S	0·136
P	0·013
Al_2O_3	1·28
CaO	7·96
MgO	8·04
Mn	2·74
Loss	None

[1] Jour. Can. Min. Inst., vol. 20, 1917, pp. 321-322.

This ore has several features which render it acceptable in the iron ore market. It contains over 2 per cent manganese, and enough lime and magnesia to render it almost self-fluxing. It contains no water. These features are likely to be possessed in much the same degree by all ore made from siderite in Michipicoten district. Moreover, the process and type of plant for roasting the siderite at Magpie mine, which were elaborated at considerable expense and much experimentation, are expected to serve equally well at the Helen siderite deposit and any other which may be mined in future.

Alice Lake Deposit

A mile south of Magpie mine, in mining claim JL 88, is a series of lenses of magnetite that extends for 2,000 feet north and south. Some of these have good-looking iron ore at the surface containing as much as 54 per cent iron, but nearly all of them contain disseminations and small patches of pyrite. Considerable trenching and 4,858 feet of diamond-drilling was done by the Algoma Steel Corporation, and one lens was found to be nearly 600 feet deep.

Drill-holes 1 and 2 on one lens of ore show 50 and 35 feet, respectively, of pyritic ore, representative samples of which yielded:

—	Hole No. 1	Hole No. 2
Fe	35·43	39·07
SiO_2	17·13	21·92
S	4·47	9·05
P	0·012	0·017

Drill-holes 3, 5, and 6 were drilled into another lens. Hole 3, vertical, was in pyritic magnetite from 26 feet to 300 feet and from 326 to 586 feet. No. 5, also vertical, cut similar ore from 5 to 127 feet and from 210 to 525 feet. No. 6, inclined 70 degrees, crossed the ore-body from 262 to 365 feet.

Average analyses of the ore in the three holes are:

—	Hole No. 3	Hole No. 5	Hole No. 6
Fe	42·57	38·85	32·37
SiO_2	15·80	19·47	20·35
S	7·74	2·29	4·918
P	0·027	0·025	0·023
Al_2O_3	1·66	2·50	4·20
CaO	5·17	5·77	6·22
MgO	3·99	3·98	3·49
Mn	1·79	2·20	1·02
Loss on ignition	3·03	3·90	5·90

The above information is taken from "Iron Ore Occurrences in Canada" by Lindeman and Bolton, and derived originally from the records of the Algoma Steel Corporation. The drill-cores were not seen by the

present writers, but judging from the proportions of lime, magnesia, alumina, and manganese in the ore it would seem to be related to the siderite of the iron formations—possibly a siderite that was converted into magnetite.

Reynolds Lake Range

A thin iron formation extends continuously from the eastern arm of Reynolds lake in township 29, range 26, southeastward for 5 miles. The northern part has no particular topographic expression, but from opposite Eva lake to Magpie river it lies in the side of a high ridge and southeast of Magpie river it again rises in a tall ridge with very steep sides, especially the north side. The northern part is included in the Magpie groups of mining claims and has been explored to some extent by trenches and shallow test pits. The part southeast of Magpie river has also been well trenched by Dr. W. L. Goodwin, of Kingston, Ontario, but the remainder seems to have attracted little attention.

The iron formation stands about on edge and seems to have its original top facing eastward, which is probably also the attitude of the Magpie deposit parallel to it. Coarse tuffs, resembling conglomerate in some places, are common on both sides of the range, but there is naturally much diversity in the character of the volcanics from one end of the range to the other. The iron formation attains a thickness of 200 feet near the northern end and 300 feet southeast of Magpie river. At the south end it thins to a few feet and is lost; at the north it is over 50 feet wide when last seen on the south shore of Reynolds lake, but no sign of it could be found on the north side.

A banded silica member composed of granular, white quartz and some interbanded iron oxides makes up the main part of the iron formation. This material is locally brecciated and much stained with limonite. At Reynolds lake it grades into a small body of pyrite and pyrrhotite and in claim JL 134 the banded silica grades eastward into a rusty brown material, which was supposed to be the weathered surface of a band of siderite mixed with pyrite. Opposite Eva lake, on the east side of the banded silica, a small outcrop of brown iron ore was seen, which may also indicate an underlying thin siderite member. No other outcrops of pyrite or siderite were seen.

Evans Creek Ranges

Two ranges of iron formation occur along the upper part of Evans creek, in township 29, range 26. The northern range was found exposed in only one place, though Dr. J. M. Bell records another small outcrop half a mile farther west. At the outcrop seen in 1919, which is situated on Evans creek, the iron formation lies immediately south of a well-stratified slate formation, either part of the Dore series or one of the local sedimentary formations known as the Eleanor slates. Slates and iron formation dip 60 degrees southward. The iron formation is around 175 feet thick and consists entirely of grey siliceous laminæ about half an inch thick alternating with shining black ones that contain a large proportion of

magnetite. It is strongly magnetic and, although elsewhere buried under a sand-plain, was easily traced for a mile northwestward with the aid of a dip-needle. Further exploration of this sort would probably prove the range to be longer than shown on the map, though it could not be located with the dip-needle on the Grassett road to the east.

The southern Evans Creek range is believed to commence east of Godon lake and to have, at first, a northerly course from 4,000 feet. At the south end of this section the iron formation is thin and could not be traced farther south either by finding exposures or with the dip-needle. Northward it increases in width to 330 feet, and develops into a distinct ridge. The ridge and the iron formation both end abruptly, presumably at a fault. A second band of iron formation 30 feet wide and composed entirely of banded silica parallels the main range 130 feet to the westward for part of its length. The main range consists largely of a light-coloured banded silica member carrying enough magnetite to affect the dip-needle. According to W. M. Goodwin, who prospected it for the Algoma Steel Corporation, there is on the east side an irregular band of pyritic material 10 to 20 feet wide containing some small aggregations of fairly good pyrite ore. Alongside the pyritic member is another band, 10 to 30 feet wide, of interbedded siderite and granular silica, siderite predominating.

No iron formation seems to occur from the fault northward to Evans creek, but on the east side of a small pond just across the creek, banded silica is exposed for a width of 790 feet. This does not represent the true width, for the banded silica is contorted and strikes in places north and south, in other places east and west. Apparently another fault, or an extension of that east of Godon lake, occurs here, for the iron formation does not continue on the west side of the pond. It is thought probable that the Godon Lake section was originally continuous with this second section of iron formation before faulting took place; otherwise it is difficult to understand the abrupt termination of each.

From the little pond mentioned above, the iron formation was traced eastward for a quarter-mile, in which distance it is at least 400 feet wide; the exposed part consists solely of banded silica in white, grey, and glistening black laminæ. It contains much magnetite and powerfully disturbs the compass or dip-needle.

At the east end of this quarter-mile section the iron formation is abruptly displaced northward for 1,500 feet, evidently by another fault. Thence eastward for 3 miles it follows the top of a broad ridge. The ridge is well covered with drift and with a forest of poplar, birch, and other deciduous trees. There are few and only small rock exposures, but the iron formation is easily located by means of the dip-needle. The magnetic part is 300 feet wide, narrowing to 200 feet towards the east end. Just before entering the sand-plain along Magpie river the iron formation is exposed in old trenches made on the Johnston claims (SSM 1000, 1007, 1008, and 1015). There, it is 125 to 220 feet wide and dips 50 to 60 degrees south. On the north side is an acid volcanic schist, on the south side either the same rock or a soft carbonated green schist. Most of the iron formation consists of hard, banded silica in grey and black layers, but a friable, white, granular silica is also present. Some of the

magnetic layers are as much as 2 feet thick and are composed mainly of magnetite.

East of the Johnston claims the iron range disappears under the level sand-plain that occupies the valley of Magpie river. It is easily traced, however, by aid of a dip-needle, which is pulled 50 degrees to 70 degrees from the horizontal. It was followed in this manner for three-fourths of a mile east of the river. Then it apparently enters a zone of profound disturbance. One short, faulted segment was found with the dip-needle beneath the sand-plain, and a second faulted fragment of highly magnetic banded silica only a few feet in diameter was found another half-mile towards the northeast.

Dreany Range

In line with the southern Evans Creek range and at about the same distance away from the parallel belt of Dore sediments is another iron range, or rather a series of short ranges, known as the Dreany range. These commence in the northwest corner of township 28, range 26, extend in a northeastward direction across township 28, range 27, beyond the limit of Map 1972, and then curve eastward across the Algoma Central railway into township 27, range 27.

As seen in township 28, range 26, by the junior author, there are numerous short bands and lenses of highly magnetic, banded silica in white, grey, and black colours. Some of them contain lenticular beds of solid magnetite up to 4 feet in width, but the total amount of ore is not sufficient to encourage mining operations. At the southwest corner of claim SSM 1805 the hard, well-laminated iron formation is 150 feet or so in thickness and appears to contain about 20 per cent of iron in the form of magnetite. It could not be traced for more than a few hundred feet in this claim and no iron formation could be found elsewhere in SSM 1805, 1806, 1807, and 1808. Thence northward the iron formation was explored by Mr. Ellis Thomson, whose report accompanies this one. Where the range crosses the railway it was examined in 1918 by the senior author. At that time surface trenching and test-pitting were being carried on by the Dreany Iron Mines, Ltd., and it was said that exploration with a diamond-drill was contemplated. The outcrop of the iron formation did not, however, seem to offer much support to the expectation of finding any considerable body of ore. It consists of highly magnetic, banded silica in the usual white, grey, and blue-black laminæ and does not appear to contain more than 15 to 20 per cent iron. In places the iron is in the form of a bright green hornblende (grünerite) and in other places green epidote is abundant, both minerals being probably metamorphic products due to the intrusive granite which approaches the iron formation closely at this place. At one place west of the railway and close to the banded silica is a lean aggregation of pyrite.

Brant Lake Ranges

The Brant Lake iron ranges are situated in the northwest corner of township 30, range 26. Altogether there are six iron formations lying

parallel to one another within a total width of half a mile, but only three of these are of considerable length and thickness. The largest is 4 miles long, attains a greatest width of 450 feet, and is on the average over 300 feet wide. All dip southward from 45 to 70 degrees and have their tops on that side. The three northernmost formations, which are stratigraphically lowermost, lie in a pale grey tuff, whereas the volcanic rocks enclosing and south of the southern or uppermost iron formation

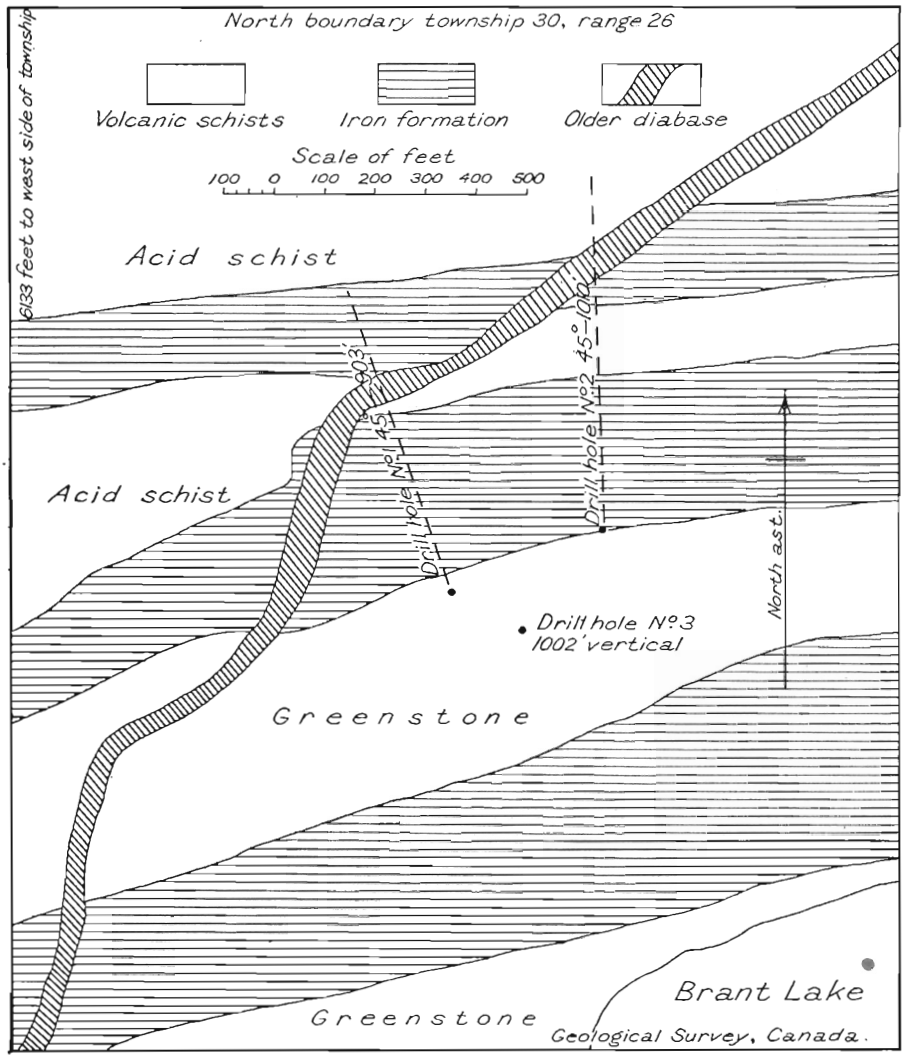

Figure 11. Plan of iron formations and diamond-drill holes at Brant lake, township 30, range 26.

are dark green basic rocks. The largest range tends in its eastern part to form a low ridge, but with this exception the iron formations have no particular topographic expression. From Brant lake westward the country has been completely deforested by fire and the iron formations and adjacent volcanics are well exposed. At the western side of the township the iron formations are cut off by a tongue of granite, but a single band continues west of this granite beyond the edge of the map-area.

The Brant Lake iron formations consisted mainly or altogether of banded silica. Snow-white layers of quartz up to 6 inches in thickness alternate in places with narrower bands of blue-black magnetite, in other places with a green material composed mainly of the iron-rich hornblende, grünerite, and actinolite. These minerals are due, in all likelihood, to the metamorphic influence of the granite which penetrates close to the iron formations. The iron formations here are much brecciated and are much less evenly banded than usual. Individual white bands can seldom be found that do not within 10 or 15 feet taper to a point or join another band (Plate VII).

No considerable thickness of siderite and no pyrite were seen outcropping along the lower (northern) edges of the iron formations, but surface trenching would probably disclose siderite at least. Just northwest of Brant lake, on the north side of the second iron formation from the south, is an exposure of brown iron ore which induced the Algoma Steel Corporation to drill (Figure 11). Three holes proved the ore-body underground to be not hematite but a mixture of magnetite and siderite somewhat resembling the ore-lenses of the Alice property, previously described. At this place the iron formation dips southward about 45 degrees and the ore-body is a sheet lying immediately beneath the banded silica member, and thus corresponding in position to the pyrite and siderite members of a typical iron formation.

The logs of the three holes are as follows:

Hole No. 1, at 45 degrees for 903 feet

	Feet
Banded iron formation	0 — 242
Ore, containing an average of 43·14 per cent Fe, 14·00 per cent SiO_2, 1·544 per cent S, and 0·22 per cent P	242 — 297
Schist	297 — 311
Diabase dyke	311 — 359
Micaceous schist	359 — 389
Banded silica member of next lower iron formation	389 — 517
Banded silica alternating repeatedly with schist	517 — 669
Schist with occasional bands of granular silica	669 — 903

Hole No. 2, at 45 degrees for 1,010 feet

	Feet
Banded silica with pyrite	0 — 161
Ore containing an average of 30·54 per cent Fe, 21·05 per cent SiO_2, 2·525 per cent S, and 0·024 per cent P	161 — 204
Garnetiferous schist and pyrite	204 — 280
Banded silica and pyrite of next lower iron formation	280 — 375
Diabase dyke	375 — 447
Banded silica	447 — 492
Schist alternating with banded silica	492 — 854
Banded silica and pyrite	854 — 890
Schist alternating with banded silica	890 —1010

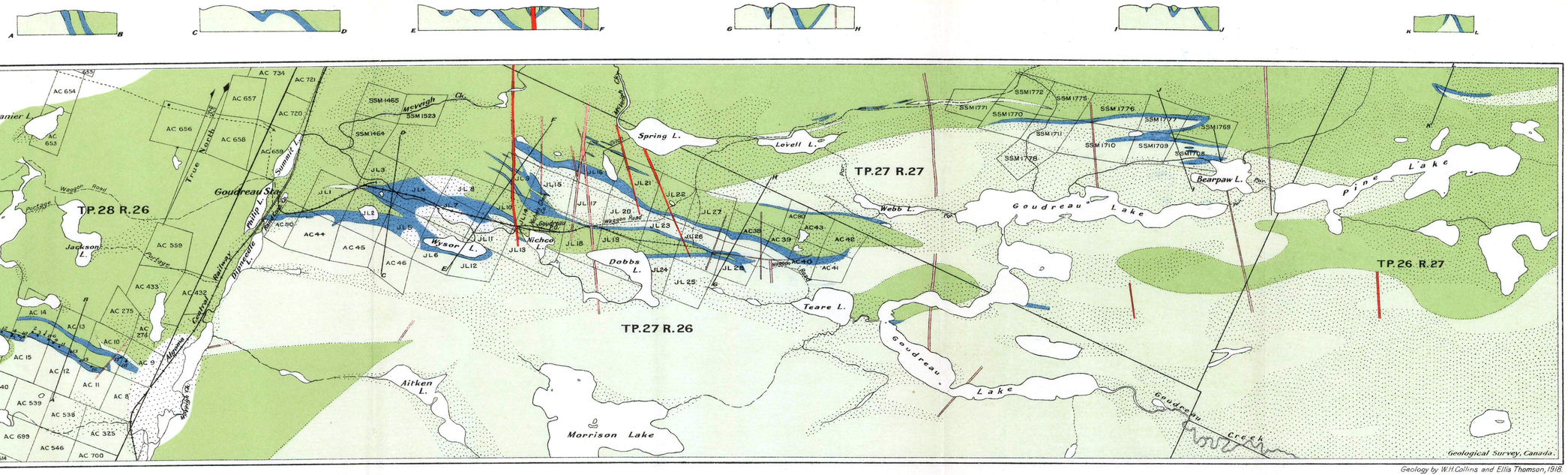

Figure 12

Geology by W.H. Collins and Ellis Thomson, 1918.

Publication No. 2081.

Goudreau Pyrite Area, Michipicoten District, Ontario

Scale of chains

20 0 20 40 60 80 100 120

Hole No. 3, vertical, for 1,002 feet

	Feet
Green schist	0 — 78
Green schist mixed with banded silica	78 — 235
Banded silica and pyrite	235 — 455
Banded silica and schist	455 — 500
Sideritic ore containing 26·56 per cent Fe, 22·80 per cent SiO_2, 3·438 per cent S, and 0·013 per cent P	500 — 513
Banded silica	513 — 533
Schists	533 — 657
Diabase dyke	657 — 697
Greenstone	697 — 743
Banded silica and pyrite of next lower iron formation	743 — 896
Green schist and banded silica	896 — 962
Green schist	962 —1002

Range in Township 30, Range 25

An iron formation was found in 1919 by the senior author about the centre of township 30, range 25, and was partly explored. It is not over 60 feet thick, and 2,500 feet long, and dips 20 degrees towards the northeast. It consists of white, granular quartz interbanded with enough iron oxides to affect a compass or dip-needle. The overlying volcanic is a dark green schist; that beneath is a pale grey schistified tuff. Traced southeastward the iron formation thins and disappears. In the opposite direction it ends abruptly at a narrow gully. This gully evidently represents a fault, and further exploration eastward along the opposite side would probably disclose a continuation of the iron formation. No pyrite or siderite was seen along the under side of the part explored, but the locality is well drift covered, and trenching would be necessary to prove the absence of these members.

Morrison No. 2 Range

The two parallel bands of iron formation 1½ miles south of Goudreau station, in township 28, range 26, are known as the Morrison No. 2 range, after the discoverer, J. W. Morrison. They are contained in mining claims AC 8 to 17, sold in 1920 to the Rand Consolidated Mines, Limited, with offices at Ellacott square, Buffalo.

The iron formations outcrop along the top of a broad ridge that rises 345 feet above the railway, with a steep southern slope and an equally abrupt eastern termination where the ridge falls away to a sand-plain traversed by the railway. In claims AC 14 and 15 and westward the ridge sinks to comparatively flat country, the surface of the iron formation in AC 16 being only a few feet above the lake nearby. The whole property is forested and fairly well drift covered, the surface trenches across the iron formations being up to 6 or 8 feet deep, and the casings of the diamond-drill holes up to 41 feet.

There are two iron formations parallel and separated by an average width of 400 feet of volcanic rocks (Figure 12). Each dips 60 to 75 degrees northward and has its top facing in that direction. The northern range could not be traced either by outcrop or with the dip-needle farther west than the eastern side of AC 14, but the southern range continues across AC 16, where it is cut off by a dyke of older diabase 90 feet wide. It is

so wide at this point of termination that there can be little doubt that it continues on the west side of the dyke, though faulted southward according to the general rule of faulting in Michipicoten district. Search was made for this extension in 1919 without success, but the writers were afterwards informed that it had been found about 1,200 feet to the south, and on the strength of this information an extension is shown on the accompanying geological map. Neither range extends eastward much beyond the crest of the ridge. The southern one is crossed near there by a dyke of younger diabase, east of which it is faulted 100 feet or so northward and can be traced northeastward for another 100 feet. The northern range goes eastward to the edge of the same plain in AC 9 and cannot be traced farther with the dip-needle. It is known that a great fault extends up the valley of McVeigh creek and this fault is believed to cut off both ranges, possibly displacing them 6,000 feet northward, to continue eastward as the Goudreau range. A small fault displaces the southern range 200 feet in AC 15.

The Keewatin volcanics south of the southern range are mostly pale-coloured schists of acid composition. Between the two ranges and northward dark green schists prevail, but there are also some light-coloured rocks. An ellipsoidal greenstone is well exposed in AC 14.

During 1915 the two ranges were thoroughly explored at the surface by means of cross trenches through the drift and between December 22, 1915, and June 22, 1916, nineteen diamond-drill holes ranging from 70 to 329 feet in depth and aggregating 4,470 feet were drilled, mostly on the southern range (Figure 12). The drill-holes reach from 50 to 250 feet vertically below the surface.

The northern range is 275 feet wide at the east end and narrows to 80 feet in AC 14. It consists principally of a banded silica member composed of white or rusty quartz sparingly interlaminated with iron oxides and only slightly more magnetic than some of the adjacent volcanic rocks. Near the west side of AC 9 two bands of pyrite, each 4 to 6 feet thick, lie just south of the banded silica and still farther south (or downward in the iron formation) siderite grades imperceptibly southward into pale-coloured schist. Diamond-drill holes 17 and 18, however, show no ore except a few feet of pyritic material, and on the whole the northern range does not seem to be of much value.

The southern range is much more important. It is from 130 to 250 feet wide. A banded silica member, composed largely of snow-white or rusty quartz, granular in places, lies on the north side. It is followed to the south by a thick and persistent pyrite member, which in places alternates with minor beds of granular quartz. In many of the diamond-drill holes and trenches the pyrite grades downward (southward) into siderite (Figure 5, section 2) and the siderite in its turn grades into the light-coloured schists beneath.

Pyrite is found for the whole length of the range, 3,800 feet, and varies in total true thickness from 12 to 50 feet, the average thickness being about 30 feet. To the depth reached by the drill there is probably three or four million tons of pyrite and, judging from the general persistence of other iron formations in depth, the ore-body is likely to extend far below the

deepest of the drill-holes. Some of this ore is too much alternated with banded silica and schists to be recoverable, but the majority appears to be in bodies of simple vertically tabular form and large dimensions. Analyses of drill-core samples yielded from 27·92 to 43·65 per cent of sulphur and an average of almost 37 per cent. The pyrite is of the usual range variety, a firm granular material composed of small crystals and grains of pyrite mixed with minor proportions of siderite.

Six of the sixteen drill-holes bored in the southern range penetrate true thicknesses of 6 to 60 feet of siderite lying between the pyrite and the volcanic schists at the south side, or bottom of the iron formation. These holes indicate the existence of a sheet of siderite 2,000 feet long and 20 feet in average thickness, extending from about the middle of AC 15 eastward. Analyses of this siderite are not available, but the drill-core samples, which are stored at the Nichols Chemical Company's property at Goudreau, appear to be of fairly good quality—30 to 35 per cent iron—and to be fairly low in sulphur. No doubt there is much ore between the good pyrite and good siderite which is too mixed to be used either as an iron ore or sulphur ore.

In 1920, the Rand Consolidated Mines, Limited, who had bought the property, commenced driving an adit into the south side of the ridge from a point 1,200 feet west of mileage 175·75 on the railway and 250 feet above it, or about 100 feet below the crest of the ridge. This work was discontinued in June, 1920, but had been driven over 100 feet towards the southern iron formation, with a view to mining on the same plan as is contemplated at the Helen siderite deposit.

Goudreau Range

Only the western end of this range is shown on the accompanying geological map, in the northwest corner of township 27, range 26, but all of it is represented in Figure 12. It is held under lease by various companies and individuals, and the different well-mineralized parts that have been discovered at different times have been given distinctive names. The Nichols Chemical Company, 25 Broad street, New York, hold under lease from the Algoma Steel Corporation, 1,171 acres comprising mining claims JL 1 to 28 (Goudreau group). This company also held mining claims AC 38 to 42 (Morrison No. 3 group) under lease from the Algoma Exploration Company, but have recently surrendered them to the owners. Claims AC 44, 45, 46, and 50, known as the Morrison No. 4 group, are held and operated by the Rand Consolidated Mines, Limited, Ellacott square, Buffalo. Two unsurveyed claims, SSM 94 and 102, contiguous with the north boundaries of JL 9 and 15, were held in 1918 by J. A. McPhail and others, of Sault Ste. Marie, Ontario. The Morrison No. 1 group, comprising SSM 1708 to 1711, 1769 to 1772, and 1175 to 1178, of 437·7 acres, is owned by the Algoma Steel Corporation. Various smaller properties, unsurveyed in 1918, were then being prospected by other parties.

Unlike the other iron formations in Michipicoten map-area the Goudreau formation does not stand on edge as a single narrow band, or range, but lies in several comparatively open folds, with dips ranging from

70 degrees to as low as 20 degrees. It does not stand up in ridges, but conforms to the ordinary hilly surface of the adjacent Keewatin volcanics; in fact a considerable part of the iron formation is in low ground between hills of the volcanic rocks. There is also an unusually thick mantle of gravel and sand in this neighbourhood and much of the iron formation lies beneath sand-plains, morainic hills of gravel, or swamp.

The iron formation and Keewatin volcanics are cut by many dykes of younger diabase and by at least three dykes of the older series of diabase which coincide with faults of large displacement. These complications, together with the heavy drift cover, make it difficult to follow the iron formation everywhere. Nevertheless, there appears to be one main iron formation, up to 225 feet in thickness, between underlying light-coloured acid volcanics and overlying ellipsoidal greenstone and green schists. There are also several smaller iron formations within the green schists and stratigraphically above the main formation, particularly in the vicinity of mining claims JL 9, JL 16, SSM 1708, and northeast of Lovell lake.

The small iron formations are lens-shaped, and consist either of white, banded silica alone or of banded silica and some pyrite. The main range consists, in descending order, of a banded silica member of considerable thickness, a pyrite member which is thick enough in many places to form large mineable ore-bodies, and a carbonate member of irregular thickness which varies from a typical siderite in places to a crystalline limestone in other places (*See* Figures 5 and 6). As a rule the carbonate grades downward into the acid volcanics, whereas the overlying greenstone or green schist is in sharp contact with the banded silica, sometimes alternating with it.

Goudreau iron formation is distinguished by the unusually white colour of its banded silica member. In a good many places it consists of white quartz interbanded in layers one-quarter to one inch thick with dark grey or reddish layers carrying magnetite or siderite, but beds of pure white or iron-stained quartz up to 2 feet thick are not uncommon. There is one mass of snow-white quartz in SSM 1709 which is at least 20 feet thick and shows no stratification. There is also much variety in texture, from a hard glassy quartz to a sugary, granular variety so incoherent that it can be reduced to sand by rubbing two pieces together. The upper bed shown in section 2, Figure 5, is of this nature, whereas the next bed 30 feet lower in the same deposit is hard and glassy. A banded silica member is present at most places on the range, but is lacking in JL 10 and wherever else crystalline limestone is present (section 1, Figure 6).

A pyrite member appears to underlie the banded silica of the main iron formation wherever it is exposed or has been drilled, but only locally is it thick enough and sufficiently concentrated to produce workable bodies of pyrite ore. At such places, however, it may be as much as 80 feet thick. The ore is a granular mixture of pyrite grains, of about the size of ordinary sand grains, with siderite or vestiges of schist, and is rather easily pulverized. A point of interest to drill and mine operators, brought out in Figure 5, is that the pyrite is richest just under the banded silica and tends to become leaner in depth. The composition of the ore is indicated by analyses given on page 62.

A good many of the drill-holes through the main iron formation show no carbonate beneath the pyrite, or only traces of it, but at other places there is a carbonate member of varying thickness (Figure 5). This is, in all but the central part of the range, composed of the same dense, pale grey siderite as is found at the Helen and other ranges. In JL 10, JL 16, and west of JL 16, however, it is a medium to coarse-grained crystalline limestone. The limestone is pale grey to pale brown, speckled with grains and small bunches of pyrite. Parts of it are uniformly grey, but other parts become speckled with brown on weathered surfaces, suggesting an admixture of iron carbonate. It seems likely that the limestone actually merges laterally into the siderite found elsewhere in the range, though the ground is too heavily covered with drift for this opinion to be confirmed. In JL 10, the carbonate member consists of crystalline limestone 60 feet thick grading downward into about 20 feet of siderite.

Rand Consolidated Mines

Besides the Morrison No. 2 range (mining claims AC 8 to 17) this company owns claims AC 44, 45, 46, and 50 (Morrison No. 4 property) at the west end of the Goudreau range. The latter property contains a section of iron formation 1,300 feet long. It lies immediately south of the Nichols Chemical Company's railway from Goudreau to their mill and dips at 60 to 80 degrees under the railway. South of it rises a high ridge of ottrelite porphyry that constitutes the foot-wall rock. A sheet of pyrite about 60 feet in greatest thickness lies between banded silica on the north and the ottrelite porphyry on the south, the contact with the latter being irregular and transitional. In spite of its steep dip work was commenced upon the deposit early in 1917 and it was successfully operated as an open-cut in 1918 and 1919. A considerable tonnage of ore was shipped from Goudreau siding, which is only 500 feet away from the pit. The ore was crushed and screened at a plant erected nearby in 1918, and was piled on the property until a cargo had accumulated, when it was hauled in train loads to Michipicoten Harbour and transferred directly to boats for shipment down the Great Lakes. An analysis of the sample of ore from a carload is given on page 62. Mining operations were discontinued in December, 1919, owing chiefly to the falling price and demand for pyrite. The ore-body, though not explored in depth by drilling, likely continues downward and contains a large tonnage of ore, but owing to its narrowness and dip beneath the railway underground methods of mining would soon have to be substituted for quarrying.

Nichols Chemical Company

This company holds claims JL 1 to 28 and until recently held AC 38 to 42 (Morrison No. 3 group). Diamond-drill explorations have been conducted at various times since 1903 in JL 3, 4, 9, 15, 16, 18, 21, 26, and 28 and in AC 38, 39, and 40. Much trenching has been done on the same claims and old exploration shafts were seen near the southwest corner of JL 4 and in JL 21. Nevertheless, a large share of the property is still untested and no reliable estimate can be made of the ore reserves.

Mining operations have centred chiefly in what is known as the C deposit in JL 15 and 9. Here, the iron formation dips southwest at 18 to 40 degrees, and can be easily worked by quarrying. It was explored in 1913 by the Madoc Mining Company, a subsidiary company of the General Chemical Company and predecessor at Goudreau to the Nichols Chemical Company. According to the reports of the Ontario Bureau of Mines, 3,000 tons of ore were mined in 1914. In 1915 a mine, steam power-plant for generating electricity, office buildings, and large boarding house were erected nearby on JL 14, and the C pit became a large producer of pyrites in 1916. When seen during the summer of 1918 the pit was L-shaped with an extreme length of 1,100 feet from east to west and 700 feet from south to north, increasing in depth westward to about 60 feet. A heavy overburden of gravel and boulders was first removed by steam shovel and then the iron formation beneath was broken down by blasting and the pyrite loaded in dump cars with a steam shovel and hauled by locomotive about 1,500 feet to the mill for crushing and sorting. At the mill, which has a capacity considerably greater than the 1918 output, blocks of ore from the pit, up to 2 feet diameter, were fed into a gyratory crusher, and reduced to dimensions of 3 inches or less. Rock was removed from this product by hand as it was conveyed on a belt to screens for separation into lump ore and fines. Lump ore consists of pieces ½ to 3 inches in diameter and fines anything smaller. A more detailed description of the plant is given in the Annual Report of the Bureau of Mines.[1] The sorted ore was fed by gravity from storage bins directly into railway cars and hauled 2 miles over a standard gauge spur (Figure 12) to Goudreau station on the Algoma Central railway. From there it was hauled 40 miles to Michipicoten Harbour in train loads and loaded on boats for shipment to Lake Erie ports.

Ore was being quarried in 1918 at the rate of 150,000 tons for the season, and about 250,000 tons had been removed from C pit. The western and southern faces of the pit where the ore was being obtained consisted, below the overburden of boulders and gravel, of banded silica 10 to 30 feet thick underlain by about 20 feet of pyrite, the floor of the pit being in volcanic rock. A large amount of ore probably remained between the pit and the dyke of diabase to the west, but the iron formation dips under greenstone in that direction, so that quarrying will probably have to be replaced by underground mining if the whole ore-body is to be recovered. Beyond the dyke the ore-body is faulted out of reach. An analysis of a sample from a carload of ore from the C pit is given on page 62. Of forty-four diamond-drill core samples analysed in 1909 by the Algoma Steel Corporation, the highest sulphur content was 39·79 per cent, the lowest was 16·77, and the average 28·33 per cent.

There are several streaks of pyrite in the green schist west of this dyke, but they appear to be impregnations along shears zones and not extensions of the C deposit. There is also a large outcrop of pyrite a few hundred feet south of the pit which seemed to lie within the green schist stratigraphically above, and probably distinct from, the C deposit. It had

[1] Ann. Rept., Ont. Bureau of Mines, 1916, p. 78.

not been touched in 1918 and its depth and tonnage were not known, though the ore seemed to be of good quality.

During 1918 a narrow gauge extension of the railway was built from the mill to the Bear deposit in JL 28, the drift was stripped from a large, gossan-covered outcrop of pyrite preparatory to quarrying, and the iron formation was diamond-drilled. Information regarding the dimensions of the ore-body and quality of the ore was not available, but there was a large outcrop of pyrite carrying around 30 per cent of sulphur. The pyrite is mixed with siderite and a purer siderite underlies it in some of the trenches. Especially towards the west end of the claim the iron formation dips steeply and underground methods of mining will probably have to be adopted.

Another band of iron formation in AC 38, 39, and 40, called the Morrison No. 3, was trenched and diamond-drilled in 1918. It is 80 to 175 feet thick and dips 50 to 70 degrees northward. It lies along the foot of a considerable ridge which separates it from the Bear deposit, with swamp just to the north. From north to south a section consists of green schist, banded silica, pyrite, and some siderite, grading into light grey porphyry that makes up the ridge to the south. The banded silica member is composed mainly of hard, white quartz interlaminated with blue-black layers of magnetite, but in part also of a sugary, friable quartz either snow-white or iron-stained. The pyrite member, including low-grade material, is up to 50 feet thick and consists of a good grade of ore, with occasional alternating bands of banded silica that grows leaner and more sideritic towards the bottom, or south side. The results of diamond-drilling are not fully known, but there is evidently a sheet of pyrite of large dimensions and fairly good quality. During 1919 a shaft was sunk at 45 degrees for 300 feet, buildings were erected, and machinery auxiliary to that in the mill in JL 14 was installed, but fire destroyed this auxiliary plant on November 26, 1919, since when no work has been done.

Preparations had also been made in 1918 for opening the A deposit in JL 16 and 21. A ditch had been dug to drain into Spring lake the shallow ponds and swamp that cover much of the iron formation, but the depression of the pyrite market that followed cessation of the Great War deferred further development. The A deposit is part of a band of iron formation 4,400 feet long that extends from the middle of JL 21 westward. Part of it in JL 21 and 16 is held by the Nichols Chemical Company and the remainder by J. A. McPhail and others, of Sault Ste. Marie, Ontario. The iron formation is 140 to 220 feet thick and dips northward at an average angle of 30 to 45 degrees. Green schists overlie it on the north side and a schistose porphyry forms the southern foot-wall. The eastern part is covered by swamps, and the remainder, though better exposed, is in comparatively flat ground. A dyke of older diabase that coincides with a fault of large throw terminates the iron formation at the west end and a similar dyke and fault displace it to a smaller extent at the east end. Numerous dykes of younger diabase cross the iron formation at other places (Figure 12).

From north to south the iron formation consists of green schist, pyrite, crystalline limestone, and grey schist; banded silica is absent or thin.

Several natural pits 8 or 10 feet deep and as much in diameter, formed presumably by solution of the limestone and pyrite, occur in JL 16. Four holes were made with a shot-drill through the iron formation in JL 16: No. 1 at 42 degrees for 235 feet; No. 2, 100 feet away from No. 1, vertical for 230 feet; No. 3, vertical for 98 feet, and No. 4, from the same site as No. 3, at 60 degrees for 148 feet, drilling being ended April 18, 1903, by fire. Holes 1 and 2 indicate the existence of a main body of pyrite 100 feet thick at a depth of 60 feet and three smaller ones 3 to 20 feet thick between the main body and the surface. Hole No. 4, the exact location and direction of which could not be ascertained from the records available, was in pyrite ore for the whole length of 148 feet without reaching a foot-wall, but the vertical hole No. 3 on the same site penetrated pyrite for only 12 feet from the surface and was in green schist for the remaining depth. Evidently there is a thick sheet of pyrite ore in claims JL 16 and 21 and natural outcrops were seen at intervals west through the McPhail property. Judging from these there is probably a pyrite body 1,800 feet long and possibly 4,000 feet long, and 20 to 100 feet thick, that descends northward at an angle of 30 to 45 degrees to depths not determined in most places, but as much as 163 feet where explored with the shot-drill. Based on such scanty data as are available the whole length of iron formation may be expected to contain not less than 1,000,000 and possibly 6,000,000 tons within a vertical depth of 150 feet—enough in any case to encourage systematic drill exploration when the pyrite mining industry recovers from its present depression. An analysis of an average piece of ore from one of the drill cores is given on page 62, but a higher grade of ore could be selected.

The iron formation appears to attain its greatest width in JL 4 to 8. Rock outcrops are not numerous enough in this locality for its continuity to be beyond doubt, but the dips are low enough—15 to 45 degrees—to suggest that the iron formation lies in shallow folds. This structure would lend itself readily to cheap open-pit development and very fair pyrite has already been found by diamond-drilling, test-pitting, and in the old shaft at the southwest corner of JL 4. Further development has been discouraged, however, by the nature of the surface, part of which is swampy and the rest a succession of hills of bouldery drift.

Morrison No. 1

The group of claims comprising SSM 1708 to 1711, 1769 to 1772, and 1775 to 1778 is known as the Morrison No. 1 property (Figure 12). It is owned by the Algoma Steel Corporation, Sault Ste. Marie, Ontario. A considerable share of the property is occupied by sand-plain and swamp, and the intervening rocky areas do not rise more than 75 feet above the general level.

The main iron formation is either drift covered or inconspicuously exposed. It dips at angles of 50 degrees or less and appears to lie in a double fold that pitches northeastward. Over most of its exposed length it ranges from 80 to 100 feet in thickness downwards, but at one place in SSM 1709 reaches 140 feet. The bulk of it is composed of banded silica fairly well laminated with iron oxides, but in SSM 1709 it includes a mass

of snow-white, sugary quartz 20 feet or more thick in which there is no stratification. A few feet of pyritic and sideritic material is commonly to be seen beneath the banded silica and in SSM 1709 and 1710 this thickens into an important ore-body. The overlying formation is in most places an ellipsoidal greenstone that lies in sharply-defined contact upon the banded silica. At one outcrop the ellipsoids of greenstone for a few feet above the iron formation are changed from the usual dark green colour almost to white as if they had been silicified. The spaces between the ellipsoids were found in other places to be filled with carbonate in which were occasional crystals and solution casts of colourless gypsum (selenite). The prevalent rock beneath the iron formation, into which the pyrite and siderite pass gradationally, is a grey, porphyry schist.

Part of the iron formation lying in SSM 1709 and 1710, where it is widest and shows good outcrops of pyrite, was diamond-drilled between January and March, 1914, by the Algoma Steel Corporation. Eight holes, varying in depth from 145 to 450 feet, were drilled within a distance of 450 feet along the strike. They revealed a lens of pyrite at least 400 feet long, and from 12 to 110 feet thick, extending to at least 200 feet below the surface. Analyses of each 10 feet of drill-core yielded from 18·50 to 42·27 per cent of sulphur. It is estimated by officials of the company that the deposit contains 300,000 tons of pyrite carrying from 38 to 42 per cent of sulphur, besides which there is an almost equal amount of lower grade ore.

Wilcox or Webb

This property lies one-third of a mile north of the east end of Pine lake, in township 26, range 27 (Figure 12). Here an iron formation is bent sharply back upon itself like a hook, and apparently represents a close anticline that pitches westward. It is exposed for 700 feet and can be located with the dip-needle for another 1,200 feet eastward under a heavy cover of sand. The outcropping part has been trenched so as to expose a thick gossan of limonite and pyrite mixed with limonite for widths of 20 to 30 feet.

McCarthy-Webb

There is reason to believe that a narrow band of iron formation 4,000 feet long underlies the deeply drift-covered area just south of Webb lake (Figure 12). Its presence is inferred chiefly from dip-needle measurements made across the contact between porphyry and ellipsoidal greenstone that lie on the north and south sides, respectively. More substantial evidence was found at one point on the small stream which enters the south side of Webb lake. At that place there are stagnant pools of water that taste of iron salts and are depositing limonite on the bottom. The length of this presumptive range has not been fully determined, as the dip-needle readings were carried only as far east as a little pond lying 160 feet south of Webb lake.

Lovell

Several narrow bodies of iron formation that lie close to the Pick wagon road, between Lovell lake and the west end of Morrison No. 1

property (Figure 12), were prospected in 1918 by D'Arcy Lovell and others. Banded iron formation, accompanied by a thin sheet of pyrite and pyrrhotite, was exposed in the trenches and could be traced in other places with a dip-needle. A small value of gold was said to have been obtained by assay of a sample of the pyrite and silica, but at the point where the sample was taken the iron formation is traversed by small quartz veins; consequently, it is uncertain whether the gold is a constituent of the iron formation or of these veins.

Minor Occurrences

Narrow bodies of pyrite and pyritic schist, apparently not of commercial value, were seen: (1) on Goudreau lake near the south boundary of township 27, range 27; (2) on Goudreau lake west of the outlet of Teare lake; (3) just north of the portage between Pine and Bearpaw lakes.

SECONDARY DEPOSITS OF IRON ORE AND PYRITE

It is perhaps a further proof of the origin of the Keewatin iron formations from heated volcanic waters reacting under conditions that excluded the atmosphere that when these iron formations are brought into the field of atmospheric conditions they prove to be unstable and destructive chemical reactions are set up in them. The pyrite and pyrrhotite, exposed to air and moisture, decompose to iron sulphate and sulphuric acid, as may be seen at any of the pyritic iron ranges. The sulphuric acid, in turn, reacts with the carbonates, liberating carbon dioxide and forming more sulphates. In the presence of a reducing agent the iron sulphate reverts to pyrite and will under ordinary atmospheric conditions slowly decompose to iron hydroxide (limonite). Even in the presence of air and moisture alone iron carbonate decomposes slowly to limonite, forming the rusty coating found on siderite deposits.

This instability of iron formation materials under atmospheric conditions has given rise in Michipicoten district to a series of secondary deposits of iron ore and of pyrite which rank ahead of the iron formations themselves in economic value. Descriptions of the most important among these follow.

PYRITIC SAND AT GOUDREAU

The least important of these secondary ore deposits in respect of size and value, but the easiest to account for, is a deposit of loose granular pyrite that was uncovered on mining claim AC 50 at Goudreau during 1918, and mined by the Rand Consolidated Mines, Limited. When first seen, in 1918, the excavation had been pumped out and a section of the deposit could be seen which is reproduced somewhat diagrammatically in Figure 13. The first 6 feet or so from the surface consisted of interstratified sand and fine gravel, lying horizontally and cemented by limonite to the consistency of a weak sandstone. Beneath this lay an uneven bed of snow-white, granular quartz easily crumbled to sand between the fingers. This bed was not over a foot thick and tapered out towards the west side of the pit. It was underlain by from 0 to 5 feet of loose pyrite grains

comparable in size and behaviour to ordinary sand. The pyrite sand lay upon a sloping surface of lean Keewatin iron formation consisting of pyrite and siderite mingled with some volcanic schist. The surface of contact with this Keewatin bedrock was indefinite in some places and quite definite in others. In fact one sample of the pyrite

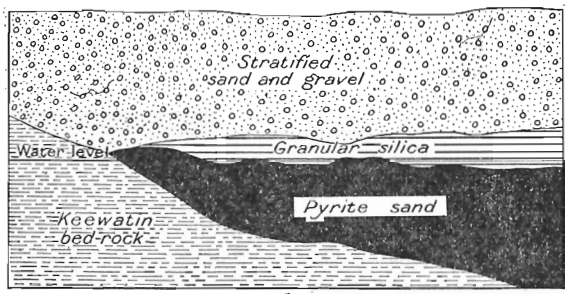

Figure 13. Diagrammatic vertical section of the body of pyrite sand on the property of the Rand Consolidated Mines, Limited, at Goudreau, showing its geological relationships. This body is post-Glacial.

sand that lay next to bedrock and was cemented to a firm ore showed a smooth striated surface corresponding to the smooth glaciated bedrock surface from which it had been detached. At all later visits water had risen to the line of contact between pyrite sand and granular quartz and according to A. W. Jackson, manager, the water remains stationary at this level.

This deposit is probably growing at the present time and its source and manner of growth are fairly obvious. The water that drains off the immediately adjacent iron range and fills the excavation contains sulphuric acid and iron sulphate in sufficient concentration to be recognized by taste and by the encrustations they form where evaporation is abundant. Probably there are also considerable proportions of silica, and sulphates of lime, magnesia, and manganese in solution, since these constituents occur in the similar water at the Helen mine. This mineralized water filters through the drift and along the slopes and inequalities of the bedrock. Decomposition takes place, either in the presence of some reducing agent or in the absence of oxygen, giving rise to the limonite that cements the drift and presumably also the pyrite sand and granular quartz.

The pyrite sand is not just a mechanical aggregation of pyrite grains released from the iron formation by weathering and carried to their present location by running water, for it differs in a significant manner from the pyrite found in the iron formations. The latter, as previously shown, contains 10 to 12 per cent of pyrrhotite and magnetite and yields on chemical analyses 1 to 1½ per cent zinc, ½ to 2 per cent manganese, 0·03 to 0·20 per cent copper, and 0·02 to 1·10 per cent nickel. The pyrite sand, as shown in the following table of analysis, contains almost

no pyrrhotite or magnetite, and greatly diminished percentages of zinc, manganese, copper, and nickel. Also, the ratio of sulphur to iron is higher than in "range" pyrite, probably because the latter contains some admixed siderite. The differences in composition seem to prove conclusively that the pyrite sand is not the same material as the "range" pyrite. They are likely due to solution of the range pyrite in the form of sulphates, and subsequent reprecipitation of the iron-sulphate as pyrite under reducing conditions, whereas the sulphates of manganese, copper, etc., being less easily reducible, would be carried away.

Water charged with sulphates and sulphuric acid is able to dissolve unusual quantities of silica, as the analysis of water from the Helen mine, given on a later page, proves. Presumably, a loss of sulphuric acid and sulphates, such as must occur when pyrite is precipitated, would reduce the capacity for dissolving silica and silica would be precipitated along with the pyrite. The layer of granular quartz over the pyrite sand at Goudreau seems to accord with this view.

Since the pyrite sand lies on a smooth surface of bedrock apparently striated in places, and is overlain by stratified sand and gravel of Pleistocene age cemented by limonite, the ore-body is clearly also Pleistocene. As pyrite and quartz are exceedingly fragile and lie under the gravel and sand they were first thought by the senior author to have been introduced by chemical replacement of some of the drift. There is little direct evidence of replacement, however, and it may be that the quartz and pyrite were deposited before the gravel and sand.

—	I	II	III
Fe	45·14	44·69	43·03
S	50·04	46·91	46·31
As	0·005	0·58	None
P	0·003	0·08	Trace
Mn	0·21	0·05	0·16
Zn	0·24	0·49	.....
Cu	None	Trace	
Insoluble siliceous material	3·62	3·74	9·71
Total	99·258	96·54	99·21
Magnetic part	1·36	0·20	3·00

I. Sample of pyrite sand from deposit in mining claim AC 50, Goudreau, that lies on bedrock beneath gravel and sand. Analysed by H. A. Leverin, Mines Branch, Ottawa.

II. Sample of pyrite sand from old Helen hematite mine, Michipicoten district. Analysed by H. A. Leverin, Mines Branch, Ottawa.

III. Average of three drill-cores from Holdsworth pyrite deposit, near Hawk Junction, Michipicoten district. Analysed for Algoma Steel Corporation by H. A. McKenty.

The deposit on AC 50, just described, contained a good many tons of pyrite sand. According to manager G. G. Dobbs and geologist D. C. Wysor, of the Nichols Chemical Company, much smaller deposits of the same nature were found at the C pit in JL 15, when the overburden of boulders and gravel was being removed.

HELEN MINE

The Helen brown iron ore deposit, situated in the southwest corner of township 29, range 24, is exhausted and the mine was closed down on April 16, 1918. Nevertheless, it is still deserving of a brief description, partly because of the bearing its known geology has upon the study of similar deposits of iron ore and partly because of its past importance to the iron mining and iron and steel industries in Ontario. This deposit had yielded more iron ore than any other deposit in Canada, its total output from 1900 to 1918 being 2,823,369 tons of brown iron ore of good quality and 51,930 tons of pyrite. When visited in 1919 and 1920 the mine was full of water; consequently, the following account has had to be derived mainly from the earlier reports by Coleman, Willmott, Parsons, and others in the Annual Reports of the Ontario Bureau of Mines, and from information given by former officials of the mine.

A large outcrop of brown ore was found at the east end of Boyer lake by Alois Goetz in the autumn of 1898. It was staked for gold, owing to the proximity of the banded silica member of the Helen iron range and to the dominating interest that was then being taken by prospectors in the gold-bearing veins south of Wawa lake; but its value as an iron ore deposit was soon recognized and it was bought by E. V. Clergue and transferred to the Lake Superior Power Company, a subsidiary of the Lake Superior Corporation. Later it was transferred to the Algoma Steel Corporation and operated by that company. A railway was built to the mine from Michipicoten Harbour, and shipments of ore commenced in July, 1900.

The ore-body is now known to have been a pocket of oxidation products in the siderite and pyrite members near the west end of the Helen iron range, already described in this report. It outcropped as a gossan or thick cap of limonite at the east end of Boyer lake, rising to about 100 feet above the water's edge. Boyer lake occupies an unusual cirque-like depression, which Coleman is inclined to regard as related in origin to the iron-ore deposit. The lake is enclosed on the north, east, and south by steep slopes of iron formation or volcanic schists that rise 150 to 400 feet above the water, but the western side is open, allowing Boyer lake to drain over a rock ridge into a second body of similar size and character called Sayers lake. Boyer lake was itself a rock basin 133 feet deep. The cirque-shaped basin shows effects of glaciation and glacial boulders coated with $\frac{1}{16}$ to $\frac{1}{8}$ inch of limonite were found in the bottom of Boyer lake when it was drained, so the depression is evidently glacial in age and origin. The relatively soft body of brown iron ore in it, and the shrinkage in volume involved in the formation of the ore-body, may have favoured deep glacial scouring at this place.

When exploration of the ore-body was commenced Boyer lake was lowered by means of a rock-cut at its outlet, and afterwards was pumped dry. The ore-body is stated by Coleman in the report of the Ontario Bureau of Mines for 1901 to have been 1,090 feet long from east to west and 400 feet wide. Beneath this cap it was later found to diminish to 700 feet by 200 feet. As greater depth was reached in mining, the

long axis shortened, but the width increased so that the floor area of the mine remained about the same until near the bottom of the deposit. The eighth level had a floor area only about half that of the levels above, and the bottom of the ore-body was reached about 700 feet below the surface, actual mining operations closing at a depth of 651 feet. The ore-body pitched about 60 degrees towards the northeast.

On the south side the ore-body was bounded by quartz porphyry schist down to the fifth level, and from there to the bottom by siderite, a zone of soft "paint rock", or decomposed and iron-stained rock, lying between the ore and the unaltered schist. On the north the good ore merged into a mixture of quartz and iron oxides representing the face of the banded silica member of the iron formation. Eastward the ore-body merged gradually into siderite, a series of samples taken in that direction showing a gradual increase of volatile matter (carbon dioxide). A similar transition westward from brown iron ore into siderite was interfered with by the presence of a dyke of younger diabase, which within the boundaries of the ore-body was converted into a soft clayey material. Down to 280 feet below the surface this dyke formed the western termination of the ore, but farther down, in the third, fourth, fifth, and sixth levels, a smaller body of ore was found on the west side of the dyke.

According to Parsons the iron ore consisted mainly of goethite ($FeO\ H_2O$) with lesser proportions of hematite and other hydrous oxides of iron. Physically it varied from amorphous brown ore to hard kidney ore with radiate, crystalline structure and smooth, botryoidal surfaces. Bolton states that the ore was porous and apparently voids of measurable size were also common. As indicative of the nature and amount of these spaces, Mr. A. Hasselbring, formerly superintendent of the mine, informed the senior author that when the drill was withdrawn from a hole bored horizontally towards the margin of the ore-body in one of the lower levels, water was projected for a horizontal distance of 20 feet and drained the levels above. The quality and chemical nature of the ore are sufficiently indicated by the following analyses:

—	I	II	III	IV	V
Fe	58·70	58·98	56·79	57·76	63·89
SiO_2	5·66	8·02	6·16	5·90	.....
S	0·047	0·067	0·264	0·391	0·034
P	0·114	0·069	0·095	0·092	0·116
Al_2O_3	0·73	0·63	0·90	0·88	.....
CaO	0·21	0·20	0·24	0·23	.....
MgO	Trace	0·19	0·152	0·14	.....
Mn	.....	0·04	0·17	0·165	.....
H_2O	16·28	8·00	4·00	4·00	.....
Insol	6·04	.....	.....	.....	.....

I. Average analyses of 20,000 tons of ore from Helen mine in stock-pile at Midland, September, 1900.

II. Sample of Helen ore from mine in 1901. *See* Annual Report, Ontario Bureau of Mines, 1902, pp. 91–100.

III. Average analyses of 1914 shipments, No. 1 ore. *See* "Iron Ore Occurrences in Canada," vol. I, p. 35.

IV. Average analyses of 1914 shipments. No. 2 ore. Ibid.

V. Average analyses of core from drill-hole No. 1. *See* Annual Report, Ontario Bureau of Mines for 1902, pp. 152–185.

This brown iron ore was accompanied rather commonly by pyrite either in disseminated grains or in pockets varying in size from a few cubic feet to large ones 30 or 40 feet in their greatest dimensions. These pockets were not numerous on the first level of the mine, but in succeeding levels constituted a serious obstacle to the recovery of the iron ore, and themselves yielded 51,930 tons of high-grade pyrite. Most of the pockets contained loose grains of pyrite which flowed like sand when an opening was made. A sample of this pyrite sand supplied in 1919 by Mr. G. S. Cowie, of the mines department of the Algoma Steel Corporation, yielded on analysis the results given in analysis No. 2, page 114. It closely resembles the pyrite sand found at Goudreau and, like the latter, differs from primary range pyrite in its higher content of sulphur and the insignificant proportions of manganese, zinc, and other accessory metals, as well as in the virtual absence of magnetic components—pyrrhotite and magnetite. As in the case of the secondary pyrite sand at Goudreau the pyrite sand in the Helen mine had associated with it a white sugary quartz sand either mingled with the pyrite or overlying it.

Respecting these pockets of pyrite sand in the Helen mine, Coleman says: "At points in the ore-body pockets of pyritic sand are occasionally met. The largest of these, which was exposed during an examination of the Helen mine last May (1901), as seen in the bottom of the pit, was 45 feet by 8 feet, but was probably wider. At both ends, however, it was cut off very abruptly by the ore-body, there being no gradation between the solid ore and the pyritic sand. Occasionally in this bed some boulders of solid ore were noticed, the largest being 2 feet in diameter. Little stringers of pure white, fine sand were occasionally seen in the pyrites, but apart from these minor occurrences the pyritic sand seemed to be a pure concentrate. It is said on the surface this deposit first made its appearance as a chimney of sand about 30 feet in diameter and that as followed down the siliceous sand was gradually replaced by pyritic sand until the present level was reached, and that the pyritic sand has been replaced in the bottom with solid (iron) ore just as abruptly as it changed on the sides."

In the northeastern corner of the basin formerly filled by Boyer lake is a body of yellowish-brown limonite powder, of undetermined size, but apparently between 50 and 100 tons. This deposit is not directly connected with the main iron ore-body of the Helen mine. It rests on the bottom of Boyer lake, commencing at the original water-level, and has the general appearance of having been precipitated there from some stream of iron-charged water that flowed off the iron range. It is presumably a post-Glacial deposit since it occupies a glacially formed basin and is much too loose and fragile to have resisted even the gentlest of erosive agents. Coleman found this yellow ochre to contain 49·50 per cent iron, 0·36 per cent manganese, 6·63 per cent silica, a trace of lime, and 4·13 per cent carbon dioxide.

Coleman, Willmott, Parsons, and other geologists who had opportunities to study the Helen ore deposit while the mine was operated, agree that the ore-body was derived by oxidation from the siderite and pyrite of the Helen iron range. This opinion seems to be the only tenable one. The

brown iron ore forms a pocket in the siderite and pyrite member of the Helen range 700 feet deep, 700 feet in diameter along the course of the range, and the full width (200 feet) of the siderite and pyrite, being bounded on the north by the banded silica of the iron range and on the south by the volcanic schists that form the base of the iron formation. All the contents of this pocket—brown iron ore, pyrite, and quartz sand—are contained in the siderite-pyrite member of the iron formation or can be derived from it by oxidation. Geologists and mine officials agree that at the eastern and western margins of the ore-body there was a gradation from brown iron ore into unaltered siderite. Indeed, such approximate data as are available seem to indicate that the siderite and pyrite which originally must have occupied the pocket, if converted into iron oxides and pyrite, would yield just a little more of these products than actually appear to have existed. The original siderite and pyrite in the pocket, if of the same average composition as that in the main body of the Helen range, would contain about 2,140,000 tons of metallic iron and, if it be assumed that 20 per cent of the brown iron ore-body was left in the mine, the pocket actually contained about 2,005,000 tons of metallic iron in the form of brown iron ore and pyrite. Apparently, therefore, the body of brown iron ore was, or could have been, formed strictly in situ and without transportation of material from outside the pocket.

The chemical processes whereby a pocket of siderite and pyrite 700 feet by 200 feet and 700 feet deep was converted into iron oxides and pyrite are indicated in part by the mine water, which presumably represents a middle stage in the process of change. When the mine was visited in 1920 by the senior author it was filled with water and the sample of mine water, an analysis of which is given here, had to be taken from a depth of only about 8 feet below the surface. In all likelihood it is more dilute than a sample taken from the bottom of the mine would be, where the original reagents, siderite and pyrite, are still present. Parsons states that the lower levels of the mine in 1915 were distinctly warmer than the upper levels, and steam could be seen rising from the walls.

—	I	II
Sulphuric acid (SO_4)	3,492	206 parts per million
Nitric acid (NO_3)	26	
Silica (SiO_2)	80	40
Iron (Fe)	507	24
Aluminum (Al)	318	
Manganese (Mn)	134	
Calcium (Ca)	71	42
Magnesium (Mg)	23	
Sodium (Na)	20	
Chlorine (Cl)	none	
Carbonic acid (CO_2)	none	
Total	4,671	312 parts per million

Analysis No. 1 is of a sample of mine water from the Helen iron mine 8 feet below surface. Collected, September 25, 1920, when the mine, which had been abandoned since April, 1918, was filled with water. Analysed, December, 1920, by E. A. Thompson, Mines Branch, Ottawa. The sample as recorded was pale brownish-yellow, had an acid reaction, and carried a small quantity of brownish-yellow sedimentary matter. Its specific gravity was 1·004 at 155°C., and the total dissolved saline matter, dried at 180°C., was 4,770 parts by weight in one million. The values given in the analysis are parts by weight in one million parts of filtered water.

Analysis No. 2, of a sample of water seeping through a deposit of limonite near Taseko lake, 8 feet beneath the surface of the deposit, is cited for purposes of comparison. *See* Summary Report, Geological Survey, 1920, Part A, page 69.

The Helen mine water is essentially a solution of sulphates, there being almost enough SO_4 to satisfy all the bases present if the iron sulphate be regarded as in the ferric condition, and more than enough if the iron is in the form of ferrous sulphate. Evidently the first step towards production of this solution was the formation of iron sulphate and sulphuric acid from the pyrite and pyrrhotite in the primary siderite-pyrite by a reaction represented by $FeS_2+H_2O+7O=FeSO_4+H_2SO_4$. The sulphuric acid thus formed would attack the siderite, forming sulphates (Fe, Ca, Mg, Mn, etc.) $CO_3+H_2SO_4=(FeSO_4, CaSO_4, \text{etc.})+H_2O+CO_2$. In proof of this the mine water contains sulphates of just those metallic elements which occur in the siderite, though the proportions of some of these, notably of aluminum, are increased owing to the fact that the acid mine water has also attacked and formed sulphates from the volcanic rocks that bound the ore-body.

The second stage in formation of the ore-body appears to have been a reduction of the iron sulphate in solution to limonite and pyrite and precipitation of these from solution. This change has occurred in the formation of the Goudreau pyrite sand deposit and is taking place in plain view near the Morrison No. 3 range, where pools of clear water charged with iron sulphate are bottomed by a crust of limonite. No evidence has been found to indicate just what reactions were involved at the Helen mine. Iron sulphate has been reduced experimentally to iron hydroxide by using organic matter as a reducing agent and that is no doubt what is happening in the above-mentioned pools; but it seems unlikely that organic matter could have found its way in appreciable amounts into the Helen ore-body. The sulphites of lime, magnesia, manganese, and alumina, being highly soluble and stable in solution, were evidently carried away from the ore-body, since only traces of these elements remain in the iron ore and pyrite.

Some of the iron oxides in the Helen ore-body may have been formed by direct weathering of siderite such as occurs at the surface of any siderite deposit, but this process appears to be very slow and would probably account for only an inconsiderable part of the ore deposit. The fact that the deposit formed only at a place on the iron range where sulphate waters could collect in a natural depression seems to point to these waters as the chemical agents which gradually digested its way downward into the siderite member of the iron formation. The total amount of pyrite from which sulphuric acid and iron sulphate could be made is greatly inferior to the amount of siderite converted into brown iron ore, but it is possible that the sulphur available could have been used more than once in the processes of oxidation and reduction to limonite.

Coleman explains the formation of the iron ore in the Helen mine in much the same manner as the foregoing, but he regards the pockets of pyritic and quartz sand in the ore-body as due to a mechanical concentration, by running water, of the sulphides that were disseminated through the primary siderite.[1] This explanation does not, however, accord with the known facts. The composition of the mine water indicates that

[1] Ann. Rept., Ont. Bureau of Mines, 1902, pp. 171-172.

the primary pyrite went into solution as iron sulphate in large quantities. An analysis of the pyritic sand (page 114) when compared with an analysis of primary range pyrite also shows that the former has lost most of the manganese, zinc, and other metals found in range pyrite and has also lost the magnetic constituents—pyrrhotite and magnetite—found in range pyrite. If, as appears to have been the case, the Helen ore-body was formed in place from the siderite and pyrite that once occupied the same pocket it is almost inconceivable that the pyrite grains disseminated through that body of siderite could have been concentrated into pockets by currents of water. Circulation of water through the ore-body was almost certainly too gentle to move pyrite grains even if these could have been freed from their matrix of iron oxide and decomposing siderite. It seems much more likely and accordant with the evidence obtained that the primary pyrite and pyrrhotite were changed to iron sulphate, dissolved, carried downward in the ore-body, freed of their manganese, zinc, nickel, etc., while in solution, and the remaining iron sulphate precipitated under reducing conditions as pyrite sand.

The pure quartz sand which is mingled with or overlies the pyrite sand in the pockets is likewise regarded here as a chemical precipitate rather than a concentration by running water of the particles of quartz which were disseminated through the primary siderite. Evidently water charged with sulphates has an unusual capacity for dissolving silica, for both the Helen mine water and that of the Taseko iron ore deposits of British Columbia carry unusually large amounts of silica. Presumably this capacity for holding silica in solution would be diminished or lost as the iron sulphate was reduced to sulphide (pyrite) and was precipitated, and the silica would also be precipitated.

Although the Helen ore-body is much larger than the pyrite sand deposit at Goudreau, previously described, and the proportions of brown iron ore, pyrite, and quartz sand are very different, the two deposits are closely analogous in character and probably also in mode of origin. Both consist of hydrated iron oxides, a pyritic sand of unusual purity, and pure quartz sand resembling granulated sugar in appearance. The Goudreau deposit is undoubtedly secondary and derived from the pyrite and siderite members of an adjacent iron range and the Helen deposit is evidently also derived from similar primary materials by processes of oxidation, solution, and precipitation. The Goudreau deposit is post-Glacial. The Helen deposit probably commenced formation before Glacial time and was sufficiently advanced to form an easily eroded spot in the Helen iron range which the ice-sheet deepened to form the basin of Boyer lake. There was good evidence, however, in the high temperature of the mine and the composition of its waters that the process of ore formation had been active, and probably continues at the present time. Coleman mentions a coat of limonite $\frac{1}{16}$ to $\frac{1}{8}$ inch thick on gneiss boulders in the bottom of Boyer lake as a measure of the rate of formation of brown ore since Glacial time, but in all probability the rate of formation at the bottom and sides of the mine, where concentrated mine waters came directly in contact with the primary siderite and pyrite, was much faster.

JOSEPHINE MINE

The iron range adjacent to Parks lake, in township 28, range 25 (mining claims Y 451-2-3), is known as the Josephine property. This part of the range was staked at about the same time in 1899 by rival representatives of E. V. Clergue and Alois Goetz, following which the ownership remained in dispute until August 24, 1906, when a settlement was arbitrated by Honourable Frank Cochrane, who ruled:

"The above mining claims (Nos. 738-747 inclusive, in Michipicoten Mining Division), otherwise known as the Josephine iron mine, have for a long time been in controversy between Alois Goetz *et al* and the Algoma Central and Hudson Bay Railway Company, the former claiming them by virtue of original discovery and the latter under the land grant made by the Legislative Assembly of Ontario.

"Having gone thoroughly into the case.. ..I am bound in equity to recognize Goetz's claim, but in view of the large amount of work done and money expended on the lands by the company, I think they should have the opportunity of acquiring the same at a reasonable figure.

"I, therefore, rule that, on the company paying to Goetz the sum of $50,000 the ten claims in question.. ..be allowed to the company. In default of the company paying over, or securing, to Goetz the said sum of money within thirty days from this date, Goetz to have the liberty of choosing five of the claims, the remaining five to be given to the company."

Following this decision Goetz selected claims 738, 739, 744, 745, and 746, and in October, 1906, had them surveyed as Y 455, 454, 451, 452, and 453, respectively.

Early in the period of dispute H. A. Wiley, of Port Arthur, secured an option of purchase from Goetz and had three diamond-drill holes bored. Between 1900 and 1906 the Clergue interests had twenty-one holes drilled, which revealed very considerable bodies of brown iron ore adjacent on the south to the banded silica member of the iron formation. Between December, 1901, and 1903, they also sank two shafts, one about 150 feet deep on the south side of Parks lake opposite the middle of Schist island (*See* Map 1972, in pocket) and one at the east end of the lake; but owing to the uncertainty of their title to the property and other disadvantages these operations were discontinued before any ore had been raised. During 1913 and 1914 five more diamond-drill holes, bringing the total footage to 10,406 feet, were bored by the Algoma Steel Corporation, which had secured a lease and option to purchase from Goetz. This option was not exercised, and at the present time the shafts are dismantled and full of water, and steel has been removed from the railway spur that had been built from Josephine junction.

The iron range is well exposed in Y 453 and 452, but it consists there mainly of banded silica, with only a little pyritic siderite along the south side. Again, southwest of Parks lake the banded silica member is conspicuous, but not accompanied by any important width of siderite. Under Parks lake, where the brown ore occurs, the iron range is concealed except for an island of nearly white, banded silica in the middle of the lake. Coleman reports that hematite (brown iron ore) outcropped on the south

shore, and that blocks of hematite were found scattered along the shore, but the senior author could not find these in 1918. However, the diamond-drill explorations proved that an important body of brown ore mixed with pyrite lies just south of the banded silica, between it and the volcanic schists to the south. The usual siderite and pyrite members of the iron formation are here converted into brown ore very much like that found in the Helen mine.

Plans and descriptions of most of the drill-holes have been furnished by Judge John McKay, of Port Arthur. The cores are stored by Alois Goetz, in Sault Ste. Marie, Michigan. These holes range in length from 41 to 1,696 feet, and as most of them are inclined 35 to 80 degrees they penetrate the iron formation to vertical depths ranging from 40 to 1,550 feet. Most of them descend between 200 and 900 feet vertically. According to these explorations the iron formation—banded silica, hematite, and intercalated schist—is from 75 to over 350 feet thick. It strikes southwest the length of the lake. Near the surface it dips northwestward, the angle being 60 to 80 degrees at the foot of the lake and 80 to 85 degrees at the other end. Hole No. 51, which intersects the iron formation at about 1,500 feet below the surface, indicates that the formation becomes slightly overturned in depth and dips about 80 degrees south. The iron formation under Parks lake is, therefore, a sheet standing about on edge, faintly convex towards the northwest, and descending probably far deeper than the drill has explored. It consists of a sheet of banded silica 50 to 350 feet thick, against the south side of which lies a thinner and less continuous sheet of brown iron ore interstratified with banded silica and schist and ranging in aggregate thickness from 0 to 135 feet.

This vertical sheet of brown ore appears to be in two parts within the area drilled. The better-explored, and apparently the larger, one begins about 200 feet east of Jasper island and extends northeastward for at least 1,000 feet, being crossed farthest in this direction by drill-hole No. 18. It is intersected in this distance by thirteen holes which show iron ore at depths ranging from 200 to 900 feet, and in the case of Hole No. 51, 1,550 feet, below the surface of Parks lake. The drill-holes define a vertical sheet of ore of oval or kite-shaped outline 1,000 feet in maximum length, 1,350 feet in maximum depth, and 5 to 125 feet thick. Of the total thickness only 5 to 50 feet is ore, the remainder being layers of banded silica or schist 5 feet and upwards in thickness, which alternate with like sheets of ore. The greatest observed band of ore in any of the holes is 45 feet thick. The upper boundaries of this oval ore-body, defined by drill-holes, seem to coincide fairly closely with the actual limits of the ore-sheet, for the ore disclosed by the upper drill-holes is thin and low grade. It seems likely, however, that the lower limits could be extended considerably if deep holes like No. 51 were drilled on either side of it.

If all ore carrying over 30 per cent metallic iron be taken into consideration, the oval sheet defined by the thirteen drill-holes is estimated to contain 2,250,000 tons. If ore carrying less than 50 per cent iron is excluded the tonnage would be reduced to 1,300,000 tons. According to

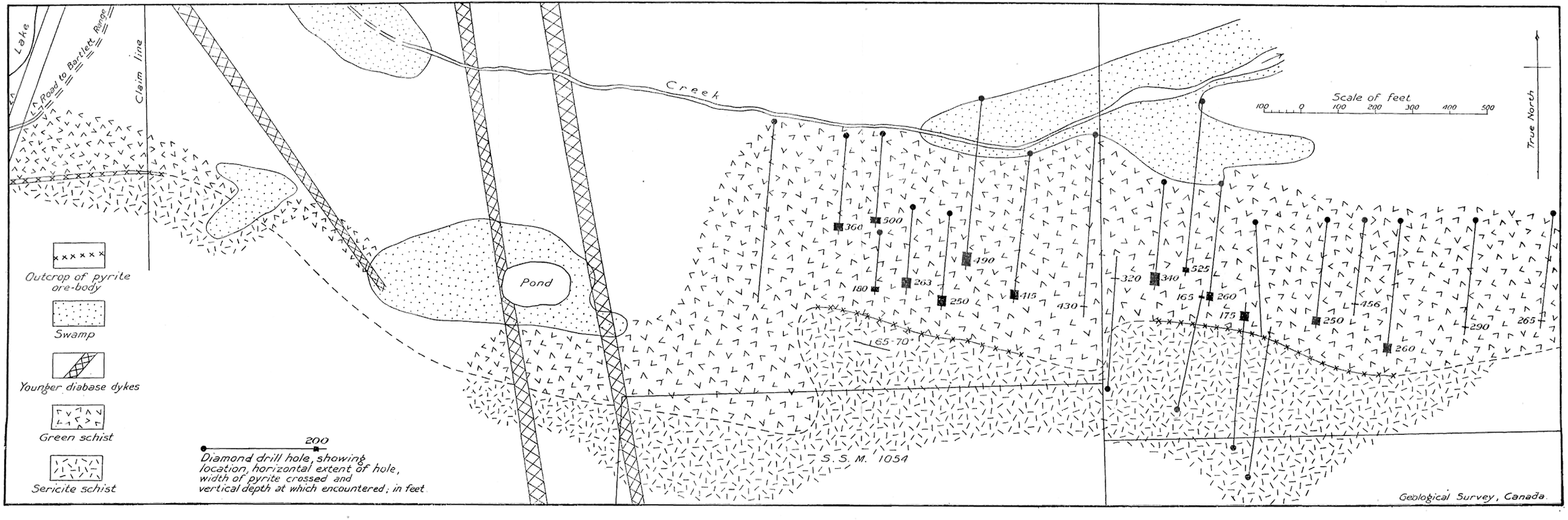

Figure 14. Plan of Holdsworth pyrite deposit, showing results of diamond-drill explorations by Algoma Steel Corporation.

Goetz and McKay[1] "there is proved up 850,000 tons of ore running 59 per cent iron and in addition there is a very large tonnage of banded ore capable of being concentrated or roasted." Reports furnished in February, 1918, by Malcolm A. McKay, of Port Arthur, gave estimates ranging from 1,250,000 to 3,000,000 tons of ore proved up by diamond-drilling. At least 850,000 tons of this are believed to be recoverable.

According to information supplied to Judge McKay by the late A. B. Willmott, the high-grade part of the ore located by drilling up to 1906 carries 59 per cent iron and 0·04 per cent phosphorus. All the ore is said to carry a certain amount of pyrite, and in the case of the ore reached by the deep hole, No. 51, the proportion of disseminated pyrite is large. Parsons states that small specks of kaolin could be seen in the iron ore in the drill-cores, thus resembling the Helen mine ore, and according to other observers there is a close general similarity to the Helen ore. In all probability it is a secondary ore deposit derived from a primary siderite and pyrite ore in the same manner as the Helen deposit.

For 1,200 feet southwest of this sheet or lens of ore no brown ore was encountered by the drill, but just beyond that distance holes Nos. 19 and 12 cut across a second sheet of fairly high-grade ore 20 to 40 feet thick at depths of 700 and 500 feet, respectively. Unfortunately these holes are close together and there are no others near enough to afford an idea of the size of this sheet.

Parks lake, under which the ore deposits lie, is about 70 feet in greatest depth. There is a descent of nearly 100 feet to Goetz lake, but in order to take advantage of this fall to drain Parks lake the present rocky channel between the two lakes would have to be deepened by a rock-cut or tunnel. The deepest part of Parks lake is 3,000 feet away from the outlet.

HOLDSWORTH PYRITE DEPOSIT

Some time previous to 1914 a block of very pure, massive pyrite about 10 feet in diameter at the surface was discovered just about the middle of mining claim SSM 1054, in township 28, range 25. In 1919, when the spot was last visited by the senior author, it had not been proved whether this block was in place or was an erratic, but it is probably the latter. Search had accordingly been made in the neighbourhood for the parent deposit and in the spring of 1918 John Holdsworth found an important deposit of pyrite about 1,000 feet north of the block of ore first discovered. It is rather doubtful whether the block came from this deposit, for the latter is represented at the surface only by a band about 2 feet wide of dull black powdery material which the prospectors call "black sand" and which is probably a ferrous oxide resultant from oxidation of pyrite. However, diamond-drill borings afterwards disclosed a large quantity of high-grade pyrite similar in appearance to that in the block (Figure 14).

The Algoma Steel Corporation secured a lease and option to purchase the property, and between May, 1918, and the spring of 1919, explored the ore-body with a diamond-drill. Twenty-two holes, ranging in length from about 225 to 740 feet, were drilled at angles of 40 to 80 degrees across the ore-body from either side. Seventeen of these holes encountered pyrite at

[1] "Iron Ore Occurrences in Canada," vol. 2, p. 80.

vertical depths ranging from 165 to 525 feet. They indicate the existence of two lenses of pyrite about 200 feet apart and offset from each other as shown in Figure 14. They dip towards the north at 65 to 70 degrees and lie between volcanic green schist on the north and a light grey schistose to massive sericitic schist on the south. The eastern lens has been located by drilling for 1,100 feet horizontally and to an extreme depth of 525 feet vertically. It attains a thickness of 18 to 25 feet at depths of 175 to 240 feet. Deeper down, towards the east and also towards the surface, it tapers to from 1 to 5 feet, but at its west end it thins abruptly from 18 feet to nothing. Here the trace of the ore-body at the surface and the greenstone and sericitic schist on either side are sharply deflected southward, probably by drag-folding, for 200 feet, to where the second, or western ore-lens begins. This western lens has a determined horizontal extent of 600 feet and an extreme depth of 490 feet vertically, at which point it attains its maximum determined thickness of 31 feet. Presumably, therefore, it continues to greater depth.

There are some surface indications that the sharp drag-folding which probably severed one original sheet of pyrite into the eastern and western lenses is repeated. At the western end of the western lens, the contact between the greenstone and sericitic schist is deflected southward for 300 feet and then resumes its ordinary course of 280 degrees. "Black sand" was found for a distance of 500 feet along this contact, as shown in Figure 14, but no underground exploration has been undertaken to ascertain whether a body of pyrite lies beneath.

Officials of the Algoma Steel Corporation estimate that the two lenses examined with the drill contain 900,000 tons of good pyrite. Analysis of 10-foot sections of the drill-core yielded a sulphur content varying from 39·88 to 49·24 per cent and an average of 46·31 per cent for three of the drill-holes (*See* page 114). The pyrite has clean contacts with the volcanic schists on either side, the change from pyrite ore to rock being complete in less than 1 inch. In a few of the drill-cores a few thin bands of country rock are intercalated with the ore. In drill-hole 308 the ore next to the greenstone is mixed with quartz and in hole 304 a cavity and some sand (presumably quartz sand) were penetrated before reaching a thin band of pyrite. The pyrite ore is, unlike the pyritic sand at Goudreau and the Helen mine, massive and brilliant, and is traversed by veinlets of even brighter and coarser-grained pyrite. Nevertheless, in chemical composition, it possesses the same characteristics which distinguish the Goudreau and Helen mine pyritic sand from primary range pyrite. It contains almost no magnetic constituents, pyrrhotite and magnetite, only a trace of manganese, and probably only traces of zinc, nickel, and copper, if these metals had been sought by the analyst. No iron formation is associated with the deposit. On account of its chemical similarity to the Goudreau and Helen mine pyritic sands, and the presence of some granular silica, it is believed that the Holdsworth pyrite deposit is also of secondary origin, though perhaps formed in Precambrian time before the Keewatin volcanics, with which it is associated, were folded into their present attitudes.

ALICE AND BRANT LAKE DEPOSITS

The Alice and Brant Lake iron ore deposits, previously described, appear to be secondary in origin. They are parts of iron formations in which the usual siderite and pyrite are replaced by magnetite and hematite. No explanation has yet been found, however, to account for the development of magnetite instead of iron hydroxides such as occur in the Helen and Josephine deposits.

GOLD

Quartz veins carrying gold appear, according to the records of the Ontario Bureau of Mines, to have been first found in Michipicoten district in June, 1896. The first discovery was made on the south shore of Wawa lake, in township 29, range 23. Wawa lake was part of a chain of lakes, streams, and portages extending from Michipicoten bay, in lake Superior, to Dog lake, over which supplies were freighted for the construction of the main line of the Canadian Pacific railway. A small village, called Wawa city, grew at the west end of the lake, where the buildings, mostly ruinous, though inhabited by a few families, are still standing. It appears to have been from this settlement that the country adjacent to Wawa lake was prospected and numerous discoveries of gold were made. The most promising of these finds developed into the Grace and Manxman (or Norwalk) mines, whereas others were abandoned after being explored by means of surface trenching, test-pits, and shallow shafts. The Grace and Manxman mines were operated, though not continuously, as late as January, 1920, and interest is still maintained in the former.

Gold-bearing quartz veins were found in township 27, range 27, during 1918, where prospectors had been attracted by the pyrite ranges which were being explored and developed for a war supply of sulphur. In the next two years extensive surface explorations were performed on the more promising of these veins, but as yet no mining and production of gold have followed.

In the spring of 1921, Thomas Murphy, of Goudreau, discovered gold in a quartz vein situated near the centre of township 28, range 26, at the eastern end of a body of granite shown on Map 1972, accompanying this report. Specimens from the vein were so rich in free gold that prospectors hurried into the district, many claims were staked, some additional discoveries made, and underground development was begun on the original discovery. These activities, however, have not been sustained.

WAWA AREA

The gold-bearing veins south of Wawa lake are situated in the Keewatin schists around the edge of an oval, intrusive body of granite, and southward to Michipicoten river. This granite differs in some respects from the greater batholithic areas of the region. Instead of being uniformly coarse grained, with pegmatitic phases indicative of slow cooling, it consists mainly of a quartz porphyry that varies in texture from a medium-grained granite with faintly developed porphyritic habit, through finer-grained and more distinctly porphyritic phases, to a very fine-grained,

pale grey rock like rhyolite. Fine-grained phases appear to be commonest towards the margin of the body, but there is too much irregularity in this respect for these phases to be regarded as the chilled periphery of a single intrusion. The contact itself is not a single definite plane; streaks and bands of the Keewatin schists alternate increasingly with the granitic rocks towards the edge, and similar bands and streaks of granitic material occur in the Keewatin far beyond the approximate main contact. Gradations occur locally from massive to quite gneissic phases in the main body of granitic rocks. Feldspars and quartz are the prevailing mineral constituents; biotite and hornblende occur in amounts so variable as to produce a variation, locally, from a pale grey rock to one of dioritic composition. The intrusion was probably of much the same magmatic composition and age as the main batholith that lies a few miles farther southeast, but it evidently cooled more quickly and exercised less metamorphic influence upon the surrounding Keewatin schists.

By analogy with most other gold mining camps in the Precambrian Shield this granite may have been the source of the gold-bearing veins, but no direct and conclusive proof of this supposition has been found. The veins are rudely marginal to the granite in distribution; but on the south shore of Wawa lake quartz veins carrying tourmaline and presumably also free gold, since they contain quite extensive test-pits, intersect wide dykes of diorite which in their turn intersect the granite, and present chilled edges to it. If these veins are of the same generation as the other gold-bearing veins, the latter must have formed well after the granite had solidified and cooled.

A very good idea of the prospecting activity near Wawa lake in the late nineties and of the number of discoveries made can be gained from the reports of inspector D. G. Boyd.[1] Most of these discoveries have been abandoned after more or less extensive exploration by means of surface trenches, test-pits, and even shallow shafts. Two properties, however, were mined and are still of sufficient interest to warrant a summary in this place of the information scattered through earlier reports, chiefly of the Ontario Bureau of Mines.

Grace Mine

Grace mine is situated on mining claim DJ 7, the property including adjacent claims occupying in all 886 acres. The ore-body is a quartz vein, varying in width from a few inches to 5 feet, and averaging 2½ feet, that strikes about 165 degrees and dips 70 degrees towards the east. It can be traced for about 200 feet along the surface, and is said to have been located at intervals across several of the claims. It consists mainly of a gangue of white, rather sugary quartz with some calcite and siderite, carrying small quantities of pyrite, chalcopyrite, arsenopyrite, pyrrhotite, and free gold. At the surface gold is said to have been plentiful and according to superintendent Nissen, in 1901, an average gold value of $12 a ton was being found in the mine. The vein had tight, definite walls against a country rock of dark green porphyrite carrying small oblong crystals of feldspar.

[1] Repts. Ont. Bureau of Mines, 1898, pp. 101, 195; 1899, pp. 100-105, 146; 1900, pp. 112-118.

Mining operations were commenced in July, 1900, by the owners, the Algoma Commercial Company, and were continued until about the end of 1903. When examined by inspector D. G. Boyd on August 12, 1903, a main shaft 4½ by 9 feet inside measurements with two compartments, one for hoisting ore, the other a manway, had been sunk along the vein at an inclination changing from 67 degrees east at the surface to 80 degrees near the bottom, to a depth of 304 feet. Drifts had been run at the 100, 200, and 300-foot levels. The 100-foot level consisted of a drift southward along the vein for 68 feet and one northward for 188 feet, communicating with a second, untimbered shaft 6 feet by 10 feet in section and 105 feet deep, situated 167 feet at 342 degrees from the main shaft. At the 200-foot level drifts extended 204 feet south and 115 feet north from the shaft. At the 300-foot level 108 feet of drift had been made, about equally north and south, and a winze connected the north end of this level with the 200-foot level at 57 feet north from the shaft. This vein had been stoped on the north 100-foot level for 100 feet to an average height of 20 feet; on the 200-foot level southward for 140 feet to an average height of 50 feet, and northward for 80 feet to an average height of 30 feet.

An output of gold was commenced during the last quarter of 1902, but there is no published statement of the amount produced.

According to mine inspectors Boyd and Carter, a small enclosed shaft house 15 feet high adjoined a power-house 26 feet by 38 feet in which were installed two locomotive type boilers of 35 and 45 horsepower, a 4-drill Ingersoll air compressor, and a Jenckes complex-cylinder single-drum hoisting engine, with cylinders 8½ by 14 inches and a drum 44 inches in diameter. The mine was unwatered by a Knowles pump 8 by 6⅜ by 6, installed over a sump near the shaft on the second level, and a Prescott pump 4 by 5 by 4¼ over a similarly situated sump on the first level. Ore was hoisted in a skip travelling on 20-pound steel rails and was carried in tramcars over a trestled tramway 350 feet long to a 10-stamp mill. The mill, 18 feet by 24 feet 6 inches, was equipped with ten 950-pound Allis-Chalmers stamps, a Blake jaw-crusher 7 inches by 10 inches, and three 6-inch Frue vanners. Power was supplied by a 60-horsepower Corliss engine in an engine room 20 feet by 30 feet, steam being provided with two 60-horsepower Mumford boilers housed in a boiler room 30 feet by 24 feet.

From the end of 1903 until the autumn of 1907 the mine was idle. Then it was purchased from the Algoma Commercial Company by the LePage Gold Mining Company, which also secured the Manxman (or Norwalk) mine, in 1910. A hydroelectric plant had been constructed by the Algoma Power Company at High falls, on Michipicoten river, in 1907, and the new owners of the mine set about obtaining a supply of electric power and converting their steam-driven mine plant to operation by electricity. A power-line was built to the mine, a 50-horsepower motor installed to operate the mill, a 100-horsepower motor to operate the air compressor, and another 50-horsepower motor for the hoisting machinery. A photograph of the mill and ore tramway is reproduced in the annual report of the Ontario Bureau of Mines.[1]

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[1] Ann. Rept., Ont. Bureau of Mines, 1909, p. 93.

Under the management of the LePage Gold Mining Company the Grace mine was operated during 1908 and produced some gold. Ore was stoped for a total length of 150 feet on the first level and a crosscut was driven 40 feet eastward from a point in the north drift 90 feet from the shaft. At 150 feet north of the shaft a winze was sunk to the second level. The slope in the north drift of the 200-foot level was extended up to the 100-foot level and stoping was also done in the south drift of the 200-foot level. On the 300-foot level the drifts were run to 80 feet north and 50 feet south of the shaft, but no ore was stoped. The Manxman mine was also operated.

The Grace mine was idle during 1909, but some gold was produced in 1910. In the latter part of 1917 it was pumped out and sampled for a Pittsburgh syndicate and in 1919 had become the property of the Grace Mining Company, president, W. A. Burmeister, of 1509 Cometra avenue, Chicago. Early in 1922 the A-Gold-Ma Mining Syndicate was formed by H. H. Lang of Toronto to take over the property, but up to the end of that year no work had been done.

Manxman (or Norwalk) Mine

This property, consisting of sixteen claims, is situated in township 29, range 22, about 2 miles south of the Grace mine, and just outside the area represented on the geological map (No. 1972) that accompanies this report.

At the main shaft, on claim No. 1229, according to inspector Carter, there is a schistose zone about 15 feet wide which strikes north and south across a formation of dioritic rock. The schist, which dips 75 degrees west, carries bands and lenses of quartz. Both schist and quartz contain pyrite and pyrrhotite, thickly disseminated and in compact lenses. This material is said to contain gold and silver values, as well as traces of nickel, and from traces to over 1 per cent cobalt. Half a mile north of the main shaft a body of quartz porphyry, said to carry some gold over a width of 30 feet and also to contain a narrow richer streak, was quarried.

Operations were begun in July, 1901, by the Manxman Gold Mining Company, and were continued until early in 1903. The mine was then idle until 1908 when it was acquired by the Norwalk Mining Company, under whose management it was worked during most of 1909. In 1910 it was transferred to the LePage Gold Mining Company and some work was done during that year. It was secured in 1919 by the Grace Mining Company, overhauling of the machinery was commenced in October, 1919, and underground work was begun in January, 1920, but continued only until May 6.

When work finally ceased a shaft had been sunk for 254 feet, 240 feet at about 45 degrees west and the remaining 14 feet at 75 degrees. At 110 feet drifts extended for about 100 feet in all and at 200 feet a second level consisted of 120 feet of drifts. A crosscut was driven 20 feet west at 48 feet in the shaft. Some stoping had been done on the second level, and on the first level the ore had been stoped to a height of 30 feet. The quarry on claim 641 was 120 feet long and a crosscut had been made for 30 feet. No production of gold is recorded by the Bureau of Mines.

The mill, situated on Mabel lake 1,300 feet south of the quarry, and connected with it by a tramway, contains ten Fraser and Chalmers stamps No. 112, a boiler, a 46-horsepower engine, and amalgamating plates. The power-plant consists of a 45-horsepower boiler, an Ingersoll-Sergeant air compressor, capacity 1,050 cubic feet of free air per minute, drawn by a 50-horsepower General Electric motor, and a Marsh and Henthorn hoisting engine 6 inches by 8 inches. An aerial tram connects the mill with a 9-inch by 16-inch jaw-crusher operated by a 30-horsepower Westinghouse motor. Electric power was supplied from High falls and reduced from 10,000 to 220 volts by three 50-kilowatts Westinghouse transformers.

The Grace and Manxman mines are apparently the only ones in Wawa area which have received active attention in recent years, but during the first period of activity, between 1897 and 1903, numerous other discoveries were made and developed but finally abandoned. The Minto property, consisting of claims 92 and 93, situated about one mile south of the western part of Wawa lake, was explored by the Wawa Gold Mining Company. Between May, 1898, and some time in 1900, veins on these claims were stripped and test-pitted, a shaft 6 feet by 11 feet and said to be 130 feet deep was sunk, hoisting and pumping machinery installed, and a camp built. On the Jubilee claim, No. 75, owned by the Great Northern Mining Company, a shaft, begun in November, 1897, was sunk 103 feet. An inclined shaft 8 feet by 12 feet and 208 feet deep was excavated on claims JD 1, 2, 3, and 4, known as the Mariposa property, and situated just northeast of the Grace mine. Another shaft 6 feet by 8 feet and 125 feet deep, with drifts 25 feet each way on the discovery vein at a depth of 80 feet was made on the Zagloba claim (No. 602) situated 6 miles east of The Mission and one mile north of High falls. On the Gananoque claim (No. 128) two tunnels, one 5 feet by 14 feet and 53 feet long, the other 7 feet by 8 feet and 22 feet long, were driven on a body of quartz. A pit 7 feet by 7 feet and 22 feet deep was excavated on claim No. 84, and a small stamp-mill erected by the Hornblende Mining Company. Various other still smaller enterprises are described by Inspector Boyd, in the annual reports of the Ontario Bureau of Mines between 1897 and 1903.

GOLD IN TOWNSHIP 28, RANGE 26

The gold-bearing quartz veins found in this township in 1921 are situated in and near the east end of an oval mass of granite about 1½ miles long that invaded the Keewatin schists. This intrusive, like that south of Wawa lake, shows plenty of evidence of having cooled quickly and of having exercised comparatively slight metamorphic effect upon the schists. It consists mainly of a medium coarse, granitic rock of light grey colour, composed mainly of quartz, orthoclase, and plagioclase, and comparatively small though variable percentages of biotite and hornblende. The granitic phase grades in many parts of the mass into one of porphyritic texture in which the feldspars are larger and more perfect crystals than the other constituents. Along the northwestern edge of the mass this porphyritic phase passes into one so fine grained as to resemble

rhyolite. Ellis Thomson states that the eastern part is traversed by numerous acid dykes which vary from pegmatites to quartz veins, the latter in some cases carrying free gold and sulphides.

The gold discoveries were examined in 1921 by A. G. Burrows, of the Ontario Department of Mines, and for the Geological Survey by Ellis Thomson, whose report is contained in the Summary Report for 1921.[1] The following descriptions of properties are based upon this report, and upon subsequent statements of mining developments in the reports of the Ontario Department of Mines.

Murphy or Goudreau Gold Mines. The first discovery—made by Thomas Murphy during the spring of 1921—was a quartz vein carrying quite coarse gold, in what is now mining claim AC 408. This vein is about 800 feet long and from 1 to 10 feet wide at the surface. It varies in course from 90 to 115 degrees and in dip from 60 degrees south to vertical. It lies mainly in AC 408, but smaller quartz stringers were found in the adjoining claim, AC 407. At one place it is offset 76 feet at 230 degrees by a dyke of younger diabase that strikes at 140 degrees. The vein consists of quartz impregnated and blackened with needles of tourmaline, and carrying native gold, pyrrhotite, chalcopyrite, bornite, pyrite, sphalerite, niccolite, and smaltite-cloanthite. Carbonate is also a constituent of the gangue in place. The Keewatin green schist on either side is impregnated with the vein minerals for about a foot in width.

Another quartz vein about a foot wide extends 65 feet at 100 degrees from a point on the boundary between AC 407 and 408, 200 feet north of Murphy lake. It also contains visible gold and the wall-rock is rusty and carried sulphides.

About 200 feet east from the same boundary line is a carbonated band of schist up to 20 feet in width, which contains stringers of quartz. It extends for 170 feet at 110 degrees. Though gold was not visible Mr. Burrows collected one sample from a width of 33 inches of quartz which assayed $6 in gold and another sample of quartz and carbonated schist across 5½ feet which yielded $4.

Goudreau Gold Mines, Limited, with Clement Foster as president, was incorporated in 1921 to purchase and operate the Murphy property. Twelve claims, containing 534 acres, and including the Murphy group, AC 407 to 410, were purchased and mining operations commenced. At the end of 1922 two shafts were sunk about 500 feet apart on the main vein. Shaft No. 1, near the southeast corner of AC 108, was down 224 feet at the inclination of the vein. No. 2, also inclined, was 246 feet deep and was being straightened for use as a working shaft. By March, 1923, a drift had been run at the 200-foot level from one shaft to the other and extended for 200 feet beyond each shaft. An electric transmission line from the Magpie mine line was finished in the spring of 1922. A mine power-house contained a 175-horsepower Canadian Westinghouse motor and a Canadian Ingersoll-Rand air compressor 18 inches by 11 inches with a capacity of 1,080 cubic feet of free air per minute. At each shaft is a Canadian Ingersoll-Rand reversing hoisting engine 8¼ inches by 10 inches.

[1] Geol. Surv., Can., Sum. Rept., 1921, pt. D, pp. 17-26.

Additional information regarding this property is given in Mr. Thomson's report which follows in this volume.

Gutcher Claim. This claim, AC 549, is situated in the granite, and Thomson regards the gold-bearing veins in it as quartzose phases of pegmatite dykes representing the last stages of cooling and differentiation of the granitic magma. Gold has been found in a quartz vein 1 to 3 feet wide that carries considerable pyrite, covellite, and muscovite, and some chalcopyrite, malachite, and ankerite. It extends for 200 feet at 125 degrees and dips about 70 degrees northward. Nearby is another quartz vein as much as 12 feet wide but without visible gold values.

Banville-Pagé Claim. Mining claim AC 532, on Rowan lake, contains a contorted, small iron formation crossed by numerous stringers of quartz in which gold has been found. The iron formation is only 6 to 10 feet wide and consists of quartz and carbonate. The quartz veinlets crossing it carry some chalcopyrite and occasional specks of gold.

Detroit-Goudreau Gold Development Company. According to the report of the Ontario Bureau of Mines, this company was incorporated January 11, 1922, and holds fourteen claims situated 1¼ miles due east of the Murphy discovery. No information is given regarding the value of the mineral deposits in the claims.

Goudreau-Superior Mining Company. According to the same authority, this company was incorporated January 31, 1922, to operate six claims that adjoin the Goudreau Gold Mines claims on the east and south.

The gold discoveries in townships 25 and 26, range 27, are described by Mr. Thomson in a report on Missinaibi map-area which accompanies this report.

ASBESTOS

Veinlets of asbestos were found on some of the islands in Eleanor lake, township 29, range 24. They are only from ⅛ to ¼ inch wide and 1 foot or 2 feet long and probably constitute less than one per cent of the rock in which they occur. They occur in patches a few feet or yards wide in various parts of at least ten of the islands, which are a hundred feet or so in width and several times longer. Though the asbestos is not here in commercial quantity it is apparently of good quality, being strong and flexible and of bright green colour. The containing rock is known to occur elsewhere within Michipicoten map-area in somewhat larger bodies, so larger and more numerous seams of asbestos may yet be found.

The containing rock at Eleanor lake is apparently an intrusive of about the coarseness of ordinary granite. When fresh, it is dark green, but on weathered surfaces it is easily distinguished from other Keewatin rocks by its rusty colour and exceedingly harsh texture. One mineral constituent, which presents extensive gleaming cleavage faces like those of bronzite, resists weathering much better than the other constituents and produces small jagged points and edges in the pitted weathered surface.

The rock is badly decomposed, but is evidently a peridotite, probably of the variety called harzburgite. Thin sections consist of about 60 per cent of rounded and polygonal individuals of one mineral now completely

changed to serpentine and about 40 per cent of a second mineral with pale brown and colourless pleochroism and straight extinction, identified as bronzite, which fills the spaces around the first mineral. The first mineral, represented now by areas of fibrous serpentine traversed irregularly by seams of powdery black iron ore, was probably olivine. The second mineral is probably a variety of bronzite approaching enstatite, for it has weak pleochroism and is partly altered to shreds of a highly birefringent mineral believed to be talc, and to grains of carbonate, probably magnesite. There appears to be no other mineral present.

A large body of rock with the same harsh, rusty-weathered surface and gleaming bronze-coloured cleavage faces occupies the eastern shore of Kapimchigama lake, township 30, range 26, from the large island northward. Its extent inland was not determined. No seams of asbestos were seen along the shore, but only a few of the outcrops were examined.

A mass of considerable size and some small dykes of a similar rock were encountered in the lower levels of the Magpie mine, where they intrude the siderite ore-body. The main mass is altered to a silvery, grey-green schist, known to the miners as "mica-dyke." Its schistosity is due largely to shreds of a secondary mineral of silvery colour and high birefringence believed to be talc. A magnesian pyroxene was one of the chief primary constituents, but no olivine could be found in the thin section. Here and there through this schist are smooth, pebble-like aggregates of white carbonate, probably magnesite, though a confirmed chemical test of the mineral has not been made.

Another body of similar peridotite was seen just north of the railway near Loonskin lake. Rock similar in appearance occurs along the west side of Baldry lake, but microscopic examination proves it to contain biotite, plagioclase, and orthoclase, and thus to be quite different from the peridotite.

Mr. Thomson, in the report which follows this one, describes a considerable mass of peridotite and small dykes of biotite picrite in the adjoining Missinaibi map-area. These, although resembling the peridotites here described in composition, are stated to be fresh and are thought to be younger than the granite, and possibly as late as Keweenawan in age.

KAOLIN

The Helen iron range is crossed by a dyke of younger diabase just where the old Helen body of brown iron ore was afterwards developed in the siderite pyrite members of the iron formation (Figure 10). In fact the dyke forms the western wall of the ore-body for 280 feet below the surface and thence to the bottom dips eastward into the ore-body. It is 75 feet thick where it crosses the ore-body, but is considerably narrower to the south.

On both sides of Boyer lake this dyke is composed of nearly black, medium-grained diabase so fresh that, when examined under the microscope, scarcely any decomposition can be seen in any of its mineral constituents. Within the boundaries of the Helen ore-body it has been converted into a nearly white material composed chiefly of kaolin and so soft that it can be dug out with a shovel. Parsons, the geologist who

last examined and described the mine before it was abandoned, states that "on the north side of the ore-body the dyke is apparently unaltered, and in the lower levels, where the oxidation of the ore is not so complete, the kaolinization has also been less complete." Apparently, the alteration of the dyke is closely confined to the Helen iron ore-body and, therefore, due to a chemical agent peculiar to the ore-body. The most powerful agent known to be present is the mine water, an analysis of which is given on page 118. Kaolinization was probably effected by the mine water, though Parsons has pointed out that the carbon dioxide liberated from the siderite by the mine water may also have reacted with the diabase.

The diabase is a nearly black rock ranging from medium grained near the edges of the dyke to quite coarse nearer the centre. It has a specific gravity of 3·09 as determined by E. Poitevin, of the Geological Survey, and of 2·96 by Mr. W. F. James, who assisted the senior author in 1920 and made a special study of the kaolin deposit. Under the microscope it is seen to be quite fresh and to consist of elongated crystals of plagioclase ($Ab_{30}\,An_{70}$) embedded in irregular individuals of reddish augite. Along with these two chief constituents are black iron ore in irregular grains and aggregates, a few small irregular areas of brown biotite, and small rods of apatite. Mr. James reports some quartz partly free and partly in micrographic intergrowth with feldspar. A Rosiwal analysis of thin sections indicates these minerals to be present in the proportions given in the table of analyses below. A chemical analysis of the diabase is given in the same table.

	I	II	III	IV
SiO_2	50·51	48·28	44·34	49·43
TiO_2	1·63	1·63	1·42	1·33
Al_2O_3	14·74	21·34	30·54	30·49
FeO	12·02	4·75	0·31	none
Fe_2O_3	1·39	4·18	11·23	4·83
CaO	10·57	7·69	trace	0·30
MgO	4·83	5·82	trace	trace
Na_2O	2·56	2·39	0·30	0·30
K_2O	0·30	0·36	0·60	0·48
P_2O_5	trace	.....	.....	.....
$+H_2O$	0·96	2·56	11·37	11·85
$-H_2O$	0·12		0·32	
S	0·08	none	none	0·24
SO_3	none	1·05	0·32	0·46
CO_2	none	.....	.....	0·52
	99·71	100·05	100·75	100·23

V	Collins	James
	Per cent	Per cent
Labradorite	48·8	48·0
Augite	46·9	41·5
Biotite	0·6	2·0
Titaniferous magnetite	3·7	4·5
Apatite	0·05	.....
Quartz	none	4·0
	100·05	100·00

VI	
Kaolin	77·25
Quartz	13·50
Carbonate (Ca, Mg, etc.)	1·20
Pyrite	0·45
Titaniferous magnetite	4·00
Limonite	2·50
Soluble sulphate (Fe, Al, Ca, Mg, etc.) from evaporation of mine water absorbed in the rock	1·10
	100·00

I. Chemical analysis of fresh diabase from dyke at Helen mine. Analysed by W. F. James.
II. Chemical analysis of weathered surface $\frac{1}{16}$-inch thick on boulders of diabase from the dyke that had lain in Boyer lake. Analysed by W. F. James.
III. Chemical analysis of reddish kaolinized material from same dyke, showing original texture of diabase better than IV. Analysed by W. F. James.
IV. Chemical analysis of white kaolinized material from same dyke in Helen mine. Analysis from Annual Report Ontario Bureau of Mines, 1915, p. 193.
V. Rosiwal analysis of fresh diabase from dyke at Helen mine.
VI. Recalculation of mineral constitution of kaolinized material, partly from separation with heavy solutions, partly from chemical analysis No. II.

An extreme product of kaolinization obtained from near the surface is almost white, faintly speckled with brown. The brown specks are the remains of the augite crystals. Even in the most completely altered phases the original texture of the diabase is well preserved; in somewhat less advanced phases the texture is perfectly preserved and more conspicuous than in the fresh diabase owing to the greater contrast in colour between the brown augite and white plagioclase. The altered material can easily be dug with a shovel, and when dry crumbles between the fingers to a fine white dust almost free from grit. A sample that had been air-dried for three years was found to have a density of 1·29, ascertained by sawing the sample into a rectangular solid, measuring the volume, and dividing this volume into the weight. A chemical analysis of this material made by W. K. McNeill is quoted in the foregoing table, page 133.

Mr. James secured intermediate alteration products (analyses II and III) by scraping a weathered material, about $\frac{1}{16}$ inch thick, off the surface of boulders of the diabase that had rolled into Boyer lake and been acted on by the mine waters; also a reddish phase of the kaolin in which the original diabase texture is better preserved than in the white phase. The density of the latter phase, obtained by weighing it and measuring its volume by displacement of mercury, was found to be 1·330. The specific gravity of the same material finely powdered is 2·741. The fully altered grey phase was found to have a specific gravity of 1·29.

By using a heavy solution Eugene Poitevin, of the Division of Mineralogy, Geological Survey, separated from this kaolinized material 4 per cent by weight of a heavy black powder which was found to contain a large proportion of titanium. This black powder is in all likelihood some of the titaniferous magnetite of the original diabase which resisted alteration. The remaining white powder seems to consist altogether of kaolin, although it must include a small percentage of limonite which could be seen outlining the areas of augite in the unpulverized specimen. The chemical analysis also indicates the presence of free silica, a trace of carbonates, a trace of sulphides, and some sulphate which no doubt represents soluble matter left by the mine water with which the rock was saturated when collected. Taking all these items into consideration a recalculation of analysis No. II indicates the kaolinized material to have the mineral composition given in column IV, page 133.

Mr. James succeeded in making a thin section of the kaolinized rock by first soaking it in hot Canada balsam. He says: "A thin section of the mottled clay under the microscope displays a field of contrasting light and dark materials, all the dark material being opaque. The outlines of the original diabase minerals can be seen, as the feldspars are replaced by a transparent silicate about equal to quartz in refringence, when highly magnified minute particles of iron oxide are seen scattered through the field. The spaces occupied by the original augite are loosely packed with particles of iron oxide, showing in reflected light the red colour of hematite. Some of the hydrous clay silicate (kaolin) may also be present in these areas, but its presence is not easily recognized since its refractive index is close to that of the Canada balsam. Grains of titaniferous iron ore are disposed almost exactly as in the fresh diabase.

"Between crossed nicols the section is almost completely dark, quartz being the only mineral to show distinctly. The closeness of its refractive index to that of the hydrous clay silicate renders it indistinguishable in ordinary light. The large part of the quartz is the original interstitial quartz of the diabase. It is present between the altered feldspar and augite crystals exactly as in the fresh diabase. The original micrographic intergrowth of quartz and feldspar is represented by unmodified grains of quartz in amorphous silicate derived from the feldspar. A secondary form of quartz, chalcedony, is also present. It is arranged in small bodies towards the centres of the altered feldspar areas."

Of the more completely decomposed grey phase he says: "The feldspars in the original diabase are replaced by lighter-coloured material than the augites, though both are rather white. A small amount of secondary pyrite was observed. The titaniferous iron ore is but slightly altered."

Less complete phases of the alteration from diabase to kaolin show the diabase texture more distinctly and are stained yellowish-brown with iron hydrate. Those seen near the surface of the mine in 1920 are just as soft as the white variety, but there are no doubt other phases, still less altered, which are harder and closer to the original diabase in physical and chemical character.

The transformation from diabase to kaolin was a chemical change accompanied by so little movement that the texture of the diabase is preserved perfectly in the kaolin and the dyke appears to have kept its original width across the iron ore-body. In other words there has been little if any change in volume. It is, therefore, comparatively easy by comparing unit volumes of diabase and kaolin to ascertain not only what changes have taken place in the chemical constituents, but also the quantity of each change; how many pounds of kaolin were derived from, let us say, 100 pounds of diabase and in the process how much of each chemical constituent was lost or added. Since the densities of fresh diabase and fully kaolinized material are 3·09 (2·96 according to Mr. James) and 1·29, 100 pounds of diabase must have yielded 41·7 pounds of kaolinized material. The amounts of each chemical ingredient in 100 pounds of diabase and 41·7 pounds of kaolinized rock and the losses and gains for each in such a transformation are as follows:

—	Fresh diabase	Kaolinized product	Loss	Gain
SiO_2	50·56	20·56	30·00	.....
TiO_2	1·63	0·56	1·07	.....
Al_2O_3	14·76	12·69	2·07	.....
FeO	12·03	none	12·03	.....
Fe_2O_3	1·39	2·01	.....	0·62
CaO	10·57	0·13	10·44	.....
MgO	4·83	trace	4·83	.....
Na_2O	2·56	0·13	2·43	.....
K_2O	0·30	0·20	0·10	.....
P_2O_5	trace	.....	.....	.....
H_2O	1·08	4·93	.....	3·85
S	0·08	0·10	.....	0·02
SO_3	.....	0·18	.....	0·18
CO_2	.....	0·21	.....	.....
MnO	0·20	.....	.....	.....
Total	99·99	41·70	62·97	4·67

Except for alumina, which is reduced only slightly, all the constituents of the diabase are reduced greatly, probably by the formation of soluble sulphates. The content of water is increased since the mineralogical change is from anhydrous to hydrous minerals. The SO_3 present in the kaolinized material is probably a foreign ingredient representing the soluble sulphate salts in the mine water with which the kaolin was saturated, in which case these sulphates should be deducted.

Coleman, in one of his descriptions of the Helen mine, tells of several feet of a soft iron-stained, clayey material (called "paint rock") between the iron ore and the Keewatin schists just to the south. Parsons, also, states that "on the wall of the ore-body below the eighth level the Keewatin rock is much decomposed, the result being a decidedly plastic kaolin of a banded or mottled character. This is at a depth of 540 feet. In colour the material is decidedly yellow, and there are nodules of goethite scattered through the mass. A sample of the material was analysed by Mr. McNeill, with the following result":

SiO_2	59·36
Al_2O_3	24·66
Fe_2O_3	6·26
FeO	nil
CaO	nil
MgO	trace
K_2O	2·11
Na_2O	1·22
H_2O	6·48
CO_2	nil
TiO_2	nil
S	trace
SO_3	nil
Total	100·09

This material, as Parsons also believes, was evidently produced by the action of the mine water on the Keewatin schists and is analogous to the kaolinized dyke rock; as these schists contain quartz, the percentage of silica in the paint rock is higher than in the product from the diabase, which contains little or no quartz.

Samples of the kaolinized diabase and paint rock were submitted by Parsons to the late Joseph Keele, of the Mines Branch, who tested them and reported, in part, as follows: "Sample 273 is a residual clay from the weathering of Keewatin schist. It is of a bright yellow colour, and in a fairly finely divided condition, over 90 per cent can be washed through a 200-mesh sieve, the residue being chiefly quartz grains and larger particles of a concretionary nature.

"When tempered with water, the clay develops only a low plasticity, being very short grained and of poor working quality, so that it is difficult to mould into shape. This clay burns to a porous light red body at low temperature, but becomes denser and grey in colour on burning to higher temperatures. It is vitrified at cone 9 (1310° C.). The softening point was not determined, but the material is probably not a fire-clay, as the amount of fluxing impurities present, notably the iron, is rather high. It is, however, a fairly refractory clay, and when mixed with a more plastic material may have some value for the manufacture of certain clay products.

"Sample No. 274 is residual from the weathering of a diabase dyke. It is of light grey colour but contains numerous small particles of dark coloured mineral. About 90 per cent of the clay can be washed through a 200-mesh sieve, the coarse residue appearing to consist mainly of particles of feldspar not completely kaolinized. This clay requires 40 per cent of water to bring it to the best working consistency. It is very plastic, being more so than most residual clays. Its shrinkage in drying is about 7 per cent. It burns to a light grey, porous body at low temperatures, the test pieces being badly cracked in the fire and the body brittle. When burned to cone 9 (1310° C.) the body is hard and dense, and of a light grey colour, with some dark fused specks on the surface. Vitrification is not quite complete at this temperature, as the absorption of the burned body is 3 per cent. The shrinkage is high, the total shrinkage at cone 9 being 20 per cent.

"The material was tested for refractoriness in a Hoskins electric furnace, and was found to be intact at the softening point of cone 30 (1730° C.). It is, therefore, a No. 1 fire-clay, and by far the most refractory plastic material yet found in Ontario. It exhibits all the physical properties of kaolin, except that it does not burn to a white colour. Washing does not improve the colour of the burned body as most of the dark iron-bearing mineral is so finely divided that it passes over with the minute clay particles during the washing process.

"This clay might be used in some pottery bodies where whiteness is not important, but the fused specks which appear on the surface of the burned clay might interfere with the proper development of the glaze applied to these wares. The refractory qualities of the clay suggest its use for the manufacture of fire-brick. It could not be used alone for this purpose but might be used as a bond in the manufacture of silica brick. Addition of about 25 per cent of this kaolin to ground quartzite would probably produce a good silica brick. These bricks would have to be burned at a very high temperature, say 1,500° C., to produce a commercial article.

"A mixture of two parts of No. 273 with one part of No. 274 produces a very good raw working body, as the latter supplies the plasticity which the other lacks. This mixture burns to a good hard strong body without unduly high fire shrinkage at cone 5 (1230° C.), and could probably be used for the manufacture of salt-glazed goods, such as sewer-pipe and electric conduits. A fairly refractory brick for use in boiler settings and stone linings could also be made from this mixture."

The kaolin and paint rock in the Helen mine are no longer accessible, since the mine was allowed to cave and fill, but probably similar materials accompany other secondary deposits of brown iron ore in Michipicoten district, such as the Josephine, and will be exposed if any of these iron ore-bodies are mined.

PROSPECTING IN MICHIPICOTEN DISTRICT

In the last thirty years Michipicoten map-area and its vicinity have yielded to the prospector deposits of iron ores of various sorts, pyrite,

and gold, many of the deposits being of commercial size and quality. Indications have been found of asbestos and kaolin and the region is of sufficient geological diversity that future exploration may reveal yet other economic minerals.

Apparently thirty years of exploration has not exhausted the possibilities of the region. Mineral discoveries have been about as numerous recently as heretofore. The Holdsworth pyrite deposit was found in 1918; asbestos was first recorded from Eleanor lake in 1920. The Murphy gold-bearing vein was located in 1921, and in 1922 Mr. Angus Gibson found what appears to be an extensive body of iron ore southeast of Wawa lake, in a part of the country which had been vigorously prospected a quarter century before. On the other hand exploration for minerals has been facilitated in several ways. Since the Helen brown iron ore deposit was found in 1898 access to all parts of Michipicoten district has been made easier by the construction of the Algoma Central railway and its branches. Also, as a result of prospecting, intensive exploration of ore deposits, mainly by the Algoma Steel Corporation, and geological study by the Ontario Bureau of Mines and the Geological Survey, the relationships of the economic minerals to the rock formations are better known than in almost any other part of the Precambrian Shield in Canada, and prospecting for these minerals is on a correspondingly good scientific basis.

IRON ORE AND PYRITE

All the known primary deposits of iron ore (siderite) and pyrite are, with few and unimportant exceptions, confined to the iron formations, and the iron formations are easy to find. They are easily recognized by means of the conspicuously coloured and banded silica member. When of considerable thickness this banded silica member, because of its resistance to erosion, usually forms steep-sided and persistent ridges. If they do not challenge discovery in this way they can be located, even under 50 feet of drift, by means of a dip-needle. During the explorations for the Geological Survey in 1918 to 1920 several iron ranges were traced under sand-plains in this way for distances up to 2 miles, the dip-needle employed recording from 5 to 60 degrees more inclination over the iron formation than over the adjacent Keewatin schists. This increase occurs chiefly over the banded silica member, owing no doubt to the magnetite present, but a similar weaker effect is observable over most pyrite members, which contain about 10 per cent of pyrrhotite and magnetite. At some places in the Keewatin schists high dips were recorded that did not appear to be due to the presence of any ore-body; these dips occur in isolated places and lack the linear continuity that characterizes a concealed iron range.

The course of an iron range in any part of Michipicoten map area can now be predicted fairly closely. Governed as it is by the fold-structure of the Keewatin, it must strike about parallel to the nearest known iron range, or band of Dore series or other sedimentary formation. A sufficient number of these have already been mapped to indicate well enough for prospecting purposes the strike in any part of Michipicoten

map-area. The iron ranges are long and narrow and exploration trips should, consequently, be made across the strike.

When a new iron range is discovered, its exploration for the useful siderite or pyrite members need be no haphazard affair. It is now known that the banded silica, pyrite, and siderite occur in that order from top to bottom in all iron formations. Accordingly, the siderite and pyrite are found only on one side of an iron range, and which side can be speedily ascertained by making one good section across it. Trenching can thereafter be safely confined to that side. The Algoma Steel Corporation had found out by experience, even before the structure of iron formations had been learned by geologists, that diamond-drill exploration of an iron range for siderite or pyrite can be indicated most economically by boring from the original bottom of the steeply folded iron formation, thus having to bore only through soft volcanic schists into the ore instead of piercing the exceedingly hard banded silica.

Most of the iron ranges are faulted, and it is evident that in the past these faults have proved serious obstacles to prospectors in tracing the range. It is now known, however, that almost all these faults caused displacement in the same direction. When an iron range is found to terminate abruptly as if by faulting, its faulted extension can be found by crossing the fault and exploring, toward the left hand side, for distances that may range from a few hundred feet to over 2 miles. The small iron range in the northeast corner of Gros Cap Indian Reserve was found in this manner. The faults are commonly occupied and signalized by dykes of the older series of diabase.

Iron ranges—such as the Goudreau—that carry a large proportion of pyrite, give rise in their immediate vicinity to pools of water charged with iron sulphate, easily recognized by its disagreeable astringent taste. The iron sulphate later decomposes to limonite. The limonite may form a conspicuous rust-coloured gossan directly over the ore-body, as at the Bear claim, JL 28, near Goudreau. Where the ground is low and wet it is likely to cement the soil beneath into a material impervious to water and the roots of plants, thus developing a muskeg-like surface occupied by shallow pools and clothed with grass but not with trees. Unlike muskeg, however, it is surprisingly firm and unyielding to the tread. Signs of this nature occur beside the Morrison No. 3 pyrite range at Goudreau, and south of Webb lake, where the range is totally concealed by drift.

Although secondary deposits of brown iron ore, such as the Helen and Josephine, do not influence the dip-needle sufficiently to be located by means of that instrument, search for them is greatly helped by the fact that they occur only within, or very close to, an iron range, since they are simply parts of the siderite member that have been converted into iron hydroxides. Both the Helen and Josephine ore-bodies were discovered by means of a gossan of limonite or limonite boulders. As pointed out by Coleman and Parsons it is, probably, also significant that both these ore-bodies underlie small lakes. The lake basin—at least in the case of Boyer lake—served as a receptacle for accumulating and holding waters charged with iron sulphate and sulphuric acid, that slowly digested their way

downward into the primary siderite, converting it into brown iron ore. Depressions along the lower side of any of the iron ranges would appear, therefore, to be worth inspection. Sayers lake, on the Helen range, is filled with water so charged with sulphates that it is not fit to drink.

Secondary deposits of pyrite, either pyrite sand or hard vein pyrite, like that in the Holdsworth deposit, contain no pyrrhotite or magnetite and, therefore, cannot be discovered with the dip-needle. Most of them, like the brown iron ore-bodies, occur in, or very close to, the iron range from which they were derived, but the Holdsworth is half a mile away from the nearest range. It lies along the contact between two volcanic formations and outcrops only as a strip of black iron oxide (" black sand ") about 2 feet wide. So inconspicuous is it, and so widespread are the primary pyrite ranges, that equally careful exploration in other parts of the Keewatin may yet disclose other pyrite bodies of the Holdsworth type.

GOLD

The gold ore deposits found within the Precambrian Shield have come from a variety of sources. Those found near Wanapitei lake, and at points along the north shore of lake Huron originated from bodies of diabase of Keweenawan age. Some of those recently found in western Quebec appear to be related to other basic igneous rocks. But the great majority, including most of the productive mines, are known or believed to have come from intrusive bodies of granite.

Gold-bearing veins are not found in association with all granite intrusives, and opinion is by no means united as to which particular kinds are accompanied by gold deposits, and why. It has been suggested that granites of the pre-Huronian, or Algoman, period of invasion were the gold-bringers, also that the mineral or chemical composition of the granite is a determining factor. If, however, the occurrences of gold in the Precambrian Shield, in known or suspected genetic relation with granites, are reviewed, these granites will be seen to be of quite diverse composition, and are not known to be of the same age. But, if considered in respect to size, it will be found that few if any gold-bearing veins occur around the margins of the great batholithic areas of granite. They are all, or nearly all, situated around or in small bosses, dykes, and other granitic bodies of subordinate size. Because of their smallness these bodies cooled rapidly and are not characterized by a porphyritic texture. So well is this relationship known to experienced prospectors in northeastern Ontario and the adjoining part of Quebec that in prospecting for gold they first look for porphyry—not necessarily a red porphyry, or a hornblende porphyry, but any porphyritic rock of granitic composition.

The available facts seem to indicate that any rock magma of granitic composition, regardless of its age or minor differences in composition, is capable of holding gold in solution and probably gives off gold when it crystallizes. Possibly the heating effect of the great masses of granite is so prolonged and intense that the siliceous, gold-carrying residues are dissipated far into the older rocks, producing a general silicification instead of collecting in cracks to form veins, whereas small intrusions exercise a less powerful effect and favour vein formation.

Michipicoten map-area is no exception to the prevalent association of gold-bearing quartz veins with small, porphyritic intrusions of granitic composition. The Wawa group is roughly marginal to a boss of quartz porphyry and granite porphyry, 4 miles by 1½ miles. The discoveries made in 1921 in township 28, range 26, are at the east end of another boss 2 miles by 1½ miles. Prospectors, consequently, should pay particular attention to the margins of other small intrusives of porphyritic habit. According to Mr. Thomson, the granite body in the southeast part of township 28, range 27, is coarsely porphyritic, containing rectangular feldspars as much as an inch long. The small intrusion 2 miles north of The Mission is a quartz porphyry, finer grained towards its margin, but it and the surrounding Keewatin rocks are largely concealed under sand. Another small porphyritic intrusive was found at Gull lake, in township 29, range 24. The other small areas of granitic rocks within the Keewatin that are shown on the accompanying geological map of Michipicoten area are of the same texture as the adjacent main batholithic areas with which they probably have underground connexions.

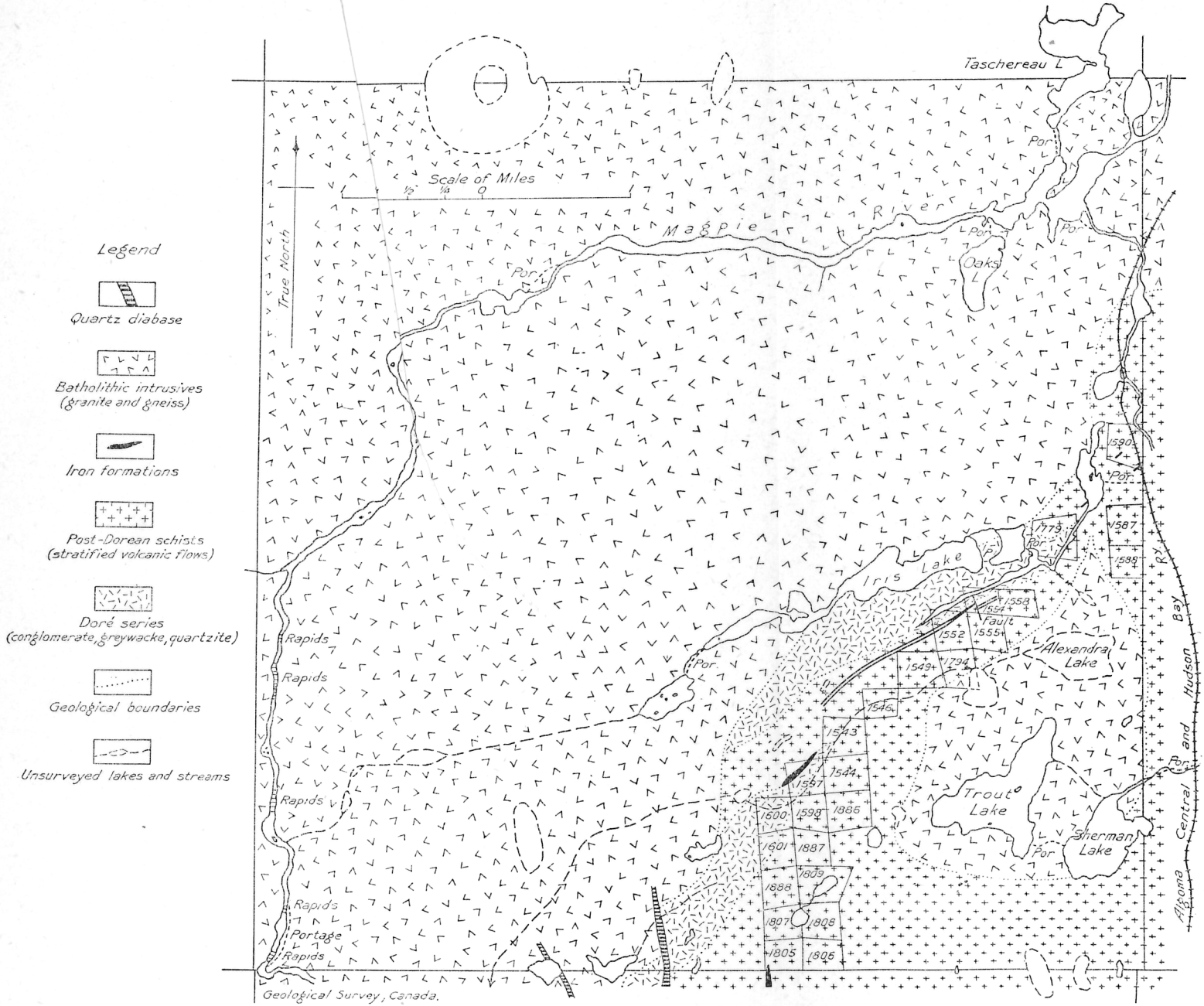

Figure 15. Geology of township 28, range 27. Scale 1 inch to 1 mile.

PART II

Missinaibi Map-area

By Ellis Thomson

INTRODUCTION

Gold has been known in Missinaibi map-area since 1896, when a small deposit was discovered near Emily bay, on Dog lake. Large pyrite deposits found within its boundaries have also made the map-area of considerable economic importance. Though the pyrite industry has suffered a decline since 1918, more recent discoveries of gold ore on the Murphy claim in township 28, range 26, made in the spring of 1921, as well as similar discoveries made in adjoining townships since that time, have revived the interest of mining men in this district. On this account it was thought advisable to make a somewhat detailed geological survey of the area in which useful minerals are most likely to exist. One small area near Goudreau[1] had already been mapped. It was decided to extend this work so as to include all the Keewatin area east of Goudreau, as shown on the geological map (No. 2050) that accompanies this report. It has been called the Missinaibi map-sheet after Missinaibi Station, on the Canadian Pacific railway, this being the principal village within the map-area.

Half the summer of 1920, and the entire summers of 1921 and 1922 were spent in studying the geology, and in making surveys with Rochon micrometer and compass of the smaller lakes and streams. The larger lakes were resurveyed by E. E. Freeland, of the topographical division of the Geological Survey, who also made a precise chain and transit survey of the Canadian Pacific railway within the map-area, which, together with a similar precise survey of the Algoma Central railway by R. C. McDonald, of the Geological Survey, in 1919, serves as a control for the township surveys and other geographical information shown on the map. The geological traverses away from the watercourses were spaced about half a mile apart, and were tied either to the minor topographical features (such as lakes or streams), or to the railways or township lines. A few weeks at the end of the season of 1921 were spent in examining the gold discoveries on township 28, range 26[2], and in making a geological survey of township 28, range 27 (Figure 15).

[1] Collins, W. H., Geol. Surv., Can., Sum. Rept., 1918, pt. E, pp. 4-30.
[2] Thomson, E., Geol. Surv., Can., Sum. Rept., 1921, pt. D. pp. 17-26.

During the three summers mentioned, Messrs. A. R. Crawford, S. H. Davis, W. F. James, H. A. Oaks, and R. H. Taschereau rendered efficient service as field assistants. In particular the writer wishes to acknowledge the excellent geological work carried out by W. F. James, whose previous experience in this field proved of great value. The officials of the Algoma Central and Canadian Pacific railways placed equipment at the service of the party and did their utmost in other ways to facilitate the work. Many of the residents of the district aided the writer and his parties. Grateful acknowledgment is also due to G. W. MacLeod, of Sault Ste. Marie, Ont., for his description of the gold property south of Lochalsh, which is quoted verbatim in this report.

ACCESS

Missinaibi map-area lies within the angle formed by the intersection of the Algoma Central and Canadian Pacific railways—which cross at Franz (Figure 15)—and is, therefore, readily accessible. Numerous claims have been staked in the district and good trails or canoe routes may be followed to most of them. There are also a few wagon roads leading to some of the older or more important claims. Of interesting historical significance are the old tote-roads and steamship-routes used in the construction days of the Canadian Pacific railway. The former are now overgrown with vegetation, but can nevertheless be followed quite easily, as in the case of the old Pick road, which runs from Pick siding on the Canadian Pacific railway to Goudreau on the Algoma Central, and beyond. A favourite freighting route in those days appears to have run first from Dalton on the Canadian Pacific railway, through Manitowik, Hawk, and Wawa lakes to lake Superior and afterwards from Missinaibi on Dog lake, through the same three lakes. Remnants of the small steamers used on Dog and Manitowik lakes are still to be seen, as well as bits of the wharves used for docking purposes.

PREVIOUS WORK

The first geological work in this map-area was done by Coleman in 1896[1], who investigated some gold claims on Emily bay, Dog lake. Other early workers in this field were Wilmott[2] and Bell[3], whose investigations were carried out chiefly in the western part of Michipicoten district. The pyrite deposits near Goudreau have been reported on at different times by geologists on the staff of the Ontario Department of Mines[4], the latest of these being the report by Hopkins on "The Iron Pyrites Deposits in South-eastern Ontario"[5]. It was not, however, until the summer of 1918, that any detailed work on the iron formations and pyrite deposits in this district was undertaken. In that year Collins[6] mapped in detail two small areas, one in the neighbourhood of Goudreau station, and the other near Hawk Junction, on the Algoma Central railway.

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1 Coleman, A. P., Ann. Rept., Ont. Bureau of Mines, vol. VII (2), pp. 136, 149, 185, 187, 188, 204, 205.
2 Willmott, A. B., Ann. Rept., Ont. Bureau of Mines, vol. VIII, pp. 255-258.
3 Bell, J. M., Ann. Rept., Ont. Bureau of Mines, vol. XIV (1), pp. 278-355.
4 Coleman, A. P., and Moore, E. S., Ann. Rept., Ont. Bureau of Mines, vol. XV, pp. 183-201.
Fraleck, E. L., Ann. Rept., Ont. Bureau of Mines, vol. XVI (?), pp. 177-186.
Parsons, A. L., Ann. Rept., Ont. Bureau of Mines, vol. XXIV, pp. 187-211.
5 Hopkins, P. E., Ann. Rept., Ont. Bureau of Mines, vol. XXV (1), p. 193.
6 Collins, W. H., Geol. Surv., Can., Sum. Rept., 1918, pt. E, pp. 4-30.

GENERAL CHARACTER OF MAP-AREA

Missinaibi map-area is very similar in general character to other Keewatin areas in northern Ontario. The general topography shows little relief except occasionally in the vicinity of fault-planes. Manitowik lake, whose shores are for the most part fairly steep, furnishes a good example of the influence of faults. Occasionally a diabase dyke stands up 100 feet or so above the adjacent country, but even these are not very prominent features. A considerable part of the map-area is covered with drift, some of it probably of glacial origin, and some undoubtedly post-Glacial. Numerous large, rounded boulders of granite in the northern part suggest old beach or terrace deposits of one of the glacial predecessors of lake Superior, or some of its tributary streams.

The area drains almost altogether into Magpie or Michipicoten rivers, which empty into lake Superior. No waterpowers have been developed within the map-area, although power is obtained from Magpie river in township 28, range 26. The only falls of consequence are to be found in the short stretch of river between Dog and Manitowik lakes, and Lomond fall at the northwest corner of Dog lake (Plate IX). According to information supplied by L. V. Rorke, Director of Surveys, Ontario, the fall between Dog and Manitowik lakes is 14 feet high.

GENERAL GEOLOGY

Missinaibi map-area is underlain by a volcanic complex of acid and basic flows, commonly known as the Keewatin, which has been intruded by a granite batholith. Associated with the volcanics is a series of ancient sediments of the Dore series. Both the volcanics and the sediments have been mountain-built, and have since been deeply eroded. The contacts between the granite and the volcanic complex are very irregular, and consist usually of a marginal zone of mixed granite and volcanics. The Dore series is closely infolded with the volcanics, and was observed in contact with the granite in only one locality. Intercalated with the volcanics are bands of iron formation at varying horizons. The following is a list of the geological formations, given in the order of their age.

Pleistocene and Recent	Beach and terrace deposits of sand, gravel, boulder glacial drift
Keweenawan dykes and intrusives	(a) Ultra-basic intrusives; biotite picrite dykes and peridotite (b) Olivine-free, or olivine diabase dykes (younger) (c) Quartz diabase dykes (older)
Batholithic intrusives	Granites, granodiorites, and their corresponding gneisses
Post-Dorean volcanics and sediments (Keewatin)	(a) Volcanics—acid and basic flows, tuffs, and breccias (b) Sediments—iron formations at different horizons
Dore series	Mostly conglomerates, but with some greywacke and quartzite

According to Collins, some of the volcanics of the Keewatin are older than the Dore sediments, and there were two sets of granite intrusions giving rise to two granites, one older than the Dore series, the other younger than the post-Dorean volcanics. In the area under consideration,

however, the volcanics could not be differentiated, nor was it possible to divide the batholithic intrusive into two sets of different ages. That there must have been two periods of granite intrusion seems sufficiently evident, since the majority of the pebbles in the Dore conglomerate are composed of granite rock.

DORE SERIES

This is a sedimentary series which was first described by Logan[1] in the early sixties, from observation of outcrops in the vicinity of Dore river, near Michipicoten Harbour. He describes the outcrops near Gros Cap in some detail, giving an observed thickness of 1,700 feet for this formation, and names the predominant rock a " slate conglomerate." Coleman, in his report on the "Michipicoten Iron Ranges," [2] places this formation in the Upper Huronian, and gives it a thickness of 7,500 feet. Other investigators that have described this interesting series of rocks, are J. M. Bell and A. L. Parsons.[3]

The formation in Missinaibi area consists chiefly of conglomerates with minor amounts of greywacke and quartzite, as well as intercalated volcanics. In the conglomerate member of the series most of the pebbles are granitic, although some quartz pebbles also occur, as well as a few of the composition of diorite. The matrix is dark in colour, and consists chiefly of quartz, and such alteration products as chlorite, hornblende, and kaolin. The rock has been so intensely sheared that most of the pebbles, though composed of such a resistant rock as granite, have been squeezed into oval shapes, with the matrix, which is very schistose, flowing round them. The greywacke and quartzite phases of this formation are of minor volume in this area. The greywacke shows cross-jointing in places, with an occasional pebble indicating its relation to the conglomerate. The quartzite was observed in only one small area, namely, near mile 183 on the Algoma Central railway. This series of rocks is underlain by granite in the vicinity of Michipicoten Harbour, as observed by Collins, but in Missinaibi map-area the Dore rocks have been found in contact with the granite in one place only, and there the plutonic is undoubtedly the younger of the two formations. The age relationships between this formation and the volcanics are somewhat obscure, but most at least of these flows appear to be younger than the sediments of the Dore series.

The Dore series is represented by two small outcrops in township 27, range 27, and a larger outcrop in township 28, range 27. Of the two smaller areas, one is a narrow band a few feet wide and about half a mile long, striking about east and west. It is located in the middle of township 27, towards the north end, where it is in contact with tuffaceous volcanics, both to the north and to the south. The granite outcrops about one-quarter of a mile to the north of this band, and a band of iron formation appears

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[1] Logan, Sir Wm., "Geology of Canada," 1863, pp. 53-54.

[2] Coleman, A. P., Ann. Rept., Ont. Bureau of Mines, vol. XI, p. 155.

[3] Bell, J. M., "Iron Ranges of Michipicoten West," Ann. Rept., Ont. Bureau of Mines, vol. XIV, pt. I, pp. 278-355.

Parsons, A. L., "The Productive Area of Michipicoten Iron Ranges," Ann. Rept., Ont Bureau of Mines, vol. XXIV, pt. I, pp. 185-213.

about 300 or 400 feet to the south of it. All these formations are cut by a younger diabase dyke, which strikes almost north and south. The formation here is a true conglomerate, though strongly sheared.

The second area in township 27 is located near mile 183, immediately south of the point where Herman creek crosses the Algoma Central railway. It is in contact with a granite body to the north, from the intrusion of which it has suffered considerable metamorphism. The granite is a body of some size, included in the post-Dorean volcanics near the northern contact of this latter formation with the main granite mass. The Dore series here is represented by a band of quartzite a few feet wide, striking a little south of west, and extending back from the right-of-way to a point 200 to 300 feet to the west. An interesting digestion process has apparently taken place between the granite and the sediment, which has resulted in a considerable amount of recrystallization, manifested in a gradual changing of the rock from a true quartzite to a true granite. All intermediate stages may be observed, and the structural features of the quartzite, such as joint-planes, persist some distance in the marginal rock.

The third outcrop of this sedimentary series, which is located in township 28, range 27, is much larger (Figure 15). It extends intermittently in a southwesterly direction for a mile or more. It is in contact with volcanics, chiefly of tuffaceous and ash-like character, and again the main granite mass appears a short distance to the north, and bands of iron formation a short distance to the south. Conglomerate is again the prominent rock, although some greywacke, or greywacke conglomerate, appears in places. The strike is the prevailing one, and the dip is vertical.

POST-DOREAN VOLCANICS AND SEDIMENTS (KEEWATIN)

As already stated, the sediments of the iron formations in this district are not all of the same age, but are intercalated with the volcanic flows of the Keewatin. However, for the sake of convenience, they will be described as one series, after the consideration of the volcanic flows.

Volcanics

These volcanic rocks have been described in considerable detail by Collins[1] for the small area in the neighbourhood of Goudreau, and the descriptions therein contained will serve for the most part for the larger area between Goudreau and Dog lake. Some further descriptions are given here to include phases of these volcanic flows, peculiar to other parts of Missinaibi area.

Ottrelite Porphyry. This rock, which was described by Collins, has a rather limited distribution, being mostly confined to township 27, range 26, and the southwestern corner of township 26, range 26. It is somewhat striking in appearance, with small black phenocrysts of ottrelite, which are likely to be mistaken in the field for hornblende, on account of their rectangular outlines and general similarity to that mineral.

1 Collins, W. H., Geol. Surv., Can., Sum. Rept., 1918, pt. E, pp. 7-10.

Feldspar Porphyry. By far the commonest of the acid types of volcanics is the feldspar porphyry, which has a widespread distribution throughout the map-area. It is noticeably porphyritic in a hand specimen, and is usually badly sheared and cross-jointed. It is of some economic importance, for a goodly number of the gold-bearing quartz veins of the district are found within it. This, in the opinion of the writer at least, is not due to any peculiarity of mineralogical composition, but rather to the fractured character of the rock, which has provided channels for the operation of ore-carrying solutions.

Quartz Porphyry. This acid volcanic, although not so common as the feldspar porphyry, is nevertheless found in many parts of the map-area. It grades into the other porphyry, a great deal of it corresponding better to a dacite in composition, and like the feldspar porphyry is badly sheared and fractured. It is also of economic importance as a carrier of gold-bearing quartz veins.

Mica Diorite or Monzonite. This rock, which, according to Collins, is intrusive, is not very common in this area, being confined to a few dyke-like bodies in township 27, range 26. It is a highly altered rock, consisting chiefly of chlorite and carbonate, the latter mostly iron carbonate. It has a characteristic rusty surface where exposed to the weather.

Ellipsoidal Greenstone. The great bulk of the basic volcanics in this region are of the familiar pillow-lava type, although large areas of more massive greenstone are also included. The rock corresponds usually to the composition of a basalt or andesite, but is highly altered, and consists for the most part of hornblende, chlorite, and kaolinized feldspars, as well as some carbonate. The spaces between the pillows are frequently filled with carbonate, and small quartz stringers traverse the rock in a great many places. This basic volcanic is not as a general rule so greatly schisted as the more acid types, but may on occasion be very schistose. Vesicular and amygdaloidal structures are not common, but occur in a few places, as on the Brothers claims on the west shore of Dog lake. Porphyritic phases are occasionally encountered with large or small phenocrysts of plagioclase in a matrix of the composition of an altered basalt or andesite. These basic lavas are frequently either partly or completely altered to carbonate, which would seem to indicate not only the presence of carbonic acid emanations from the lava, but also the subsequent operation of carbonate solutions in the rock after it had cooled. The carbonate is mostly iron carbonate, as evidenced by the rusty character of the weathered surface. This formation is not so important from the standpoint of gold deposits as the more acid types, chiefly because it is not usually fractured to the same extent.

Latitic Greenstone. This phase of the ordinary greenstone is of very limited distribution, being observed mostly at a few places in the vicinity of Goudreau, and not at all at the other side of the field. The small grains of bluish quartz scattered through the rock constitute a characteristic feature which differentiates this phase from the ordinary greenstone.

Coarse-grained Phases of Volcanics. In places where the individual flows have attained a considerable thickness, the volcanics at the base of the flow assume a fairly coarse texture. This is particularly true of the more basic types, which often give place to a coarse-grained plutonic type of rock, corresponding to a diorite or quartz diorite in composition, or even, in the more basic phases, to a pyroxenite or amphibolite. These coarse types, though not very common, are nevertheless widely distributed throughout the map-area.

Marginal Types. At the contacts between the granite intrusive and the Keewatin volcanics, interesting rock types result from the recrystallization of the Keewatin rocks by contact metamorphism. For the most part these border phases are coarse-grained pyroxenite or amphibolite. In places, however, peculiar nepheline-bearing rocks develop. An example of one of these types was encountered in township 27, range 27, east of Herman lake. This is a coarse-grained rock, consisting chiefly of pyroxene and nepheline, but with minor amounts of biotite, quartz, apatite, and secondary hornblende and carbonate. It seems to be a recrystallized Keewatin rock, of the general composition of an augite nepheline syenite. The rectangular outlines of the nepheline crystals, which may readily be observed even in a hand specimen, give this rock a characteristic appearance, which is not easily mistaken in the field. Unfortunately, the observed outcrop was very small, being located in a part of the area where the drift is fairly thick, and outcrops few and far apart. There appeared to be no gradation to other rock, but this is not surprising, in view of the small size of the outcrop. It is interesting to note the presence of nepheline as a recrystallization product, where it is not usually expected. The writer has, however, remarked the presence of the same mineral, playing a similar rôle, in other localities outside of this field.

Another special marginal type of plutonic character is encountered on the shore of Dog lake, in the neighbourhood of Missinaibi. It shows a fine micrographic intergrowth between the quartz and the feldspars, and contains considerable quantities of hornblende, epidote, and biotite, as well as a few apatite and tourmaline crystals. This seems to be a specially acid phase of the marginal Keewatin, corresponding to a micropegmatite in composition.

Volcanic Tuffs and Fragmentals. In some parts of the map-area fine-grained ash rocks are encountered, consisting chiefly of quartz and light and dark micas, often with considerable carbonate as well, and minor amounts of magnetite, feldspar, and tourmaline. They are, as a general rule, altered to very schistose mica, or mica-carbonate schists. From their field relationships there can be little doubt that they are volcanic tuffs. They are best seen in township 28, range 27, where they are in contact with the conglomerates of the Dore series. In some places, as in township 27, range 27, they are composed of alternations of light and dark-coloured bands, and are in close association with the bands of iron formation. They sometimes show a breccia-like character, roughly approximating to agglomerates. Another interesting feature of these banded tuffs is the occasional development of garnet crystals, as the result of recrystallization.

Iron Formation

The bands of iron formation in Dog Lake map-area are of varying ages, and appear to have been deposited at different times during the period of deposition of the Keewatin lava flows. They occur at various horizons of this volcanic series. These bands, which vary in length from a few feet to a mile or more, rarely have a greater width than 20 or 30 feet, and usually have bands of Keewatin volcanics interbanded with them. They consist, for the most part, of alternate layers of silica and iron carbonate, but frequently include massive or disseminated pyrite members as well. These ranges are particularly common near Goudreau, in townships 26, 27, and 28, range 26, but are found also in other parts of the field. In general, the iron formation in this area is of two types, the one sideritic in character, the other magnetic; the former predominating to a large extent.

BATHOLITHIC INTRUSIVES

The rocks of this series, chiefly granites, granodiorites, and the corresponding gneisses, have been referred in the past to the Laurentian series. It seems certain now, however, that there were two periods of igneous intrusion, one before Dore time, which supplied the material for most of the pebbles in that formation, and the other subsequent to that period of sedimentation.

As the writer was unable to differentiate two stages of intrusion in Missinaibi area, all these acid intrusives will be described as one formation. They consist for the most part of granite, granodiorites, and their corresponding gneisses, the gneissoid structure being particularly well marked in some localities, and almost, if not entirely, lacking in others. Areas of these intrusives bound the Keewatin rocks on both the north and the south, and at almost all points show, not only a decidedly irregular line of contact, but also a marginal band of mixed plutonic and volcanic rocks. These two factors make the accurate determination of the contact a matter of some difficulty. This is particularly noticeable in the southeastern corner of the field, where comparatively narrow bands of Keewatin rocks, representing erosion remnants of that formation, are seamed and fissured throughout their entire width by numerous stringers, and apophyses of granite. In the opinion of the writer, this is probably due to a low-dipping contact, in conjunction with the fact that the volcanic flows have been worn down by erosion fairly close to the large mass of the intrusive. In places the granite intrusive shows basic segregations of a local character, but the great bulk of this plutonic is acid in composition. In township 28, range 27, where there is an isolated body of fair size (Figure 15), this intrusive has the texture of a granite porphyry, with phenocrysts of orthoclase, sometimes attaining a length of an inch or more. In the township to the south of this, another small boss of granite protrudes in the neighbourhood of the Goudreau Gold Mining Company's property on Murphy lake. Here, also, it shows porphyritic phases, but resembling more the quartz porphyry type. Irregular bodies and dykes of pegmatitic material are also found within the main granite masses. These pegmatites are particularly common in the mixed material to be found in the marginal contact zone with the

Keewatin. Small aplite veins are also encountered, usually as apophyses in the Keewatin, but occasionally also in the main granite mass. The granitic rocks are not of economic importance, except indirectly as the source—in the opinion of the writer at least—of the gold-bearing solutions. Gold has been found in quartz veins of a pegmatitic character in the boss of granite already referred to in township 28, range 26, showing that these ore solutions were not entirely foreign to the granite magma, and were in all probability part of the residual mother-liquor of that intrusive.

KEWEENAWAN DYKES AND INTRUSIVES

The granitic Keewatin and Dore formations are cut by two sets of diabase dykes, and also by bodies of ultra-basic composition corresponding to biotite picrites or peridotites. The diabase dykes have already been described by Collins and Quirke, but as they vary in character locally their outstanding characteristics in Missinaibi map-area will be briefly reviewed. The peridotite bodies have not before been recorded for this particular part of the country, although peridotites are described by Collins and Quirke from the adjoining Michipicoten map-area.

The diabase dykes are of two different types, one a comparatively fresh olivine, or olivine-free diabase, the younger of the two; and the other an older and a more altered quartz diabase. The age relationships of these two sets of dykes to the peridotite is somewhat obscure, but, from the freshness of the peridotite, and their general petrographic similarity to the diabase dykes, it seems probable that they are nearly contemporaneous with them. All three are undoubtedly younger than the granite or the Keewatin.

The strike of the younger diabase dykes is more uniform than that of the older quartz diabases, and usually varies between 155 and 190 degrees, although other directions are encountered. The quartz diabase dykes have been subjected to more movement than the younger diabases, and are consequently more fractured. They are mostly more resistant to the weathering than the others, and frequently stand out in fairly bold relief.

Quartz Diabase Dykes

The description of these dykes by Collins and Quirke needs only a brief word as to their general distribution in Missinaibi map-area. These dykes are not nearly so widespread as the younger dykes, but are more common in the vicinity of Goudreau than elsewhere in the area. They are generally highly altered and it is difficult on occasion to distinguish them from the coarse Keewatin lava flows of basic composition. Their chilled edges serve as very good guides in this matter. In thin section the interstitial quartz, which is often intergrown with the feldspar in a micrographic way, is a prominent feature which helps to distinguish this diabase from the younger one.

Younger Diabase Dykes

These dykes are much fresher than the quartz diabases, both in hand specimens and in thin sections. The writer prefers to call these "younger" diabases, rather than "olivine" diabases, as, from a critical examination

of thin sections of these rocks, chiefly from parts of the field to the east and north of the Goudreau section, he was unable to discover any olivine. This absence of olivine is not uncommon in other parts of the country where some of these dykes carry the mineral and some do not. Under the microscope the writer found the diabases from this eastern part of the area to consist of a diabasic aggregate of plagioclase, pyroxene, and magnetite, with minor amounts of biotite and secondary hornblende and limonite. Unlike the quartz diabases, both the feldspars and the pyroxene crystals are in most cases only slightly altered. In hand specimens the two striking features are the comparatively fresh appearance of the rock, and the very common porphyritic texture, with numerous large or small phenocrysts of plagioclase. At the edges of these dykes the rock is chilled to a very fine-grained or glassy consistency, this feature being much more prominent than in the quartz diabase dykes. Where the dyke is very narrow it becomes a diabase glass with small needles of plagioclase, as the only visible mineral constituent in thin section. Such a narrow dyke cuts a large quartz diabase dyke on the north shore of Dog lake, in the neighbourhood of Missinaibi. These diabases, as well as the quartz diabases, frequently carry enough magnetite to affect the compass quite seriously.

Peridotites

This series is represented in the area by a few very small biotite picrite dykes, too small to be mapped, and one good-sized body of peridotite at the northwest corner of Dog lake near Gutelius siding. The biotite picrites have been mentioned by Collins[1], but, so far as the writer is aware, the peridotite has not been recorded from this area up to the present time. The biotite picrite dykes are quite rare, only two or three of them being encountered in the whole district. Under the microscope they consist chiefly of olivine, pyroxene, and biotite, with minor amounts of magnetite. The olivine is altered, either partly or completely, to serpentine, and the pyroxene is frequently altered to secondary hornblende. In some sections the biotite occurs in about equal quantities with the olivine and pyroxene; in others it is in subordinate amount. The body of peridotite is located a short distance west of a bay in the northwest corner of Dog lake, and, as indicated on the geological map, is of fair size. Under the microscope the rock is remarkably fresh, consisting chiefly of pyroxene and olivine, with lesser quantities of plagioclase and biotite. There is extraordinarily little alteration except on the more exposed surfaces, the olivine being altered very slightly to serpentine, and the pyroxene to hornblende. Its age relationships are somewhat obscure, but it seems probable, from its fresh unaltered character, and its general petrographic features, that it, along with the biotite picrites, is of Keweenawan age, and is close to being contemporaneous with the younger diabase dykes. This body, though not of any proved economic importance, might be an interesting field for prospecting investigation.

[1] Collins, W. H., Geol. Surv., Can., Sum. Rept., 1918, pt. E, p. 12.

PLEISTOCENE

These later deposits have been described in some detail by Collins.[1] The only additional information regarding these deposits that the writer has to contribute concerns beach or terrace-like deposits of large and small granite boulders, which are particularly prevalent in township 27, range 27, east of Herman lake. Some of these boulders are several tons in weight and suggest transportation by ice action. Sand-plains, which are said by Collins to be outwash plains, are common in a great many parts of the area, but attain considerable dimensions in townships 26, 27, and 28, range 27, and townships 26 and 27, range 26. Where these are in the vicinity of granite rocks it seems likely that some of the sand was derived from the acid rocks by the ordinary weathering processes, but there still remain large areas which appear to the writer to be of undoubted glacial origin. The general evidences of glaciation are not very numerous in the area, although scattered morainic material and drumlin-like hills may be observed in some places.

STRUCTURAL FEATURES OF THE PRECAMBRIAN FORMATIONS

The geological structure of this area has been outlined in Collins' report on the Goudreau area, in which he states: "Sediments and volcanics alike have been closely folded along an axis pointing 60 degrees east of south. According to current geological theory, this folding is referable to the period of intense crustal disturbance which preceded or coincided with the intrusion of granite gneiss." He also states that: "Intrusion of the late Precambrian quartz diabase was intimately connected with another milder crustal disturbance, which resulted in faults of considerable magnitude." These faults sometimes run about due north and south, but more often in a northeasterly direction. The best example of the former type is furnished by the extended fault which runs for the greater part of its length along the chain of small lakes which parallel the Algoma Central railway between Hawk Junction and Goudreau. This has given rise to a considerable displacement of the formations, particularly in the southern part where both the granite and the bands of iron formation have suffered an horizontal displacement of a half mile or more. This fault has been traced from the granite contact south of Alden to the northern contact south of Wanda. As already stated, the effects of the disturbance are more noticeable at the southern than at the northern end of the fault, but some diminishing effect may be noted at the north also. At this end the fragments of Dore sediments have been faulted a considerable distance, but the granite intrusive does not show the displacement here that it does to the south, and it seems likely that the movement gradually died out in this direction. Besides this major fault, there are minor faults located in other parts of the area. One of these, running down the middle of Smith lake, in township 27, range 26, had displaced both the granite formation and the bands of iron formation between one-quarter and one-half a mile. This fault has the more common northeasterly direction, and

[1] Collins, W. H., Geol. Surv., Can., Sum. Rept., 1918, pt. E, pp. 12 and 13.

it seems probable that the chain of small lakes running across the township in the same direction represents the line of this fault. This would give it a length of several miles. The high cliff on the east shore of the lake at the southwest end of the chain near the Algoma Central railway suggests the possibility of some vertical displacement as well. Another fault is to be found in the bed of Manitowik lake. Here the effect is not so noticeable, as it takes the form of a drag in the granite formation near the northeast end of the main lake, and there is no clear-cut displacement. It is interesting to note in this connexion that most of the lakes in this area have a northeasterly trend, probably due in great part to the general direction of folding, but in minor degree, some at least of these lakes may be occupied by basins formed by faulting.

ECONOMIC GEOLOGY

PYRITE AND IRON ORES

The pyrite and iron ores of Michipicoten district have been described at length by Collins and Quirke, who distinguish two types of pyrite deposits: primary range deposits, and secondary deposits either in veins or irregular bodies of pyritic sand. The first is the more common, and comprises most of the larger deposits in the area. The secondary vein type is best illustrated by the pyrite body on Smith lake, in township 27, range 25, whereas the pyrite sand type is very well shown in the old pit of the Rand Consolidated Mining Company, at Goudreau station.

Range Deposits

As already mentioned, the iron formations in this district are mostly composed of three main constituents: namely, banded silica, pyrite, and iron carbonate, with hematite occasionally replacing some of the carbonate. An exception is constituted by the Dreany range, in townships 27 and 28, range 27, in which the silica is banded chiefly with magnetite, and may be associated with considerable epidote, hornblende, and garnet. The close association of this range with the sediments of the Dore series, or the close proximity of the granite batholith, may have been a deciding factor in the differentiation of this range in mineralogical composition from others in the area. Bands of volcanic schist are often to be found included both in the carbonate and the magnetic type of iron formation, although somewhat more prevalent in the latter type. Good examples of this association are to be found near the middle of township 27, range 27, on the Dreany range, where banded volcanic tuffs, as well as basic volcanics, are interbedded with successive layers of the iron formation. In some cases, the pyrite member of the series is scattered through the carbonate in disseminated form, and is not separated out in masses of any size, but the Goudreau ranges and also the west shore of Smith lake contain distinct and large pyrite zones. They also contain varying amounts of pyrrhotite, sometimes scattered through the banded silica, sometimes in stringers in the massive pyrite. Pyrrhotite is found also in small amounts in other carbonate ranges in the district, but is practically absent in the Dreany range.

Goudreau Ranges. The iron formations in the vicinity of Goudreau included in townships 26, 27, and 28, range 26, are described in the preceding report by Collins and Quirke.

Hamilton Range. One of the most important iron formations in Missinaibi map-area occurs in the vicinity of Smith lake, extending from the centre of township 27, range 25, into the western part of township 26, range 25. Part of the same band is to be found extending from near the Algoma Central railway to a point about half a mile to the east. This is described by Collins and Quirke. It appears again in the vicinity of Smith lake, and extends to the western shore of that lake. Here it is faulted about one-quarter mile to the northeast, the faulted band extending then in a more or less continuous line to within a quarter-mile of the west boundary of township 26, range 25. This iron range is of the common carbonate type, consisting chiefly of carbonate banded with silica, with some disseminated pyrite, and acid, or basic, volcanics intercalated in places. In some parts the pyrite is segregated into bodies of some size, as in the neighbourhood of Smith lake. The formation has been tilted to a vertical position with an acid volcanic to the south and a younger volcanic of basic composition to the north. In places, as on the west shore of Smith lake, the iron content has been leached out of the upper part of the band, and redeposited in the lower half in the form of pyrite. Like most of the ranges of this type, the weathered surface has a characteristic rusty appearance. Although originally a considerable length over all, this band has been eroded and faulted to such an extent that it consists now of discontinuous fragments, extending from east to west across one township, and part of another. Its width varies from a maximum of 100 to 200 feet to a minimum of a few inches.

Emily Range. Another iron formation of the same type is to be found near the northwest corner of Dog lake, in township 25, range 27. This is represented only by a few, short, narrow bands running east and west, a short distance apart. They can be traced for about 200 to 300 feet, and are never more than a few feet in width. Their mineralogical composition is much the same as the last-named band, although they contain more admixed rock, and much less pyrite. The carbonate is often replaced by mixed hematite and carbonate, and native gold is to be found in cross stringers of quartz of later formation. The stratigraphic relations are more obscure here, the bands being tilted up in a vertical position, but intercalated between post-Dorean rocks of about the same age and composition, chiefly basic.

Dreany Range. An iron formation of different character from these two occurs in the Dreany range, remnants of which outcrop in townships 27 and 28, range 27 (Figure 15 and Plate VIII A). This range approaches more nearly to the mineralogical character of iron formation observed in other fields, consisting chiefly of interbanded silica and magnetite, along with varying amounts of epidote, hornblende, and garnet, as well as a little hematite. It is more continuous than most ranges in the area, extending continuously from east to west for a mile or more in township 28, range 27, and discontinuously from the west boundary to about the middle of

township 27, range 27, in the same direction. It has been extensively explored, both by stripping and diamond-drilling. The range varies in width from 200 feet down to 2 or 3 feet. Narrow bands of country rock are frequently intercalated with the iron formation, which is tilted to a vertical position along with the volcanics. In both townships the associated rocks at the northwest (top) and southwest (bottom) of the iron formation are basic volcanics and volcanic tuffs, and in both townships, also, Dore rocks lie a short distance beyond these volcanics to the north. Unlike most of the iron formations in the Missinaibi map-area, the Dreany range is quite easy to explore magnetically, the compass being strongly affected. It is displaced about half a mile by the major fault which strikes along the line of the Algoma Central railway. This displacement is not clean-cut, but takes the form rather of a drag.

Surface waters have operated on the iron ranges in the southern part of the map-area and have induced extensive gossan deposits and also, in some cases, have cemented the Pleistocene gravels nearby with limonite. In marked contrast with these conditions, the Dreany range, being composed largely of resistant magnetite, has suffered little, if any, weathering.

The origin of these iron formations is obscure, but there is sufficient evidence at hand, both of a chemical and mechanical nature, to suggest a mixed sedimentary origin. The appearance of some pyrrhotite in secondary stringers, cutting the pyrite, would suggest the action of meteoric waters, which have circulated to some depth. An interesting weathering-product in dry weather is the white sulphate of iron, probably melanterite, which coats the pyrite during seasons of drought, but disappears in the first rains.

Secondary Sand-like Deposits

These secondary deposits are not so common as the range deposits, in fact, the writer has encountered them in only two places. One has been mentioned already as being the Rand pit, near Goudreau station. The other is on a property alongside the Pick road, not far from Goudreau, where a fair amount of this sandy pyritic material has been deposited at water-level in a small opening near the road. The conditions here are almost exactly analogous to those at the Rand pit, except that the gravel cemented with limonite produced by the action of ferruginous waters has not been developed to the same extent. The pyrite in this type of deposit appears to be entirely free from pyrrhotite.

Secondary Vein Deposits

Only one example of this type of deposit was found by the writer. This is in the Hamilton range, bordering the west shore of Smith lake, in township 27, range 25. It occurs here right at the water's edge, immediately below some banded silica. Just what the extent of the pyrite body might be it was impossible to determine at the time of the writer's visit, as most of it was under water. From the dimensions showing, however, it would seem to be of considerable size. The banded silica has a strike of 95 degrees, with a dip of about 30 degrees to the west.

It shows a thickness of 4 to 6 feet, and is overlain by a volcanic rock of basic composition, and underlain by the body of pyrite, which starts at the water's edge and runs down an undetermined depth. The pyrite body at the surface is 50 feet wide from southwest to northeast, and is composed of massive, dull pyrite cut by later stringers of more lustrous pyrite. As far as the writer was able to ascertain, there was little or no pyrrhotite contained within it. No analyses were obtained of the pyrite from this range, but, from its marked similarity to that found on the Holdsworth property near Hawk Junction, it seems almost certain that the sulphur content is much higher than in the range ores. The secondary stringers of late pyrite would point toward a leaching of the upper members of the series, in particular the banded silica, of their iron content, and a subsequent deposition in the form of secondary pyrite stringers in the main mass of the pyrite. Some range pyrite is also found in conjunction with the iron formation bands a short distance north of this pyrite body, but this is more disseminated in character, and several small pits have failed to disclose bodies of any size.

GOLD

The gold properties near Goudreau were described in another report by the writer,[1] in which the theory of ore deposition was discussed. Additional descriptions are given here of all properties of any importance which were undiscovered or undeveloped at the time the earlier report was written, or at some distance from Goudreau, and hence, not properly included in the Goudreau area. The writer sees no reason to change his views, as expressed in the previous report, as to the genesis of the gold ore, nor as to the three types of veins found in Goudreau area. He will, however, have occasion to add what he considers valuable information as to the origin of the ore at the property of the Goudreau Gold Mines, Ltd., in township 28, range 26.

Dog Lake Claims

Most of these claims are situated on Emily bay, a long, narrow, westward arm of Dog lake, and are in the immediate vicinity of the old Emily mine. Development work was done for the most part on a series of small quartz veins, in both acid and basic Keewatin rocks, which carry small amounts of pyrite, chalcopyrite, and free gold. These veins are for the most part short and narrow, and are not strongly auriferous. Small test-pits have been sunk, some of them to a depth of 4 or 5 feet, and considerable stripping has been done to ascertain the extent of the ore-zone. Some of these veins (as at the old Emily mine) occur in an acid volcanic corresponding to quartz or feldspar porphyry, and others traverse the more basic type, such as altered basalts or andesites. North of these claims are several staked by J. J. Brothers, of Sault Ste. Marie, Ontario. These claims are located fairly close to the narrows at the northwest corner of Dog lake, and have been staked for the most part on small

[1] Thomson, E., Geol. Surv., Can., Sum. Rept., 1921, pt. D, pp. 17-26.

bands of iron formation. These bands are crossed by stringers of quartz, from which the gold values appear to come. On some parts of these claims a series of parallel stringers of quartz closely resembling iron formation appear in the basic Keewatin rocks, and carry some gold values. Pyrite and pyrrhotite are the usual metallics that can be observed in hand specimens. The character of these small bands of iron formation has already been described under the iron ranges. The Keewatin volcanics are for the most part altered basalts or volcanic tuffs, with occasional surficial types, such as amygdaloidal or vesicular rocks. Considerable development work has been done on these claims. Six or seven small test-pits have been sunk to a maximum depth of about 6 feet, and a considerable amount of stripping has exposed the extent of the mineralized zones. A small outlier of the main granite batholith appears about half a mile to the north of these bands of iron formation, and would seem to be the likely source of the gold-bearing solutions. Both the bands of iron formation and the series of parallel quartz stringers appear to be too small and discontinuous to suggest that further work will disclose deposits of economic importance.

Godon Lake Claims

At the eastern end of Godon lake. in townships 25 and 26, range 27, a gold property was discovered by W. Webb, of Sault Ste. Marie, Ontario. The deposits on this claim were examined hurriedly by the writer in the summer of 1921, and a brief description of this property was included in the previous report.[1] Since that time considerable development work has been done on the property by the Algoma Exploration Company, who had it under option during the summer of 1922. They have since disposed of their option to the Detroit Goudreau Mining Company, who are to carry on the work. The writer was unable to find time during the summer of 1922 to pay this property a second visit, but was so fortunate as to secure a report of recent developments on the property from G. W. MacLeod, of the Algoma Exploration Company, part of which is appended herewith:

" This property consists of a group of four contiguous claims, Nos. 2469, 2470, 2474, and 2475. They are located about 1¾ miles south of Lochalsh station, on the Canadian Pacific railway. They lie just north and east of Godon lake, the west claim lying in the east-central part of township 26, range 27, and the remaining three claims in line with and immediately east of this claim, and in township 25, range 27. They are all easily accessible from Lochalsh by a canoe route with three short portages. A road from this point on the Canadian Pacific railway to the claims will be built in the near future, and will be about 2½ miles in length.

" These claims were staked in November, 1920, by W. J. Webb, and are at present owned by G. L. Michael, A. H. Chitty, T. J. Wilcox, and J. Webb, all of Sault Ste. Marie, Ontario, and J. J. McFadden of Spragge, Ontario. The assessment work has all been completed, and the claims surveyed.

" The topography on these claims is the same as on a large part of the country from Dog lake westward. It consists mainly of a series of low

[1] Thomson, E., Geol. Surv., Can., Sum. Rept., 1921, pt. D, pp. 22 and 23.

ridges with swamps in between. The general strike of the ridges is east and west. On the southwest part of the claims the land slopes down to a swamp which borders on Godon lake. The ridges are mostly bare, but between them there is a heavy covering of drift, so that prospecting has largely been confined to the ridges. No point on the ridges is over 75 feet above the level of Godon lake.

"The rocks in this area are almost entirely volcanics of Keewatin age. About 400 feet from the southern boundary of claims 2469 and 2470, there is a well-defined shear zone which strikes in an easterly direction, and varies in width from 75 to 175 feet. The shearing is more pronounced along the south boundary of the zone, and decreases in intensity towards the north. Several quartz porphyry lava flows were noticed at different points in the zone. These are very irregular in width and extent, and are highly schisted and altered. Throughout the zone there are many lenses of quartz, which vary greatly in size. These lenses have filled the fissures in the shear zone, and in some cases at least have replaced the volcanics. Evidences of this were to be seen in the larger lenses where unaltered portions of the greenstones were noticed in the centre, grading gradually into the quartz towards the edges. A large amount of iron carbonate was found in the schist at practically all points. The weathering of these carbonates gives the surface of the zone a rusty brown colour. The schist is well mineralized with pyrite, and lesser amounts of pyrrhotite, chalcopyrite, and galena.

"As far as the work done thus far has shown, the larger lenses of quartz are to be found in the southerly part of the zone. The schists on the south side of these lenses carry about the same values in gold as does the quartz itself, over a width approximately equal to that of the quartz in the lens. The values in the schist on the north side of these lenses average over $1 for a distance of at least 50 feet. The quartz lenses and enriched country rock vary in extent. The largest of these mineralized zones extends for a distance of about 100 feet, and has an average width of about 7 feet. The values for this distance averaged over $8. This zone has not yet been delimited and it is very probable that it extends over a much larger area. The necessity for further trenching and unwatering prevented further work being done on it.

"The entire sheared zone has an average width of 125 feet, has been traced for nearly 1,000 feet, and probably extends much farther than this. Samples were taken from over one hundred places, and in every instance these carried gold values varying from $1 to $19, the higher values being obtained from the quartz lenses and enriched country rock mentioned above. It would seem well within the range of possibility that ore-bodies of commercial size and richness might be found in this zone.

"The property is now under option to a Detroit company, who expect in the near future to explore this zone systematically with diamond-drilling. The surface indications certainly seem to warrant further investigation."

Since writing this report Mr. MacLeod has published an article in the *Canadian Mining Journal*[1] on the Goudreau gold area, and, from his description in that article it would appear that drilling operations have not yet started but will commence shortly.

Goudreau Gold Mines, Ltd.

Since the writer's report on the Goudreau gold area appeared in 1921 (Plate VIII B) considerable work has been done on this property. The gold is found in a vein cutting at a small angle to the strike of the volcanic rocks it traverses. It has a maximum width of about 4 feet, and has been traced for over 1,000 feet. The gangue material is partly quartz and partly carbonate. The metallics present are chiefly chalcopyrite, pyrrhotite, and native gold, with bornite, pyrite, sphalerite, niccolite, and smaltite-chloanthite, as uncommon constituents. Numerous fine needles of tourmaline are to be found in the quartz part of the gangue, giving this mineral a dark brown to black colour. The country rocks are acid and basic volcanics, cut by a younger diabase dyke. The vein has a strike varying from 90 to 115 degrees and dips 60 degrees to the south.

The company's equipment has been brought up-to-date by the introduction of electric power from Steephill falls on Magpie river.

Two shafts have been sunk on the main vein, some 500 feet apart, to a depth of 200 feet, and drifting has been done at that level to connect up these two shafts, and also some distance beyond them to make up a total distance of about 1,000 feet of drifting along the main vein. An interesting mineralogical development in No. 1 shaft close to the 100-foot level is the occurrence of niccolite and smaltite-chloanthite. These two metallics appear to be associated most closely with the carbonate part of the gangue, and would lead one to suppose that there were two periods of ore deposition, the first siliceous in character, and coming in all probability from the last magmatic juices of the nearby granite boss, and the second carbonated, and resulting from the activity of ascending meteoric waters whose source would appear to be entirely conjectural. It is at least worthy of note that two metallics like niccolite and smaltite-chloanthite, which are ordinarily associates of native silver, should have been found in association with native gold. However, when the presence of such sulphides as pyrrhotite and chalcopyrite is taken into account, the association does not seem so remarkable, as both niccolite and smaltite-chloanthite have been reported in the Sudbury nickel ores, in association with these two minerals. According to the management, sinking will be continued in these two shafts to the 400-foot level, and conditions there noted very carefully before plans for a mill are considered.

General Conclusions Regarding Gold Deposits

The work done so far on gold properties in Missinaibi map-area seems to emphasize the importance of exploring fissure veins in the neighbourhood of small granite bosses as likely ore-carriers. The prospector would be

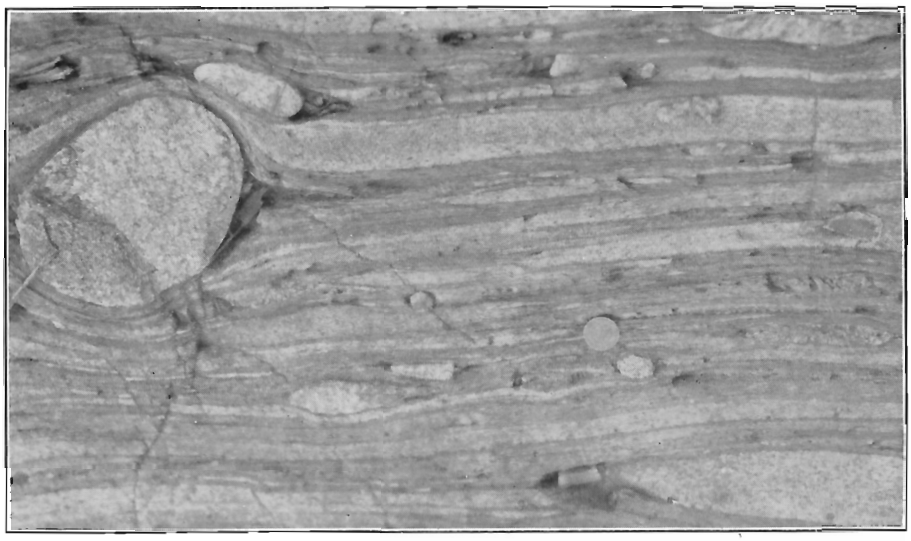
[1] MacLeod, G. W., Can. Min. Jour., vol. XLIV, No. 16, April 20, 1923, pp. 295-297.

well advised to investigate thoroughly the vicinity of such masses of intrusive. In addition to this, in the acid members of the Keewatin volcanics, there would appear to be, in some cases, fairly extensive shear zones in which gold-bearing solutions have acted, and in which the ore is concentrated in a sufficiently confined area to hold out promise of deposits of commercial importance. Since attention has been directed in Timiskaming district to the importance of the Timiskaming conglomerate as an easy zone of entrance for porphyry or other granitic rocks, it might also be profitable to explore the immediate vicinity of the remnants of Dore conglomerate. Though probably not of the same age a similar zone of weakness might exist in the Dore formation to make it of commercial importance. A great number of claims have been staked in Missinaibi area, and most of them have had sufficient development work done on them to prove their promise, or otherwise. The writer feels, however, that more intensive prospecting and surface exploration will be needed to place this district in the ranks of the important gold-producers of the province, but that it holds out sufficient promise to justify the expenditure of considerable money on both surface and underground exploration. It is to be hoped also that some time in the not too distant future the pyrite industry may come into its own again, when this district, which boasts as large deposits as any on the continent, may find this also a source of mining revenue.

PLATE II

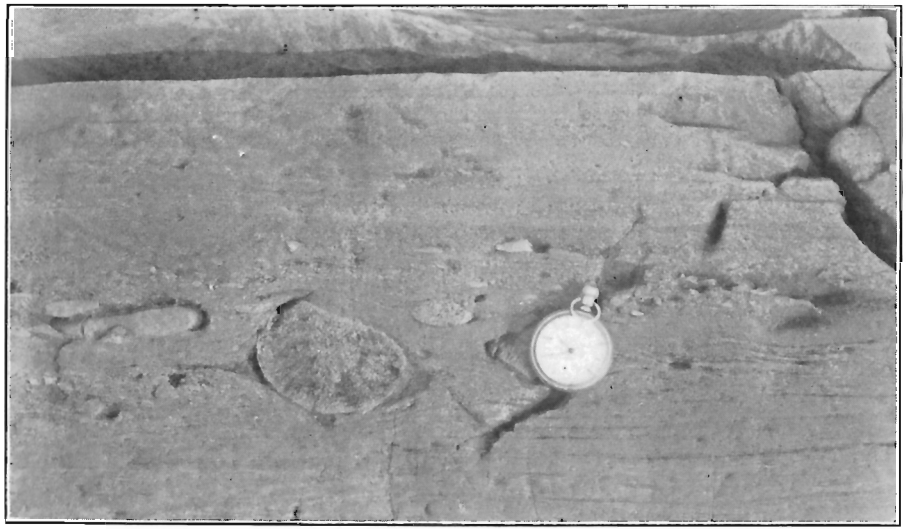
Characteristic phase of the Dore conglomerate: boulder conglomerate, scale $\frac{1}{12}$, from near mile-post 2 on the railway north of Michipicoten Harbour. (Pages 14, 23.)

PLATE III

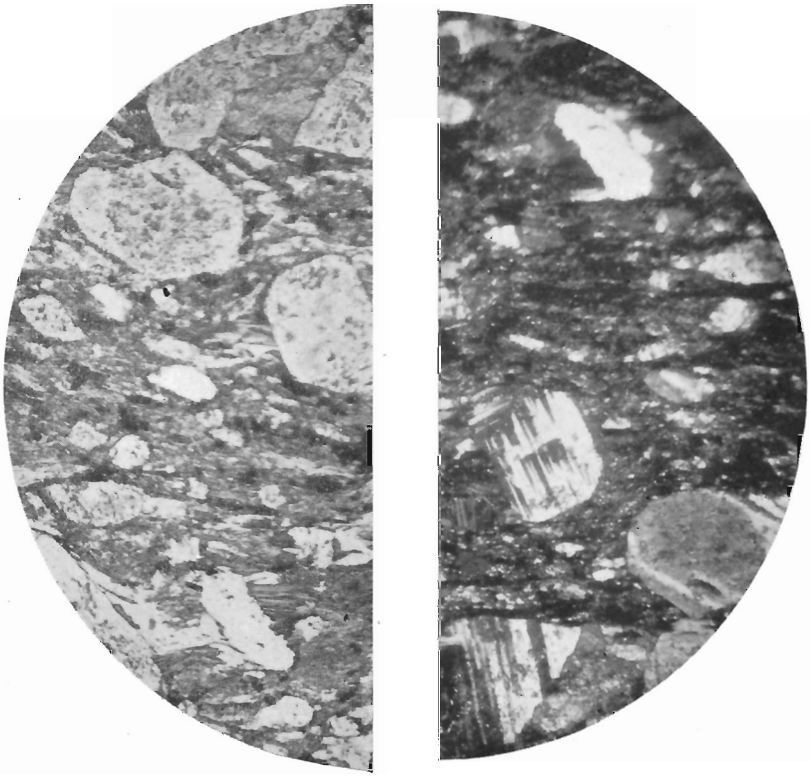


A. Characteristic phase of the Dore conglomerate: the stratified boulder conglomerate showing undeformed boulders of grey granite and flattened boulders of softer rocks. Scale about $\frac{1}{8}$. (Pages 14, 21, 23.)

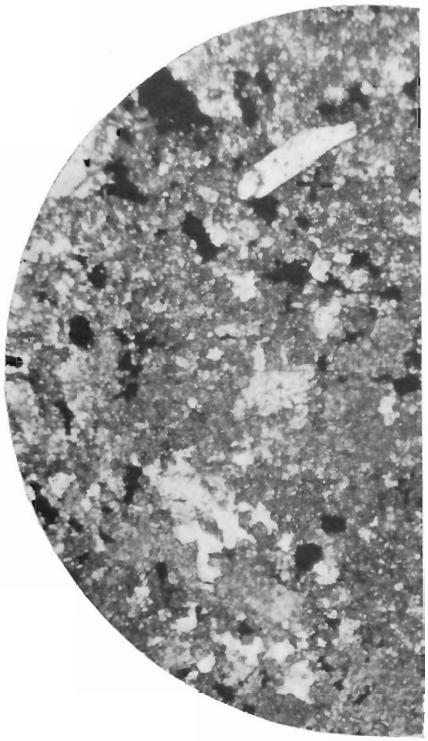
B. Characteristic phase of the Dore conglomerate: same as A, but greatly contorted. Scale about $\frac{1}{8}$. A and B are from near mile-post 2 on the railway north of Michipicoten Harbour. (Pages 14, 23.)

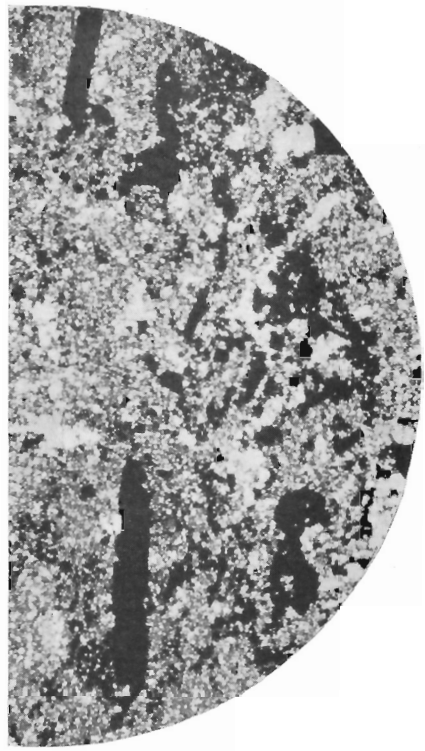


A. Characteristic phase of the Dore conglomerate: greywacke from near top of the Dore series, containing beds of conglomerate. Scale about ¼. From islets in lake Superior off mouth of Dore river. (Page 16.)



B. Photomicrograph of A magnified 30 diameters. (Pages 17, 22.)

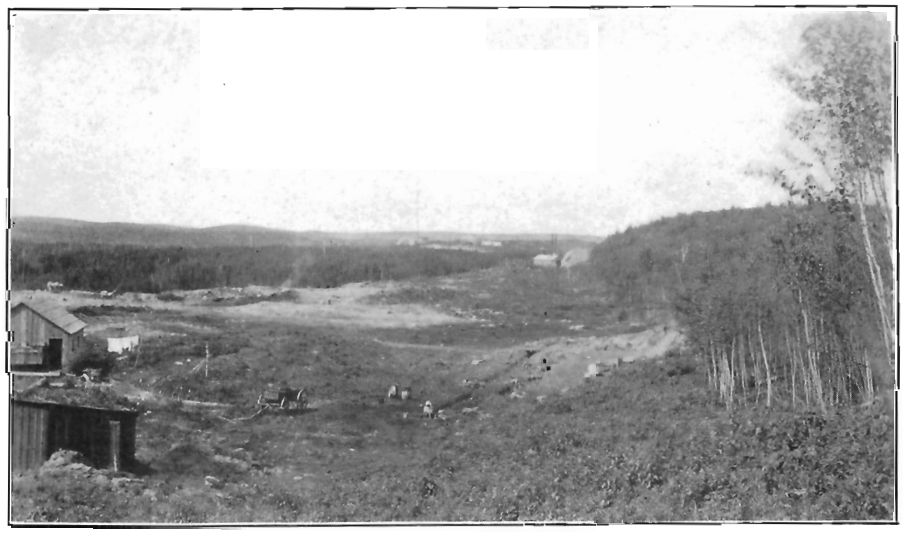




A. and B. Photomicrographs of carbonate member of Helen iron formation from 694 and 714 feet in diamond-drill hole No. 105, showing manner of introduction of sulphides:

A. Crystals of ferromagnesian minerals —hornblende (large, oblong, white individual, in upper part of plate, marked by a cross below it)—from original lava; magnified 250 diameters. (Page 68.)

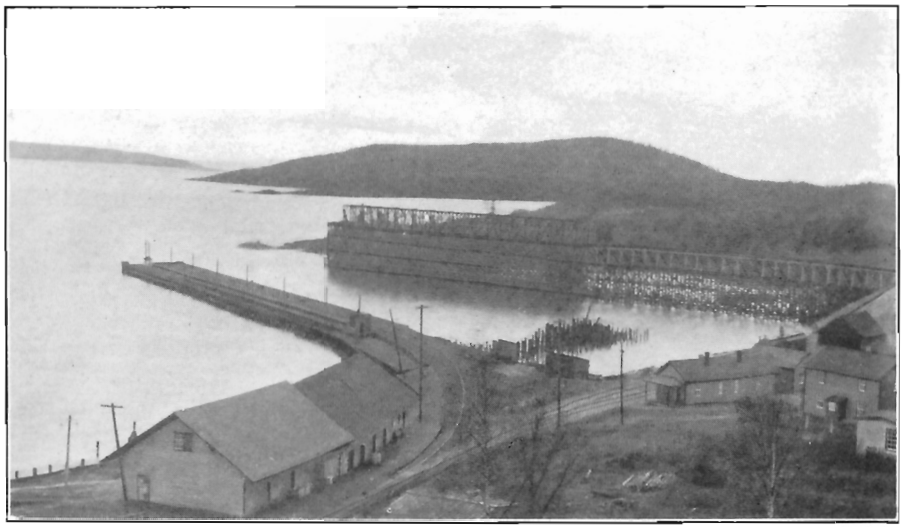
B. Same as A, completely replaced by pyrite (black), between crossed nicols; magnified 175 diameters. (Page 68.)



C. View westward in 1918 over Bear claim (JL 28), Goudreau pyrite range; plant of Nichols Chemical Company, on JL 14, in distance. (Page 105.)

PLATE VI

A. Section in small sand-pit at side of the wagon road between The Mission and Wawa, showing peculiar ripple-like marks. Scale about $\frac{1}{8}$. (Page 46.)



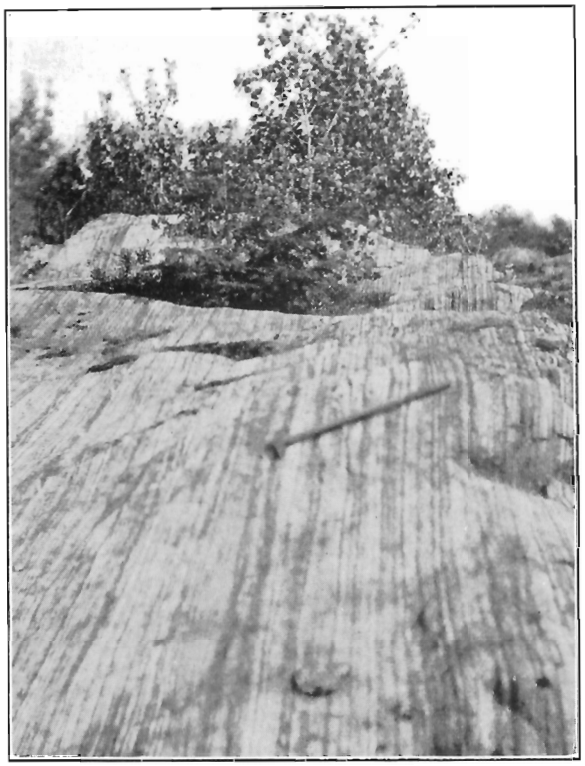
B. View of Michipicoten Harbour. (Page 46.)

PLATE VII

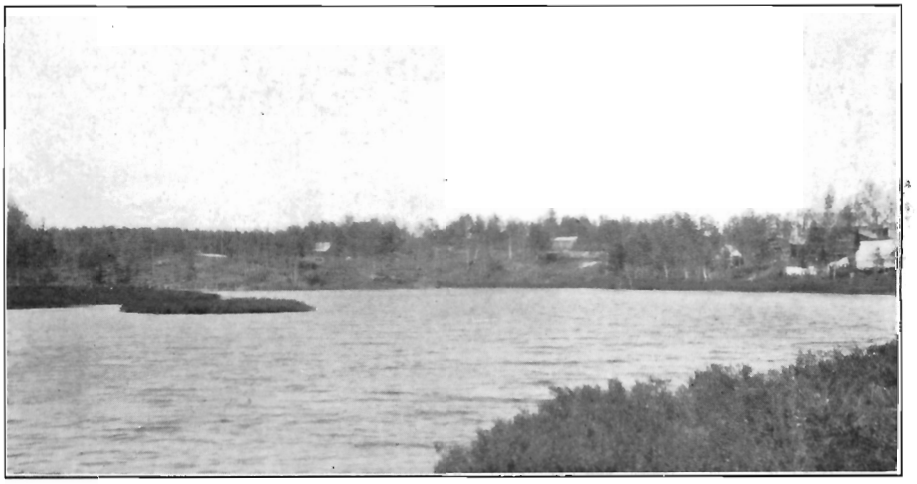
A. Banded silica member of an iron formation near Brant lake, township 30, range 26, illustrating how irregular the stratification may be. Light bands are composed of silica, dark ones of grünerite. Scale about $\frac{1}{12}$. (Pages 59, 102.)

B. Brecciation of banded silica member, at same locality as A. Scale about $\frac{1}{6}$. (Page 59.)

PLATE VIII

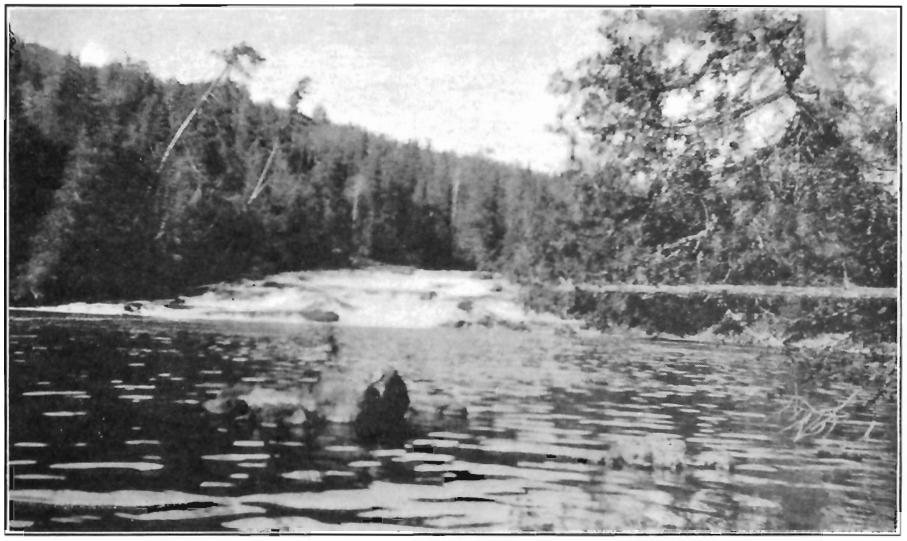


A. Banded silica member of Dreany iron range. (Pages 59, 155.)

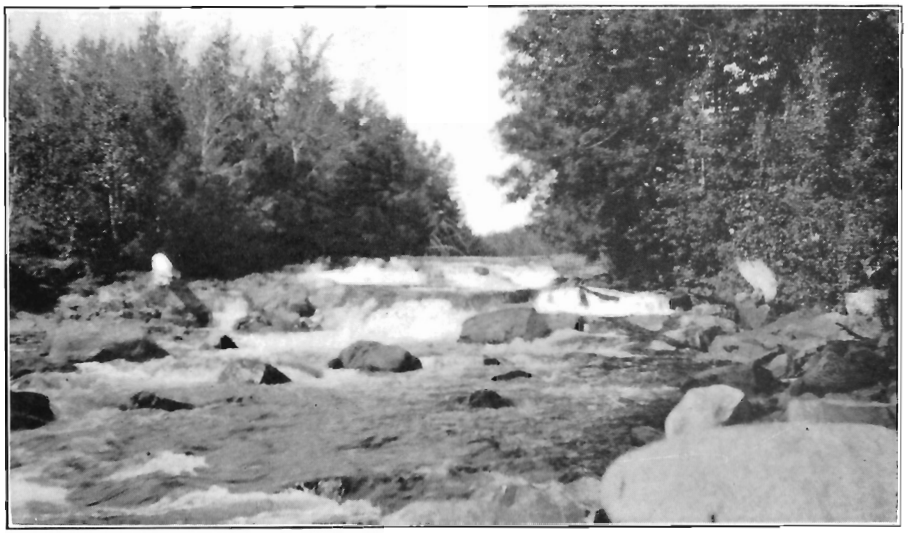


B. Camp of Goudreau Gold Mines, Limited, in 1921. (Page 160.)

PLATE IX



A. Big Stony fall, Michipicoten river, township 25, range 26. (Page 145.)



B. Lomond fall, near Dog lake, township 25, range 27. (Page 145.)

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