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HON. JAMES A. MALONEY, *Minister* H. C. RICKABY, *Deputy Minister*
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Gunflint Iron Range in the Vicinity of Port Arthur

By

W. W. MOORHOUSE

Gunflint Iron Formation of the Whitefish Lake Area

By

A. M. GOODWIN

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ABSTRACT

The gently-dipping Animikie rocks of the Port Arthur region unconformably overlie the greenstones, tuffs, greywackes, and granites of the Archean. The Gunflint iron formation, the lower part of the Animikie, is separated into three subdivisions on the accompanying maps. The Lower Gunflint, beginning locally with gravelly conglomerate, consists of lenticular beds of ferruginous carbonate, chert, jasper, algal cherts, hematite, and magnetite taconites, and west of the Kaministikwia River, silicate taconite. The Lower Gunflint is overlain by the argillite-tuff unit, of black and grey argillite, tuff, carbonate, and chert. The Upper Gunflint, in the vicinity of Loon Lake, is thin-bedded chert and ferruginous carbonate. Similar but thicker beds outcrop along the Current River. West of Port Arthur the Upper Gunflint is largely chert, jasper, and silicate taconite.

The Gunflint is overlain by the Rove formation consisting of argillite, greywacke, and thin carbonate layers. Calcareous concretions are locally abundant. Overlying the Animikie with unconformity but with small angular discordance, is the Keweenawan Sibley formation, consisting of conglomerate, sandstone, limestone, and silty red carbonate rocks. All these rocks are intruded by sheets of diabase, which are responsible for the cuestas, buttes, and mesas that characterize the landscape around Port Arthur and Fort William.

Brief summaries are given of the mineralogy, texture, metamorphism, sedimentary facies and chemical composition of the Gunflint. The prospects for the development of an iron mining industry in the area mapped are not promising at the present time.

Gunflint Iron Range in the Vicinity of Port Arthur, District of Thunder Bay

BY

W. W. Moorhouse[1]

INTRODUCTION

The survey of the Gunflint iron range, described in this report and in the accompanying report by A. M. Goodwin, had as its object a re-examination of the stratigraphy, structure, and relationships of the Gunflint iron formation, and an appraisal of the Gunflint as a possible source of direct-shipping or concentratable iron ore. The author was engaged in this work during the field seasons of 1950 and 1951. The survey covered outcrops of the iron formation from Whitefish Lake to Loon Lake, a total distance of 65 miles. The results of this work and that of Dr. Goodwin (see following report) are shown in the eight maps in the case at the back.

No new indications were found of commercial concentrations of direct-shipping ore, or of deposits of concentrating ore likely to be profitable under present conditions. Some interesting stratigraphic and structural relationships have developed from the mapping program and are summarized in the report.

From time to time surface prospecting and drilling have been carried out by individuals and companies to locate mineable iron ores, but have so far met with little success.

Methods of Mapping

Since the main objective of the mapping program was the location, lithology, and structure of outcrops of the Gunflint iron formation, most of the mapping was confined to areas in which these occur, and to determining the limits of the iron range as at present exposed. In the part of the area northeast of Port Arthur, the Gunflint was mapped by means of systematic traverses spaced at 10-chain intervals; traverse lines were located on Forest Resources Inventory vertical photographs, at a scale of approximately 1 inch to ¼ mile, of the Ontario Department of Lands and Forests. In the section between Navilus and Conmee Point, Animikie outcrops are mostly restricted to the coast line of Thunder Bay, and detailed work was limited to these outcrops, with a few reconnaissance traverses to the north to confirm the absence of any significant outcrops of the Animikie.

West of Port Arthur and Fort William, outcrop is so scarce that it was felt to be unprofitable to systematically traverse the area in which the Gunflint occurs. Here all the major creek and river valleys were traversed in search of outcrop, and all roads were traversed to locate exposed rock in the interstream areas. As a result of this procedure, together with a systematic stereoscopic examination of

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[1] Professor, Department of Geological Sciences, University of Toronto.

air photographs, it is thought that the most important outcrops have been examined and mapped. It is certain that all rock exposures have not yet been located; however, owing to the difficulty of identifying the stratigraphic position of isolated outcrops, little important information has been lost through this.

The assignment of a particular outcrop to its proper stratigraphic position in the Gunflint is difficult, not only because of the interrupted and sometimes sparse distribution of rock, but also because of marked facies changes and numerous faults, most of which are of unknown displacement. For this reason the position of the contact separating the Lower and Upper Gunflint on the accompanying maps is only provisional and may well be modified if further information is obtained from drilling or excavation.

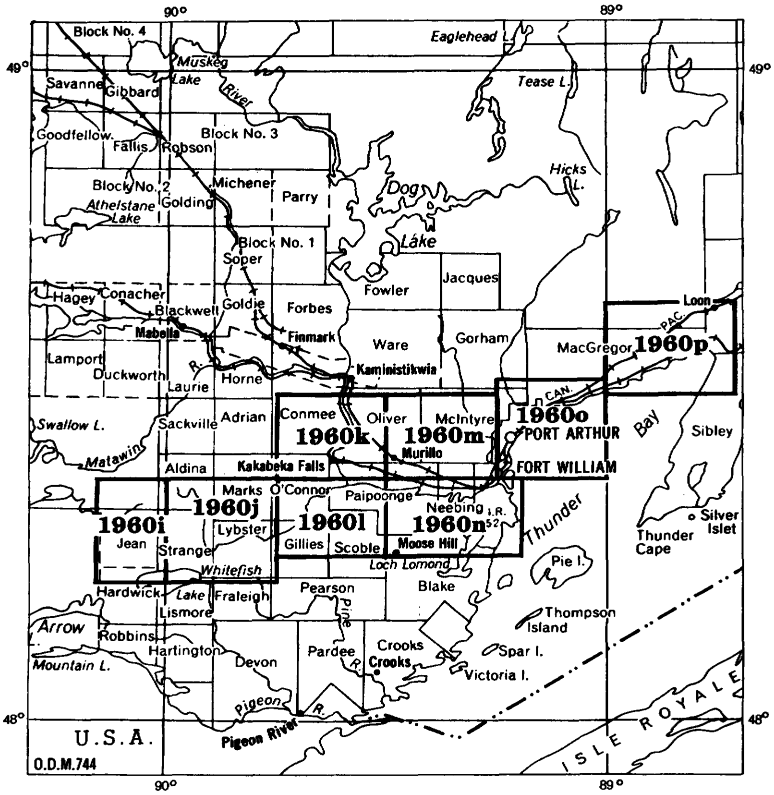

Figure 1—Key map showing the locations of the map areas described in this and the following report. Scale, 1 inch to 20 miles.

Acknowledgments

The author is indebted to M. W. Bartley, consulting geologist, and to W. L. C. Greer, resident geologist of the Ontario Department of Mines at Port Arthur at the time the mapping was done, for many favours and much useful information. Jules Cross assisted by giving the benefit of his experience and knowledge of the area. Thanks are also due to E. G. Pye, now resident geologist at Port Arthur, for his co-operation on several occasions.

In both 1950 and 1951, A. M. Goodwin was senior assistant on the field party and was responsible for much of the mapping. His careful work and willing co-operation at all times are sincerely appreciated. The work of mapping was facilitated by the willing and efficient efforts and interest of G. A. Sears and M. J. Salm in 1950, and J. D. Godfrey and E. A. Matchett in 1951.

Means of Access

All parts of the area are readily accessible from highway No. 17, the Dawson Road, the Oliver Road, all of which are paved, or from township roads, some of which are now paved. Few parts of the area mapped are more than one hour's walk from roads accessible with car or truck.

Population

The Port Arthur–Fort William area is one of the most populous areas of northern Ontario. In 1951 there were more than 66,000 inhabitants. Like most of the larger centres in northern Ontario, the population is very mixed; Scottish, Scandinavian, and Finnish elements probably constitute the largest ethnic groups.

Natural Resources

Between Loon Lake and Whitefish Lake, extensive areas are cleared for cultivation or pasture. Most of the agricultural produce of the area is consumed locally. Forest, which crowds the urban and agricultural land against the shore of Thunder Bay, is almost entirely second growth; some pulp is cut in the area and processed in the local pulp mill.

Although many attempts have been made to produce silver from veins in the area, significant production came only from Silver Islet, just off Thunder Cape. There is no metal production in the area at the present time.

Sand and gravel are abundant and are produced for construction and road-building. Diabase is quarried at Silver Harbour for riprap used in the construction of breakwaters in the harbour. Owing to their position at the head of navigation on the Great Lakes, the twin cities are of great importance to the transfer of wheat from the west, and iron ore from Steeprock Lake to lake carriers .

Previous Work

A review of the history of stratigraphic terms used in the Thunder Bay area has been given by Tanton. (See below.) A summary of early geological work in the area, and a complete bibliography are also given in his report. Therefore, a detailed discussion of previous work, and a full bibliography are not given here.

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W. N. Smith, "Loon Lake Iron-bearing District," *Annual Report*, Ont. Bur. Mines, Vol. XIV, 1905, pt. 1, pp. 254–60.

T. L. Tanton, *Fort William and Port Arthur, and Thunder Cape Map-Areas, Thunder Bay District, Ontario*, Geol. Surv. Can. Memoir No. 167, 1931.

C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior District*, U.S. Geol. Surv., Monograph No. 52, 1911, pp. 45, 46, 81–83, 94, 95, 100, 101, 110–15, 205–10, 366–70.

Since Tanton's report of 1931, a few publications dealing with rocks of the area, or with correlation problems, have become available, among which are the following:

R. G. Blackadar, "Differentiation and Assimilation in the Logan Sills, Lake Superior District, Ontario," *American Journal of Science*, Vol. 254, 1956, pp. 623–45.

B. A. Bradshaw, *Petrological Comparison of Lake Superior Iron Formations*, unpublished Ph.D. Thesis, University of Toronto, 1956.

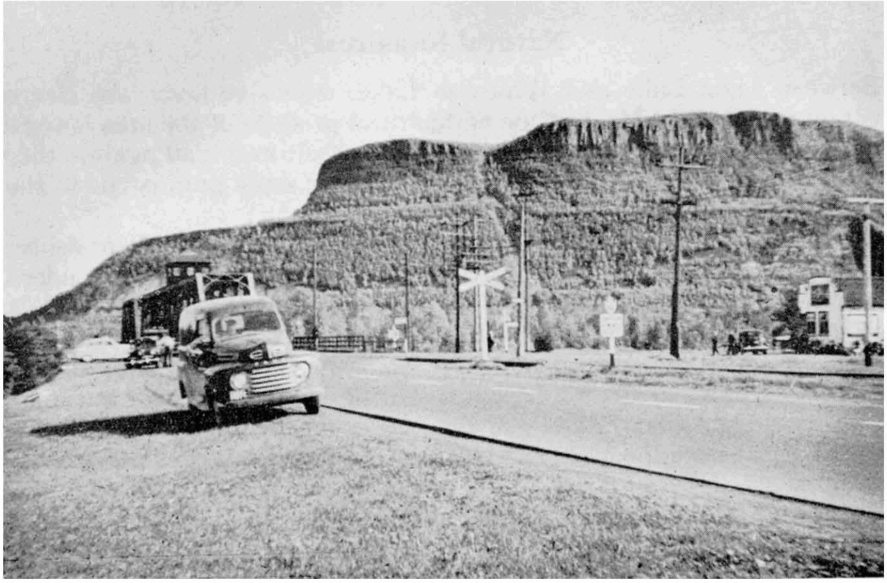
A. M. Goodwin, *Stratigraphy of the Gunflint Iron-bearing Formation*, Ph.D. Thesis, University of Wisconsin, 1953.

A. M. Goodwin, "Facies Relations in the Gunflint Iron Formation," *Economic Geology*, Vol. 51, No. 6, 1956, pp. 565–95.

C. K. Leith, Richard J. Lund, and Andrew Leith, *Pre-Cambrian Rocks of the Lake Superior Region*, U.S. Geol. Surv., Professional Paper No. 184, 1935.

W. W. Moorhouse, "The Proterozoic of the Port Arthur and Lake Nipigon Regions, Ontario," *The Proterozoic in Canada*, (edited by J. E. Gill), Roy. Soc. Can., Special Publication No. 2, 1957, pp. 67–76.

M. E. Wilson, "The Canadian Shield," in *Geologie der Erde, Geology of North America—I*, Verlag von Gebrüder Borntraeger in Berlin W. 35, see especially pp. 238–44.



Mount McKay, a butte capped by diabase; the terrace is floored by a thin diabase sheet.

Topography

The countryside between Loon Lake and Whitefish Lake is dominated by cuestas, mesas, and buttes resulting from the weathering and erosion of the flat-lying to gently dipping Animikie sediments and the diabase sheets that intrude them. The highest of these are the mesas capped by diabase, such as Thunder Cape (1,768 feet above sea level or 1,166 feet above lake level), Pie Island, and the range of hills of which Mount McKay (1,581 feet above sea level) is the most northerly (see photo). To the north of Mount McKay and similar mesas and cuestas to the west, a broad flat plain, largely covered by drift, extends northward to the contact with the granites and schists of the Archean. These rise at a low angle from below the unconformity that separates them from Animikie to form the rugged upland of generally low elevation (900-1,400 feet above sea level) typical of most of northern Ontario.

The relatively flat plain lying to the west of Port Arthur and Fort William is occupied by the valley, flood plain, and delta of the Kaministikwia River, and those of the Neebing and McIntyre rivers. Between the river valleys, it is covered by a thin layer of glacial drift, mostly boulder clay, swamp deposits, and varved clays. Varved clays are exposed locally, as on the Current River above the Lyon Boulevard bridge and around the northeast end of Thunder Bay.

Like the lower reaches of the Kaministikwia River, the Whitefish River below Nolalu is entirely in drift. Between Nolalu and Leeper, this drift, largely stratified sand and gravel, attains thicknesses of about 100 feet.

Thunder Bay is essentially a drowned lowland, bounded on the north by the unconformity between the Animikie and the Archean, on the east by the Sibley escarpment, and on the west by the deltas of the Kaministikwia, Neebing, and other rivers.

GENERAL GEOLOGY

The consolidated rocks of the area are Precambrian in age. Oldest are the old, folded, metamorphosed greenstones and sediments, indicated on the maps as Keewatin type, cut by granites and related batholithic rocks. These are typical Archean rocks. Overlying them are relatively flat-lying Proterozoic rocks, which have been grouped together as the Kaministikwan group by Tanton.[1] In this group are included the Animikie series, the Sibley sediments, the Osler sediments and volcanics, and the diabase sills and dikes that cut these rocks. The Sibley and Osler sediments and diabase intrusives are grouped with the Keweenawan by most authors. The term Kaministikwan is not used in this report.

TABLE OF FORMATIONS

PRECAMBRIAN	
KEWEENAWAN:	
Intrusives:	Diabase sills, sheets, and dikes.
	Intrusive Contact
Sediments:	Sibley formation.
	Unconformity
ANIMIKIE:	
Rove formation.	
Gunflint iron formation.	
	Unconformity
ALGOMAN TYPE:	Granite, granodiorite, syenite, pegmatite, porphyry, aplite, lamprophyre.
	Intrusive Contact
KEEWATIN TYPE:	Greenstone, pillow lava, rhyolite, andesite, amphibolite, minor sediments.

Keewatin Type

The most extensive area of Keewatin-type rocks examined in the survey lies southwest of Loon Lake, between highway No. 17 and the Canadian Pacific railway, extending westward along the highway as far as Silver Harbour. Pillow lavas are found among these outcrops, as well as metadiabases, which in most

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[1] T. L. Tanton, *Fort William and Port Arthur, and Thunder Cape Map-Areas, Thunder Bay District, Ontario*, Geol. Surv. Can., Memoir No. 167, 1931, pp. 17, 23, 24.

cases are presumed to represent the coarse parts of flows. Minor acid and intermediate volcanics were also encountered, but these are largely tuffaceous in nature. A fairly widespread rock type is a curiously massive, fine-grained biotite andesite or trap. North and west of Blende Lake there are many outcrops of this rock, which are lamprophyric in aspect. Dioritic or diabasic bodies of much coarser grain are associated with it.

Recrystallized gneissic and amphibolitic greenstones are found as inclusions in granite, and at contacts with granites.

A few outcrops of greywacke were encountered north of McKenzie Station, and southwest of Bittern Lake. Greywacke was also observed underlying Animikie conglomerate on the Pass Lake road, just east of the north end of Blende Lake, and in the same area it has been reported from diamond-drilling operations. The greywackes are not as abundant as might be thought from the descriptions of the geology given by Van Hise and Leith,[1] and Smith.[2] There were insufficient outcrops to establish the existence of a distinct sedimentary series in the area mapped.

Algoman Type

Along much of its contact with the older Precambrian, the Animikie overlies granites that are similar to those called Algoman in northern Ontario. Generally these are massive, light-coloured granites, granodiorites, and similar rocks. No detailed petrographic study has been made of them, but some outcrops, such as those northwest of Bittern Lake, and at the dam at Kakabeka Falls, are gneissic in character.

Small intrusives, apparently shonkinitic or syenitic in composition, are exposed north of Navilus, but were not encountered elsewhere.

Dikes of pegmatite, aplite, felsite, porphyry, and lamprophyre are found cutting greenstones or granites, but are not sufficiently numerous or prominent to warrant detailed description here.

All the rocks mentioned cut the Keewatin-type lavas and sediments, and are overlain unconformably by the Animikie.

Pre-Animikie Unconformity

The unconformity between the Animikie and the underlying Archean is an exceptionally even surface. Minor irregularities may occur, suggesting slight differences in elevation of the original surface, but these are of much less magnitude than the variations in elevation visible in the present glaciated surface on the Archean. So in general, it seems that the Animikie was deposited on a perfect peneplane.

Also of interest in the relationship between the Animikie and the older rocks is the lack of weathering and alteration of granites immediately below the unconformity. In many areas, the unconformity is marked by a thin skin of conglomerate, the Kakabeka conglomerate of Tanton. Almost unaltered granite is separated from this conglomerate by about ½–1 inches of green chloritic material, containing feldspar and quartz fragments. In many places where the contact may be seen, even this meagre evidence of weathering and decay is absent, and conglomerate or taconite lies directly on granite as fresh as glaciated outcrops of the same rock.

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[1] C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior District*, U.S. Geol. Surv., Monograph No. 52, 1911, p. 205.

[2] W. N. Smith, "Loon Lake Iron-bearing District," *Annual Report*, Ont. Bur. Mines, Vol. XIV, 1905, pt. 1, pp. 254–60.

The lack of weathering at this surface seems inconsistent with the idea that it was the site of prolonged and deep chemical weathering. It must be pointed out, however, that the Animikie and Keweenawan sediments indicate progressive marine overlap in their distribution. This would probably destroy any layer of soil or clay overlying the bedrock as the sea advanced over the peneplane.

Animikie Series

In this report two formations are included in the Animikie series, the Gunflint iron formation and the Rove formation. Tanton includes a third, the Kakabeka formation, a conglomerate at the base of the series; but this conglomerate is so thin, so erratic in its occurrence, and so closely associated with other units of the Gunflint, that it has been considered better to include it as a basal member of the Gunflint. Therefore it does not appear as an independent unit in the table of formations.

The Gunflint iron formation is an extremely complex formation. The complexity has two main causes: the great variety of rock types in the Gunflint, due to the varied combinations of possible mineralogy, texture, and structure; and the rapid vertical and horizontal changes in the rock type. Horizontal changes in lithology are so rapid, that the section on one side of a quarry may be different from that on the other. In consequence, only one member, an argillite-tuff complex, with some carbonate, can be traced throughout the area mapped. This divides the iron formation into a lower unit, of extremely varied lithology, but usually chert, and an upper unit, which in some areas, for example Loon Lake, is predominantly banded chert and carbonate, but elsewhere, as west of Fort William, is predominantly granular taconite. West of Kakabeka Falls, the lower Gunflint increases rapidly in thickness, according to the correlation used in this report, and becomes predominantly a silicate chert taconite.

West of Nolalu, Goodwin has divided the Gunflint into lower and upper units at an algal horizon, which persists throughout the western part of the Gunflint range. The argillite-tuff beds lie above this unit. At, and east of, Kakabeka Falls, the algal bed cannot be traced. Therefore the argillite-tuff band has been used for the separation of the Upper and Lower Gunflint.

West of Kakabeka Falls, another argillite band has been recognized by Goodwin[1] and Gill[2] near the base of the Gunflint. This has been correlated with the Intermediate Slate of the Gunflint Range in Minnesota, and the Lower Slaty of the Biwabik iron formation on the Mesabi range. At Nolalu this unit is very thin, and apparently it is absent farther east. It should be emphasized that the correlation proposed here is not necessarily the only one possible. In the early stages of mapping it was thought that the argillite-tuff section east from Kakabeka Falls corresponded with the Intermediate Slate. Therefore the correlation finally decided on and used in this report is subject to correction on the basis of additional information.

LOWER GUNFLINT

The Kakabeka conglomerate at the base of the Gunflint may be seen at a number of localities: as isolated patches in an outlier of Animikie rocks about ½ mile north of Crystal Beach; east of the Hodder Avenue bridge over the northeast branch of the Current River; in Oliver township, 3 miles north of Murillo;

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[1] A. M. Goodwin, *Stratigraphy of the Gunflint Iron-bearing Formation.* Ph.D. Thesis, University of Wisconsin, 1953, pp. 7, 8.

[2] J. E. Gill, "Gunflint Iron-Bearing Formation, Ontario," *Summary Report,* Geol. Surv. Can., 1924, Part C, p. 44C.

on islands in the Kaministikwia River, just below the dam above Kakabeka Falls (see accompanying photo); in north-central Marks township; and in the bed of the Whitefish River west of Hillside. According to Tanton, the conglomerate and associated quartzite are up to 4 feet thick; they usually amount to only a few inches. The pebbles of the conglomerate are mostly not over an inch or two in diameter. Most are vein quartz, but a few pebbles of jasper and Archean iron formation are generally visible. Locally, pebbles of granite or greenstone may occur. In some places the matrix is siliceous, elsewhere it is chloritic.

The Lower Gunflint is an extremely varied formation. The rock types represented include algal cherts and jaspers, thin beds of hematite and magnetite taconite, layers of chert, jasper, ferruginous carbonate, and taconites of chert, jasper, and iron silicates.

The finest exposures of the algal facies are to be seen in and near the Whitefish River at Hillside. Most of the concretionary structures are cauliflower-shaped heads 1–2 feet in diameter. One reef-like structure in the river is about 20 feet long and 10 feet wide. The core of this reef consists of partially bleached jasper, with thimble-like or tube-shaped structures. Around the core are 2-inch-thick layers of chert, jasper, and carbonate. In the same locality there are small cabbage-like and biscuit-shaped concretions up to 6 inches in diameter.

Well-preserved growths up to a foot thick were found on islands north of the bridge at Kakabeka Falls; little seems to remain in place here. A small outcrop of jasper with concentric structures is exposed along the sideroad to Silver Harbour and along the railway cut just north of Green Point. A layer of laminated algal structures is also exposed on highway No. 17 just east of the road to Loon Lake.

Most of the algal remains consist of chert or jasper. The presence of cherty oölites associated with them indicate that silicification has taken place, and it is considered probable that the growths were originally calcareous and have since been silicified.

Some representative sections from the Gunflint are illustrated in Figure 2. In the northeastern part of the area, Loon Lake, the outcrops are composed chiefly of chert, granular chert, and fairly thick-bedded carbonate, with some thin layers of hematite. Along the Current River (see accompanying photo), beds that have been assigned to the Lower Gunflint are predominantly carbonate and chert. At the top of the section, under the Lyon Boulevard bridge, is exposed 4–5 feet of grey, crystalline limestone, overlain by 2 feet of chert, with some ferruginous carbonate. At the railway underpass at the east boundary of Port Arthur, and along the Pass Lake road, near highway No. 17, thick, massive beds of carbonate make up a large part of the section.

West of Port Arthur, this part of the Gunflint is poorly exposed, but occasional outcrops and locally derived boulders in the drift indicate that it consists predominantly of ferruginous carbonate and chert. A few small outcrops appear on the east bank of the Kaministikwia River, between the dam and the highway bridge. These also consist largely of carbonate and interbedded chert and carbonate, with some beds of carbonate and chert taconite.

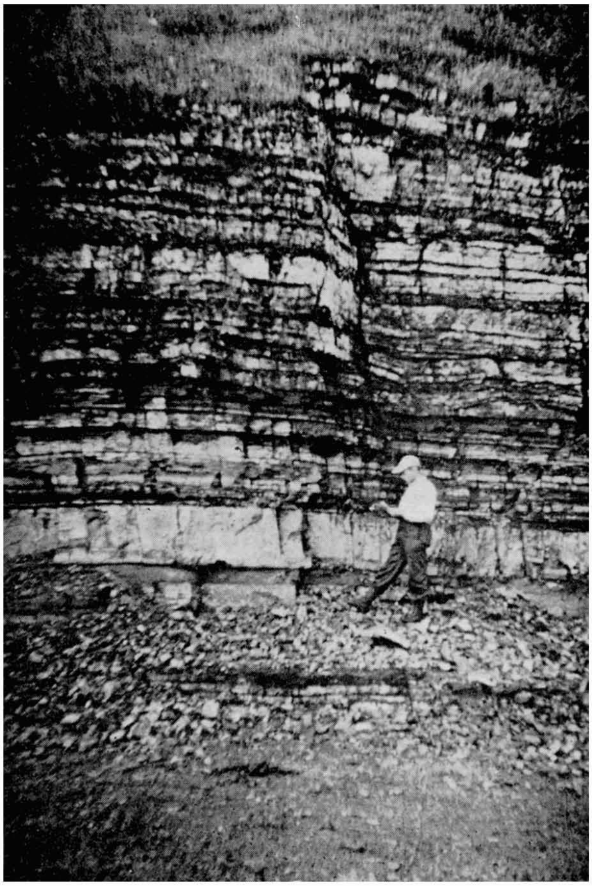
On Pitch Creek, a marked change in thickness and lithology of the Lower Gunflint is apparent. A few feet of argillite near the base is followed by 100–200 feet of silicate taconite with wavy bedding, often interbedded with thin layers of shaly silicate. This succession is overlain by an algal layer and beds of jasper and chert taconite, as reported farther west by Goodwin.

No continuous section of the Lower Gunflint has been measured in the area described in this report. The thickest measured section east of Kakabeka Falls is

Kakabeka conglomerate, Kakabeka Falls.

Iron-formation outcrops, Current River.

on the Current River. Here about 25 feet is exposed, but the distance to the basement below this section is not known. Results of diamond-drilling by M. A. Hanna Company in McTavish township, made available through the courtesy of this company, are reported to have shown thicknesses of 27–41 feet. At the Shuniah mine, just west of the Current River, a thickness of about 45 feet is indicated.[1]



Regularly bedded chert-carbonate, Highway No. 17, west of the Pass Lake Road.

ARGILLITE-TUFF UNIT

The argillite-tuff unit is very persistent, but in general is poorly exposed. The best outcrops are found in the cuesta faces of the diabase-capped ridges, and in the gorges of the Current River (see Figure 3) and the Kaministikwia River at Kakabeka Falls.

In general the unit is characteristically a black, fissile, thin-bedded argillite, with which are interbedded thin layers of carbonate, thin beds of fine-grained tuff, and a few 2-foot beds of coarse tuff, which are seen only at Kakabeka Falls. These tuffs have a coarse-grained carbonate matrix. Possibly related to them are limestone beds up to 10 feet thick, exposed in Mariday Park, Port Arthur. They

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[1] W. M. Courtis, "The Animikie Rocks and Their Vein Phenomena as shown at Duncan Mine, Lake Superior," Amer. Inst. Min. Eng., *Transactions*, Vol. XV, 1886-87, pp. 671-76.

contain considerable chert and traces of volcanic shards and fragments. A similar coarsely crystalline limestone is exposed at the corner of Summit and John streets, Port Arthur, and just below the argillite on the Current River (photo, p. 9).

Farther northeast, about ¼ mile west of Blende Lake, very fine-grained tuffs, some displaying small-scale cross-bedding, are associated with argillite and beds of ferruginous carbonate. Less well characterized tuffs appear as thin layers with normal argillites in beds underlying the diabase east of Silver Harbour.

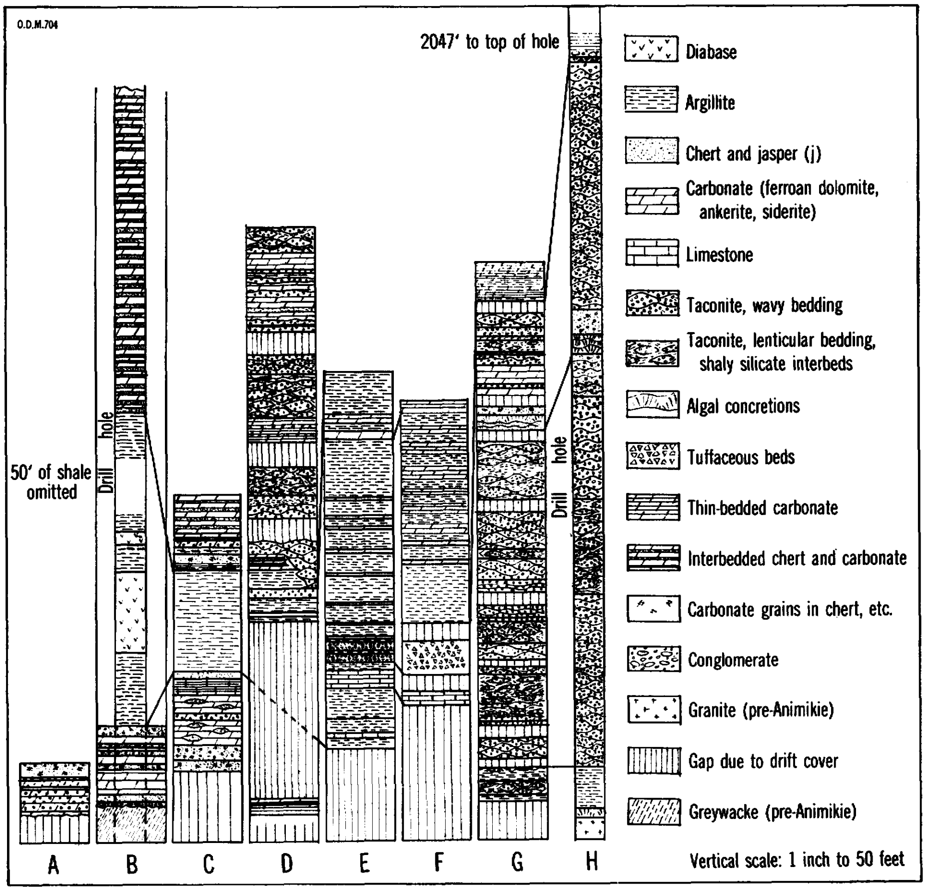

Figure 2—Columnar Sections from Selected Areas and Drill Holes

A—Roadcut south of Loon Lake, highway No. 17.
B—Outcrop east of Pass Lake Road, and log from nearby drill hole.
C—Lyon Boulevard bridge, Current River.
D—McIntyre River.
E—Kakabeka Falls section.
F—Kaministikwia River, south of Kakabeka Falls.
G—Pitch Creek section.
H—Part of drill hole at Mink Mountain (log from A. M. Goodwin).

Along the Current River, the argillites are fairly uniform, thinly laminated, and dark-grey in colour (Figure 3) with little variation, except at the upper transition to carbonate and chert of the Upper Gunflint.

The thickness of the tuff-argillite unit is extremely variable. In the eastern part of the area no exposures of more than 20 feet are to be seen. Drilling records[1]

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[1] M. A. Hanna Company.

suggest considerable variation in thickness, 28–105 feet in McTavish township. On the Current River, about a mile upstream from the Lyon Boulevard bridge, 30 feet of argillite is exposed, with chert and siderite both above and below. The most complete and thickest section of argillite exposed is at Kakabeka Falls. Here at least 100 feet of black argillite, with numerous interbeds of ferruginous carbonate, chert, and a tuffaceous zone, comprising several beds of tuff as described above, form the face of the falls. The cap rock of the falls is a massive bed of ferruginous carbonate about 2 feet thick. Downstream from the falls, a rapid change in facies appears to take place, for the upper half of the section becomes rich in carbonate, in the form of thin interbeds with the argillite (see Figure 2).

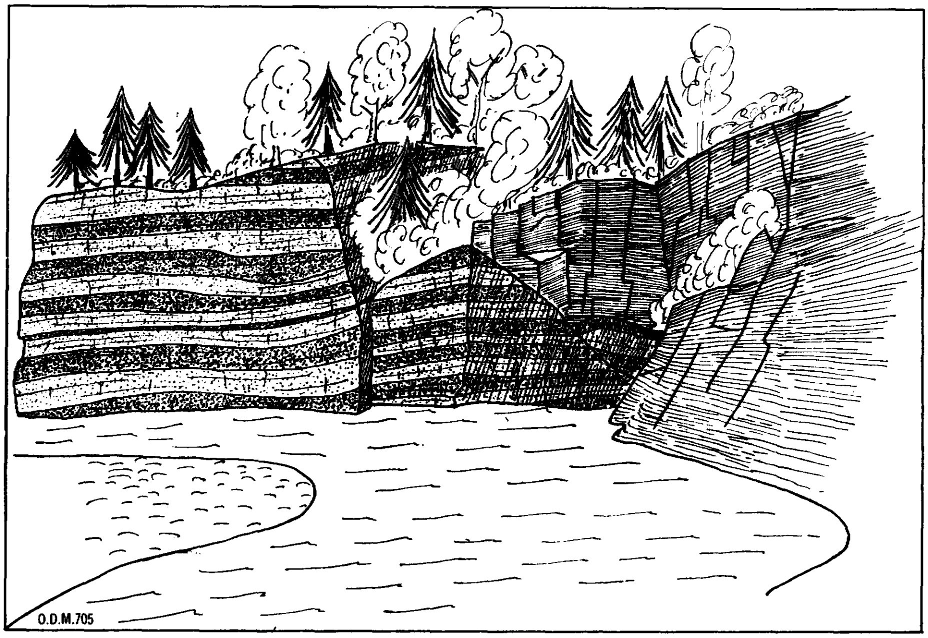

Figure 3—Sketch illustrating argillite and carbonate-chert iron formation in fault contact, Current River.

UPPER GUNFLINT

The Upper Gunflint is a very complex unit, with apparently extensive variations in facies. In the Loon Lake area, however, it is relatively simple, consisting of alternate beds of ferruginous carbonate and chert. The individual carbonate beds average about 1 inch in width and range from ⅛ to 5 inches. The chert beds average ¾ inch in width and range from ⅛ to 2½ inches. Beds of both chert and carbonate show subsidiary fine-scale laminations, and chert beds contain some admixture of carbonate, and vice versa. The principal exposures are found in the vicinity of Chert Lake, and on the Canadian National railway west of the Blende River bridge.

The next major exposure of the Upper Gunflint is along the Current River (see Figure 2, section C). Here again the predominant components are chert and carbonate, but the facies is evidently different from that of the thin-bedded, fissile chert and carbonate to the northeast. Cross-bedded, brecciated beds, and conglomeratic zones occur at several levels. A little greenalite occurs here and there, and stylolitic surfaces form the boundaries of a number of beds.

West of Port Arthur, the Upper Gunflint is well exposed in McIntyre River, Neebing River, and elsewhere, but no continuous section can be constructed owing to the interrupted nature of the outcrop and the presence of faults of unknown displacement. A composite section (Figure 2, section D), based on outcrops on McIntyre River, suggests that about the lower 30 feet is predominantly of thinly bedded chert and carbonate, with interbeds of taconite. Above this is 11 feet of lenticular taconite beds, with interbedded shaly layers. Above this is at least 30 feet of massive, flaggy, lenticular beds of taconite, with occasional shaly silicate interbeds. The irregular bedding shown by many of these outcrops is illustrated in Figures 5 and 6. The lenticular beds range from 1–2 inches to 1 foot in thickness, and from one to several feet in length. When examined in plan, it is found that the lenticular beds have an elongated form, in which the east-to-northeast trending dimension is several times the dimension at right angles. In effect these taconite beds are windrows or drifts of granules, and their elongation noted above probably corresponds with the trend of the shore line along which they accumulated. Cross-sections of these structures give the appearance of crude and irregular ripple marks. The term wavy bedding may be applied to this feature.

Folded thin-bedded chert-carbonate, railway cut, west of the Blende River bridge, C.N.R.

In the western part of the area, the Upper Gunflint is very thick, being 253 feet thick at Mink Mountain.[1] To the northeast, due in part to the truncation of the Gunflint by the Keweenawan sediments, and probably to an actual thinning of the section in this direction, the Upper Gunflint appears to be much thinner. The maximum thickness measured by the author is 130 feet. Smith[2] reports a thickness of 200–250 feet, and Van Hise and Leith[3] give 250–300 feet, but available drill information and detailed mapping do not substantiate these figures.

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[1] A. M. Goodwin, *op cit.*, p. 7, Table I.

[2] W. N. Smith, "Loon Lake Iron-bearing District," *Annual Report*, Ont. Bur. Mines, Vol. XIV, 1905, pt. 1, p. 258.

[3] C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior District*, U.S. Geol. Surv., Monograph No. 52, 1911, p. 206.

ROVE FORMATION

The Rove Formation consists predominantly of dark-coloured fissile argillites. Some calcareous beds occur, and in the vicinity of Pass Lake, varicoloured green and red shales appear.

An outstanding feature of the Rove is the presence of calcareous concretions up to 8 feet or more in diameter (see accompanying photo and Figure 4). A few are exposed in a roadcut on the Pass Lake road. Very many concretions are to be seen in cliffs of argillite along the Slate River. They were first referred to by Logan.[1] The concretions occur at definite horizons in these argillites, and the concretions of each appear to have a characteristic form. The concretions partly replace and preserve the bedding of the enclosing argillites, and partly displace and distort them. Generally the carbonate is fine-grained and dark in colour, but some carbonate is in coarse, flamboyant, dark crystals, and some layers, in a few concretions, are pure white crystalline carbonate. Pyritic cores are often

Concretion in quarry of Rove argillite, Pass Lake Road.

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[1] Sir William E. Logan, "Report on the Geology of Canada," *Report of Progress to 1863*, Geol. Surv. Can., 1863, p. 69.

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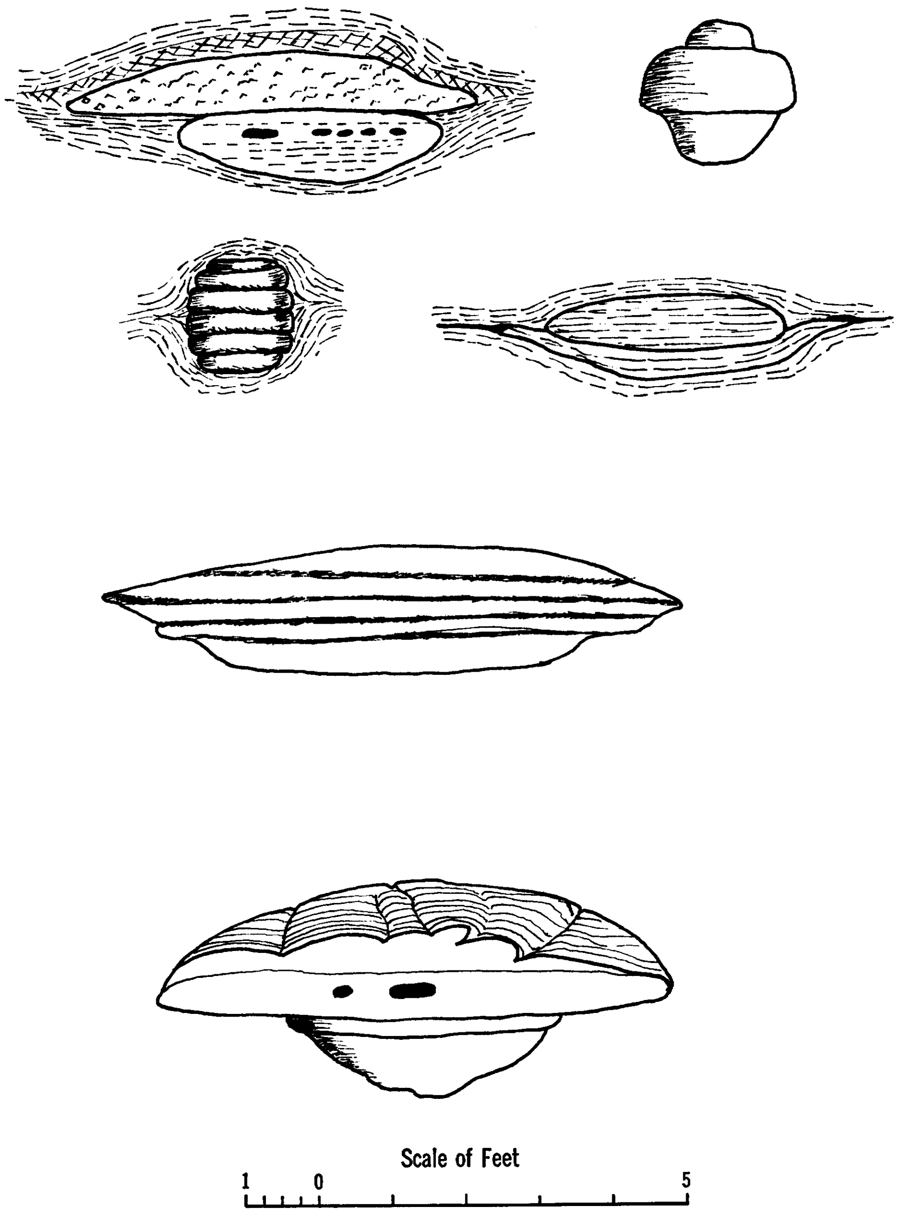

Figure 4—Sketch of various types of concretions, Rove argillite on Slate River.

present. Cone-in-cone structures may occur at the borders of the concretions, as described by Tanton[1] and Logan.[2]

The thickness of the Rove formation is reported to approach 3,000 feet in Minnesota.[3] Southwest of Fort William, Tanton estimates a thickness of 2,000 feet or more; in the vicinity of Pass Lake he finds only 130 feet.[4] To the north, the Rove thins owing to the unconformity that separates it from the overlying Sibley sediments. West of Loon Lake, the Sibley overlaps the Rove and the underlying Gunflint to lie on the Archean.

The Rove appears to be conformable with the underlying Gunflint formation. The marked reduction in thickness of the Gunflint to the northeast is thought to be a result of the thinning of the formation in this direction rather than due to an erosion surface below the Rove. No other evidence of unconformity was recognized.

Unconformity between the Rove and the Sibley

A pronounced and general angular unconformity does not appear between the Rove and the overlying Sibley formation. Locally, however, an angular discordance is apparent.[5] (See Figure 7.) Moreover, the greatly reduced thickness

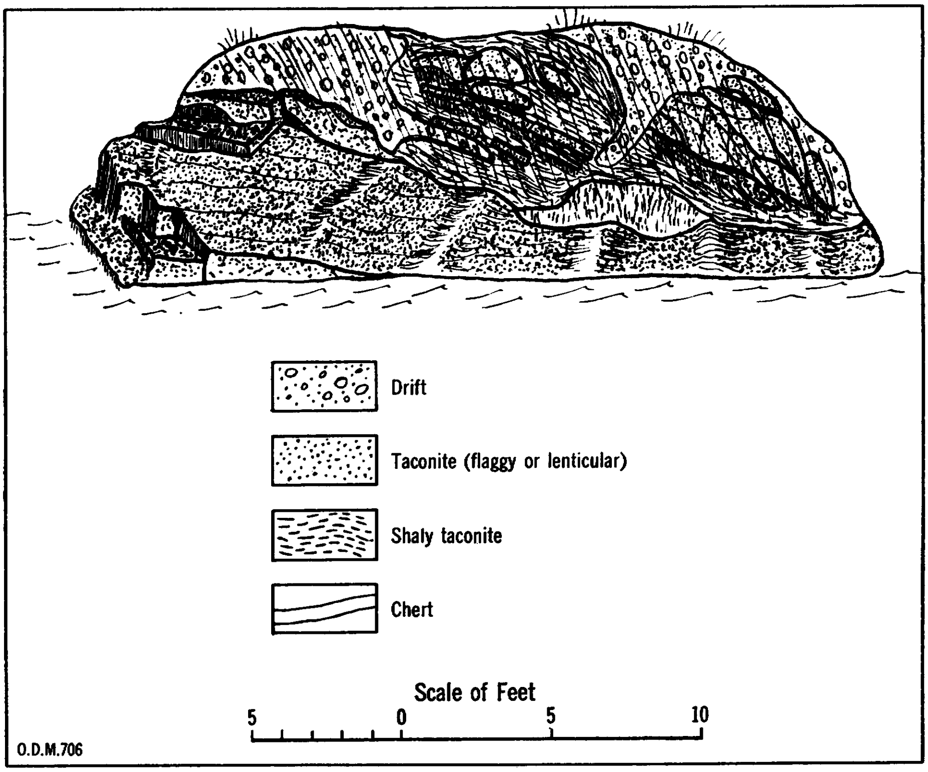

Figure 5 — Irregular, lenticular bedding in taconites, McIntyre River, showing elongated "windrows" of granules appearing in the outcrop.

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[1] T. L. Tanton, *Fort William and Port Arthur, and Thunder Cape Map-Areas, Thunder Bay District, Ontario*, Geol. Surv. Can., Memoir No. 167, 1931, p. 42.

[2] Sir William E. Logan, *op. cit.*, p. 68.

[3] F. F. Grout and G. M. Schwartz, Bulletin No. 24, Minnesota Geol. Surv., 1933, p. 16.

[4] T. L. Tanton, *op. cit.*, pp. 36, 37.

[5] L. P. Silver, "The Animikie Iron Range," *Annual Report*, Ont. Bur. Mines, Vol. XV, 1906, pt. 1, p. 169.

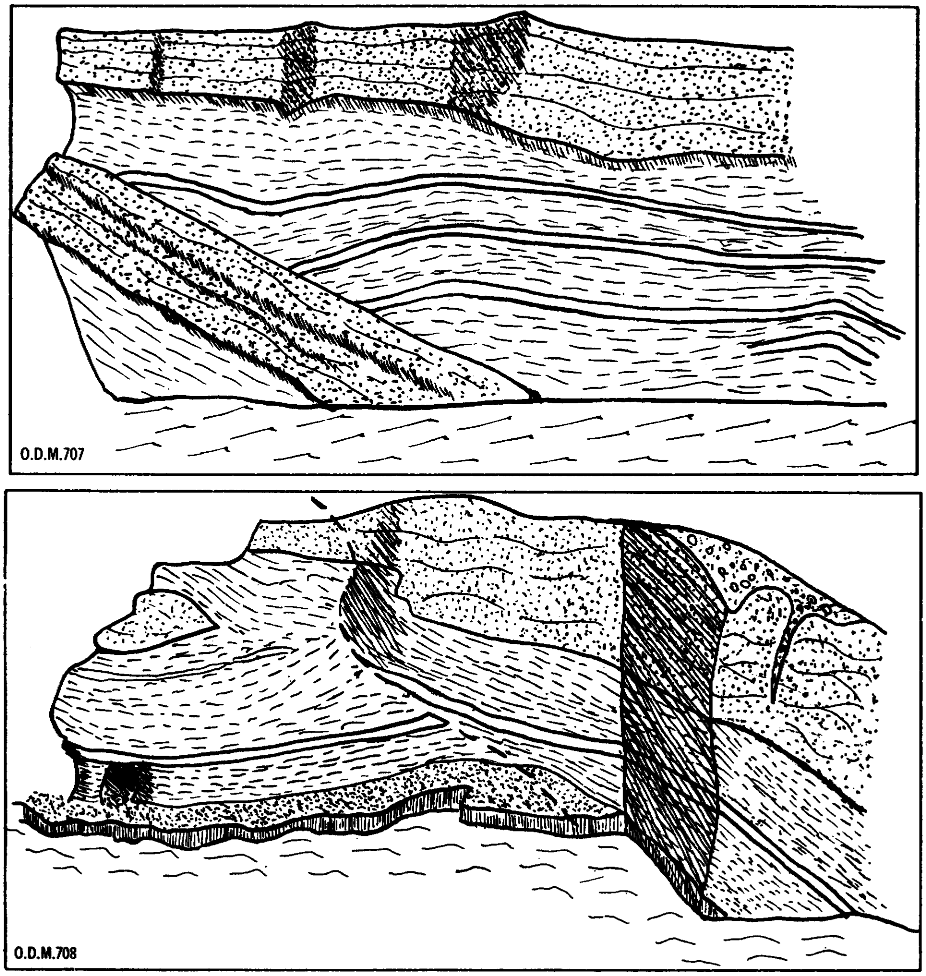

Figure 6—Irregular, lenticular bedding in taconites, McIntyre River.
(See Figure 5 for legend.)

of the Rove in the northeastern part of the area, and the progressive cutting out of the Rove and the Gunflint as the Sibley overlaps onto the Archean, suggest a prolonged period of erosion, with deposition of the Sibley on the resulting erosion surface. Since throughout Animikie and Keweenawan time, the Port Arthur area was a relatively stable one, the lack of an angular unconformity of regional extent is not in itself proof that there is no great interval between the Animikie and the Keweenawan.

Keweenawan

SEDIMENTS

Sibley Formation

Since the primary purpose of this report is to describe the Gunflint iron formation, the Sibley formation has been studied only along the cliffs forming the eastern boundary of the Animikie, between Pass and Loon lakes.

In this area, the basal unit of the Sibley is a conglomerate, which appears to be rather erratic and variable in its thickness; it reaches a maximum thickness of 36 feet, but pinches out in places. It contains interbeds of sandstone, some of which are red and ferruginous, and for part of its outcrop, encloses a band of creamy coloured limestone up to 6 feet thick.

The conglomerate is well exposed in a rock-cut on the Canadian Pacific railway, west of Loon Lake. (See accompanying photo.) The lower, western, exposures contain a predominance of iron formation boulders, while the upper, eastern, part contains a predominance of granite boulders. In the western part, a 5-foot-square area of the conglomerate was found to contain 12 boulders of granite, 43 of iron formation, 6 of vein quartz, and 1 each of pegmatite, chert syenite, greenstone, and quartzite. In the eastern part, a similar area contained 145 boulders of granite, 4 of iron formation, 3 of vein quartz, 7 of pegmatite, 2 of chert, 17 of greenstone, 2 of quartzite, and 1 of jasper. The matrix is predominantly carbonate, particularly in the eastern part of the cut. The largest boulders measured had major and minor dimensions of 18 inches and 10 inches when iron formation, 15 inches and 9 inches when granite. Boulders and pebbles of other rock types are much smaller. In all, 20 feet of conglomerate is exposed in this cut, of which the topmost 5 feet is mostly limestone.

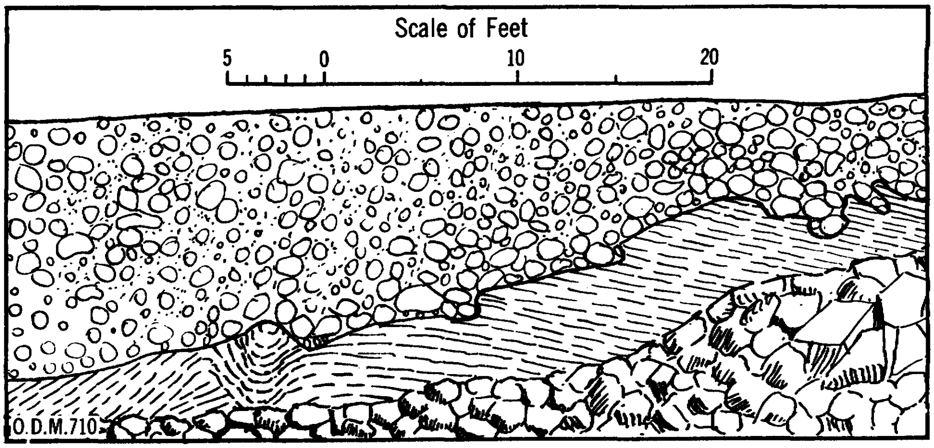

Figure 7—Sketch showing unconformity between Rove argillite and Sibley conglomerate.

In some places along the cliff, north of Pass Lake, the conglomerate is represented by coarse, thin-bedded, red and white sandstones, sometimes with scattered pebbles.

The conglomerate is overlain by a section of rather loosely consolidated white to yellowish sandstone. Some sections show fairly thick beds, 3 feet or so, at the bottom of the layer, becoming thinner bedded towards the top. Even the thicker beds show traces of thin lamination within them. Some outcrops show vague ripple marks and cross-bedding, but in general the bedding is the most prominent feature of this unit. A thickness of as much as 51½ feet has been measured in the cliffs north of Pass Lake. Thin quartz stringers, filling joints, are a noticeable feature of the outcrop of this sandstone, because owing to their superior resistance to weathering, they stand out above the surface of the sandstone that they cut.

This sandstone, which is Unit B of Tanton's subdivision of the Sibley, is overlain by a second sandstone, reported to be 40 feet thick by Tanton and called by him Unit C. In the area examined in the present survey, the two sandstones are similar if not identical, and no attempt was made to separate them on the map.

Unit D of Tanton, overlying the preceding formations, is composed of limestone and chert. It was encountered only west of Silvern Lake, where it was about 10 feet thick. Tanton reports a maximum thickness of 3 feet on Thunder Cape and the Sibley Peninsula.

Between Iron Lake and Silvern Lake, and south and east of Pass Lake, the succeeding Unit E is represented by brick-red, massive carbonate rocks and deep-red shaly material. In thin section the carbonate rocks are found to be of unusual character, for clastic sand grains of quartz and feldspar are enclosed in a fine-grained, iron-stained carbonate. The only structure visible in the outcrop, apart from the bedding indicated by shaly layers, is the presence of pale-greenish to yellowish spots in the otherwise red rocks. Many of these blotches enclose a black spot or grain about the size of a pinhead. It is thought that this black spot is organic matter, and that the ferric iron typical of this formation has in its vicinity been reduced to the ferrous condition, resulting in the change in colour. The more shaly phases of the unit appear to be very rich in iron. Large hills of the massive red carbonate rocks and shaly material are visible south of highway No. 17, between Loon Lake and Nipigon.

Sibley conglomerate, carbonate matrix.

The top unit of the Sibley, Unit F, and the overlying Osler series of sediments and volcanics were not encountered in the area mapped and have not been examined. They are briefly described in Tanton's report.[1]

INTRUSIVES

Logan Sills and Diabase Dikes

The Logan sills of diabase are the most important structural units in the topography of the Thunder Bay region, forming as they do the cap rocks of the typical cuestas, buttes, and mesas that surround the Bay. (Photos, pp. 4 and 20.)

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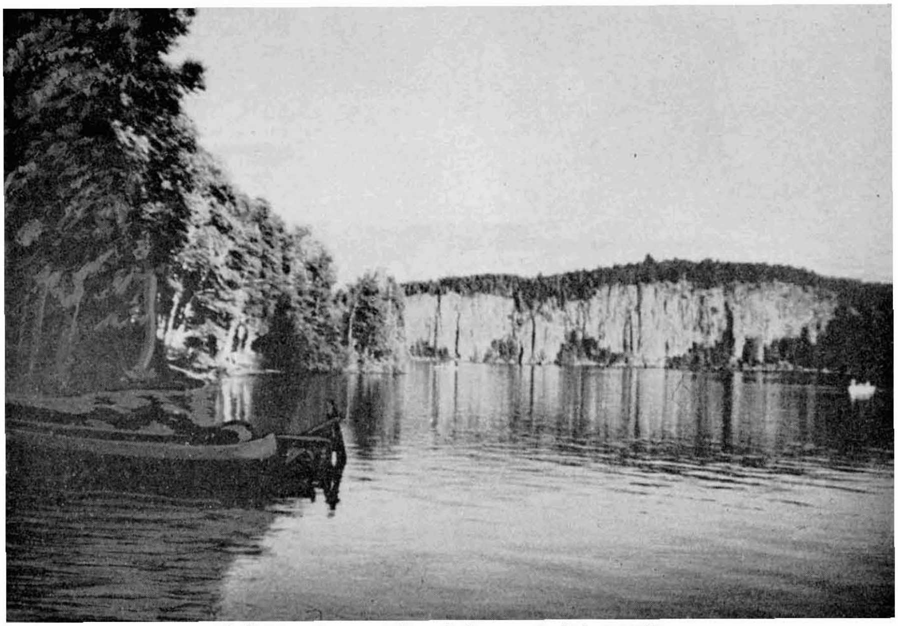
[1] T. L. Tanton, *op cit.*, pp. 55, 57–62.

In contrast to the sills in the Lake Nipigon region, which may reach thicknesses of 1,000 feet, the Logan sills are relatively thin. The greatest thickness recorded by Tanton is 200 feet, this being the thickness of the sill remnant capping Mount McKay and the adjacent eminences. Most of the sills whose thicknesses were measured in the area mapped, were considerably less than 100 feet. It is rarely possible to determine the full thickness, since the capping of most has been removed by erosion, and the bases of many are concealed by talus. Many sills are of course considerably thinner; for instance, a sill lower down on Mount McKay, which forms the floor of the lookout on the north face of the hill, is only 15 feet thick. It is impossible to state confidently the number of sills represented in the area, because of repetition by faulting.



Diabase outcrops, Oliver Lake, west of Fort William.

The term sill is actually inappropriate for these intrusions, since many of them cut across the Animikie at a low angle. Those along the coast northeast of Port Arthur are in many places in contact with pre-Animikie granite at the lake shore, but a short distance inland they have cut through the Lower Gunflint to insinuate themselves into the argillites overlying it. In fact, northeast of Port Arthur, the diabases occur very generally in the argillite-tuff unit. Since they cut across the formation in this way, these intrusions should be called sheets rather than sills.

The petrology of the diabase sheets has been described by R. G. Blackadar.[1] Except near their contacts, the diabases are olivine diabases, invariably with a small amount of quartz, which is mostly intergrown with alkali feldspar as micropegmatite. The diabase is considerably altered at its contacts with argillite, becoming enriched in biotite and hornblende.

Several variations in texture are found in the diabase. The most striking variations are visible on broad, gently sloping upper surfaces of the sheet north

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[1] R. G. Blackadar, "Differentiation and Assimilation in the Logan Sills, Lake Superior District, Ontario," *American Journal of Science*, Vol. 254, 1956, pp. 623–45.

of Navilus, just northeast of Port Arthur. The diabase is very light coloured and contains numerous crystals of feldspar together with grains of bluish milky quartz readily visible to the eye. In the vicinity of these grains, the diabase may have a lamprophyric aspect. This anorthositic phase of the diabase is apparently due to incorporation of granite material, in which the potash feldspar has become dissolved in the diabase, while the larger plagioclase and quartz grains have survived. The plagioclase is, however, fretted by the diabase and veined by fine-grained pyroxene. Many of the quartz xenocrysts are enclosed in rims of pyroxene. Lamprophyric phases of the diabase are also developed around a large inclusion of granite, 400 feet long, in diabase on Mary Island just west of Silver Harbour.

At several places along the shore northeast of Port Arthur, granite outcropping is coated with dense trap (chilled diabase), which contains fragments of granite up to a few inches in diameter.

In addition to the xenocrysts of feldspar and quartz mentioned above, there are local porphyritic phases in the diabase sheets. The best developed is found in an abandoned trap-rock quarry northwest of Navilus. Here are found greenish phenocrysts, some of which are several inches in diameter; epidotic blotches also occur in the upper part of the quarry face.

On Conmee Point and on the small island to the east, the upper contact of the diabase with shale has been marked by the development of a distinctive hybrid rock. Very white weathering, the rock is a siliceous, sodic granite, containing numerous black inclusions of argillite. Argillite overlying the granite is contorted and injected by the granite. Thin sections of the argillite inclusions show that it has been almost completely replaced by albite laths, the form and colour of the inclusions being due to fine-grained carbonaceous matter that still outlines the original bedding.

Diabase dikes are not common in the area mapped. Most of those observed are in the sandstone cliffs east of the Pass Lake road. Their relationship to the diabase sheets is not known, but there is no reason to think that they are different in age.

STRUCTURAL GEOLOGY

The dominant structural feature of the area is the gentle southerly dip of the Animikie and Sibley strata, and the associated diabase sheets. The dip varies considerably, about 0–12 degrees, and local reversals may be observed on the accompanying maps.

Localized folding is present, particularly in the banded chert-carbonate of the Upper Gunflint south of Blende Lake. These structures are very well exposed along the Canadian National railway west of the Blende River bridge. (See Figure 8, and photo on p. 13.) These thinly bedded formations have been thrown into small folds, which range in width from 100 to 300 feet or more. Some of the folds are recumbent. In several of the more highly deformed folds, the carbonate in the core of the fold has flowed, fragmenting the enclosed chert, so that a very distinctive chert-carbonate breccia has formed. The cause of these structures is not clear. In this occurrence, the folds overlie the diabase sill. Similar structures in other parts of the Gunflint range do not have this relationship. It seems possible that here the deformation may have resulted from the heat and movement of the underlying diabase. Gill and Goodwin have attributed it to slump of unconsolidated sediments due to volcanic disturbances. Their localized character proves that the folds can hardly have resulted from normal orogenic forces.

Faults

Faulting is widespread in the area. The faults recognized are, with one exception, steeply dipping faults of the normal type. They are marked by breccia and slickensides, and are commonly filled with vein material, consisting largely of quartz, amethyst, fluorite, barite, and carbonate, often well crystallized. Lean mineralization of galena and sphalerite is found in almost all of these veins, and silver has been mined from several of them. The most productive mine was on Silver Islet, which lies outside the map area. The faults are all younger than the consolidated rocks of the area, since they cut all rocks including the diabase sheets. Diabase dikes may occupy some of these faults, which must therefore be Precambrian in age. Most of the faults strike east-west to northeasterly. A number of faults have also been recognized with north-south to northwest strikes. Owing to the extensive drift cover, it is probable that faults are much more abundant than appears from the maps. Lawson[1] and others have suggested that the succession of north-facing cuestas and cliffs, typical of the Thunder Bay area and northern Minnesota, result from faulting. Since in the area mapped, some of these cuestas are evidently the result of erosion alone acting on gently dipping sediments and intrusive sheets of variable resistance, only those faults have been indicated that are marked by breccia zones, veins, and slickensides.

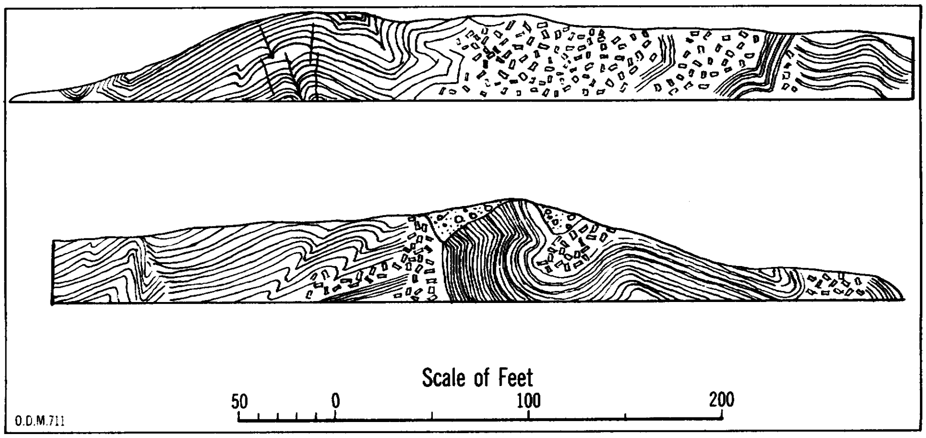

Figure 8—Sketch of folding in thin-bedded chert and carbonate; rock cut on Canadian National railway, west of Blende River bridge. Cores of folds made up of breccia or chert in carbonate. Top section, north side of cut, looking north; bottom section, south side of cut, looking south.

In general, the fault pattern in the area appears to be the result of vertical movements of small crustal blocks. This type of fracturing is probably attributable to the failure of the competent pre-Animikie crystalline complex resulting from the downwarping of the Lake Superior basin.

A major factor in the structure of the Animikie area in Ontario is the nature of the Lake Superior basin in this region. Martin[2] has shown that the northwest shore of the lake in Minnesota and its continuation across the mouths of Thunder Bay and Black Bay, and the off-shore islands opposite Nipigon, is a relatively steep scarp with a relief of 1,000–1,200 feet. He regards this as a fault-line scarp,

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[1] Lawson, *Bulletin*, Geol. and Nat. Hist. Surv., Minnesota, No. 8, 1893, p. 33.
Lawson, *Twentieth Annual Report*, Geol. and Nat. Hist. Surv., Minnesota, 1891, p. 192.

[2] C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior District*, U.S. Geol. Surv., Monograph No. 52, 1911, pp. 112–15.

that is, an ancient fault scarp resurrected by glacial erosion. This scarp is parallel to the main direction of faulting in the Port Arthur area. Apparently there have been relatively late movements along some of these faults; Gill[1] reports a fault displacement of a glaciated surface west of the present map area.

Measurement of displacements along the faults is usually difficult because of the lack of distinct marker horizons. Most of the faults appear to be minor; the largest movement observed was 40 feet, on a fault exposed in the face of the Sibley cliffs east of the Pass Lake road. Courtis'[2] cross-section of the Shuniah mine indicates a displacement on the fault, in which the vein is located, of nearly 120 feet. Gill[3] mentions a displacement of 300 feet on a fault in the North Lake area west of Whitefish Lake. Van Hise and Leith[4] report a displacement of 300 feet on the fault south of Loon Lake. It is probable that few faults in the area mapped have such large movements.

Only one unimportant flat-dipping fault has been recognized in the area; this cuts argillite on the west branch of the Current River near the north boundary of the map area.

GUNFLINT IRON FORMATION

The stratigraphy of the Gunflint formation has been outlined above. It is now proposed to discuss the mineralogy, textures, and sedimentary structures, chemistry, and economic geology of the Gunflint.

Mineralogy

A variety of minerals occur in the different phases of the Gunflint; variations in the proportions of these minerals, and in their textures, result in many mutually gradational rock types, the lithology of which can only be described in general terms. A considerable amount of mineralogical work has been done by B. A. Bradshaw[5] on specimens of the Gunflint collected by the author. Much of what is reported in this section comes from this source.

The minerals of the Gunflint may be classified briefly into silica minerals, oxides, carbonates, and silicates.

SILICA MINERALS

Quartz

Quartz occurs sparingly in the Gunflint as clastic sand grains. Of far greater importance is its occurrence as recrystallized chert. In many of the taconites, all gradations appear from extremely fine-grained chert to well-crystallized quartz. Most of the quartz occurs within the cores of granules, as mosaic aggregates, but in some taconites it develops extensively in the matrix of the granules. Quartz and amethyst are the most abundant constituents of the veins that occupy the late faults in the iron formation.

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[1] J. E. Gill, "Gunflint Iron-Bearing Formation, Ontario," *Summary Report*, Geol. Surv. Can., 1924, Part C, p. 51C.

[2] W. M. Courtis, "The Animikie Rocks and Their Vein Phenomena as shown at Duncan Mine, Lake Superior," Amer. Inst. Min. Eng., *Transactions*, Vol. XV, 1886–87, pp. 671-77.

[3] J. E. Gill, *op. cit.* p. 40C.

[4] C. R. Van Hise and C. K. Leith, *op. cit.* p. 208.

[5] B. A. Bradshaw, *Petrological Comparison of Lake Superior Iron Formations*, unpublished Ph.D. Thesis, University of Toronto, 1956.

Chert

Chert is the most characteristic silica mineral in the iron formation, and one of its most abundant constituents. It occurs: in distinct beds and lenses; as granules in taconites and carbonate beds; as patches, nodules, veins, and replacements in carbonate; as concretions or nodules and beds in argillites; and as algal structures. The grain size is extremely variable. In some taconites, the grain size is so minute that individual granules of chert stand out under crossed nicols because of their very low birefringence; in others, the chert shows all gradations in grain to quartz.

Jasper is chert that owes its colour to fine-grained disseminations of hematite. It is erratic in its distribution, but is often associated with algal beds. A deep-green chert or jasper is less common than the red variety but may be found locally west of Port Arthur.

Chalcedony

Chalcedony is closely related to chert and is found in some taconites as a matrix of the granules, and locally in vugs, veins, and colloform crusts. It is distinguished by its fibrous, flamboyant appearance under crossed nicols and its low index of refraction as compared with chert and quartz. It does not occur in large amounts in the Gunflint.

OXIDES

Magnetite

Magnetite is present in many specimens of taconite, mostly as tiny grains, often euhedral in form. In a few taconites, granules of magnetite, free from other minerals, occur, but generally the magnetite forms clusters in, or rims around, the granules. Magnetite is quite abundant in beds of iron formation immediately beneath diabase sheets, in some specimens being accompanied only by a little chert. Except in this relatively restricted situation, magnetite never attains the abundance that characterizes its occurrence in the Lower Cherty of the Mesabi Range. Some granules of magnetite are thought to be original constituents of the sediment, since they are found in association with granules of carbonate, chert, and hematite.

Hematite

Hematite is the most abundant oxide in the Gunflint. Many chert granules and silicate granules contain fringes, clusters, and grains of hematite. These may be in the form of fine dust, or in distinct blades, which often project beyond the borders of the granules. Some granules consist exclusively of hematite, and thin beds in the Lower Gunflint, for instance on the Current River at Hodder Avenue, on a small creek near Birch Beach, and on highway No. 17 south of Loon Lake, are made up exclusively of granules of hematite or of hematite and magnetite.

Some massive hematite is exposed in heavily mineralized zones in old workings north of Bittern Lake. Brilliant crimson carbonate, exposed just south of highway No. 17 near Loon Lake, owes its colour to very finely divided hematite. Similar hematite, widely dispersed in small amounts, is responsible for the colour of jasper.

Goethite and Limonite

Yellowish to reddish limonite crusts and coatings are common on weathered surfaces of the iron formation and occupy fractures. Carbonate-rich iron formation is particularly subject to this weathering effect.

Goethite crystals are also found locally as crusts on weathered iron formation and are frequently encountered as small grains and patches in thin sections of surface taconite specimens.

CARBONATES

The carbonates show a considerable variety in composition. Calcite is relatively uncommon, except in limestone beds within, and immediately below, the argillite-tuff unit of the Gunflint, and in the Rove argillite. Mention has been made of abundant calcite concretions in the Rove formation on the Slate River and elsewhere. Dolomite, ferroan dolomite, ankerite, and siderite are all found in the iron formation. These minerals are not readily distinguished in thin section, but index determinations by Bradshaw suggest that ferroan dolomite is the most abundant carbonate, and available analyses of carbonate iron formation support this conclusion. The carbonates occur in a variety of forms and relationships: (1) interbedded with chert in thin, finely laminated beds of fine-grained carbonate and cherty carbonate; (2) interbedded with argillaceous beds at Kakabeka Falls and in the Current River; (3) massive beds of fine- to medium-grained carbonate; (4) fragments in, and matrix of, intraformational breccias and conglomerates; (5) matrix of many taconites; (6) replacing chert granules; (7) as granules like chert, silicates, and oxides; in a few taconites they are the principal granules; (8) stringers of carbonate cutting many of the iron formation members.

SILICATES

Identification of the silicates in the iron formation is difficult because of the varied colour and habit of each species and the lack of diagnostic optical properties in the fine-grained granules. In many thin sections, the silicates are so fine-grained or so darkened by oxidation that they cannot be identified optically with certainty. Such occurrences can only be described as iron silicates, and any more precise terminology is quite unjustified without the application of more exact methods of identification.

Greenalite

Greenalite is regarded as one of the most typical constituents of the Animikie iron formations. It is a poorly characterized iron silicate, which occurs typically in the form of granules and is described by Gruner and others as optically isotropic. In all the thin sections of iron formation examined by the author, no definitely isotropic material could be found. All greenish minerals occurring as granules, patches, flakes, or layers, showed at least feeble interference colours. The presence of greenalite has been confirmed by Bradshaw with X-ray powder photographs. Without these it is impossible to obtain a reliable identification.

Many chert granules in the taconites are stained green or brown, either on the rims or throughout the granule. These stains have been attributed by most authors to submicroscopic greenalite, but there seems little justification for this assumption.

Stilpnomelane

The biotite-like mineral stilpnomelane was shown by Gruner to occur in the Mesabi range. It occurs fairly abundantly in the Gunflint taconites, but is somewhat erratic in its distribution. It varies from clear pleochroic flakes and rosettes to dense, brown aggregates in which the optical properties are difficult to observe.

Minnesotaite

This pale-green, iron-rich talc is also found in the taconites, as fibrous bundles and fine-grained aggregates. It is less abundant in the Gunflint than in similar taconites from the Mesabi range.

Chamosite

The mineral chamosite is reported from the Gunflint by Bradshaw from X-ray identification. It appears as bright blue-green granules and flakes in some of the carbonate-rich members of the Gunflint. Its abundance in the Gunflint is not yet known.

Chlorite

Chlorite flakes were observed in several specimens as alterations of stilpnomelane. Possibly many of the patches and granules of green, weakly birefringent material, which have been referred to as greenalite, are actually chlorite. Much more work is required before a reliable estimate of the abundance of chlorite in the iron formation can be made.

OTHER MINERALS

Pyrite is present locally in the iron formation, usually as small crystals and aggregates. In the argillites at the foot of Kakabeka Falls, it occurs in concretions up to one inch or more in diameter, and as rims on chert nodules.

Occasional grains of chalcopyrite may be seen in the taconites along Pitch Creek.

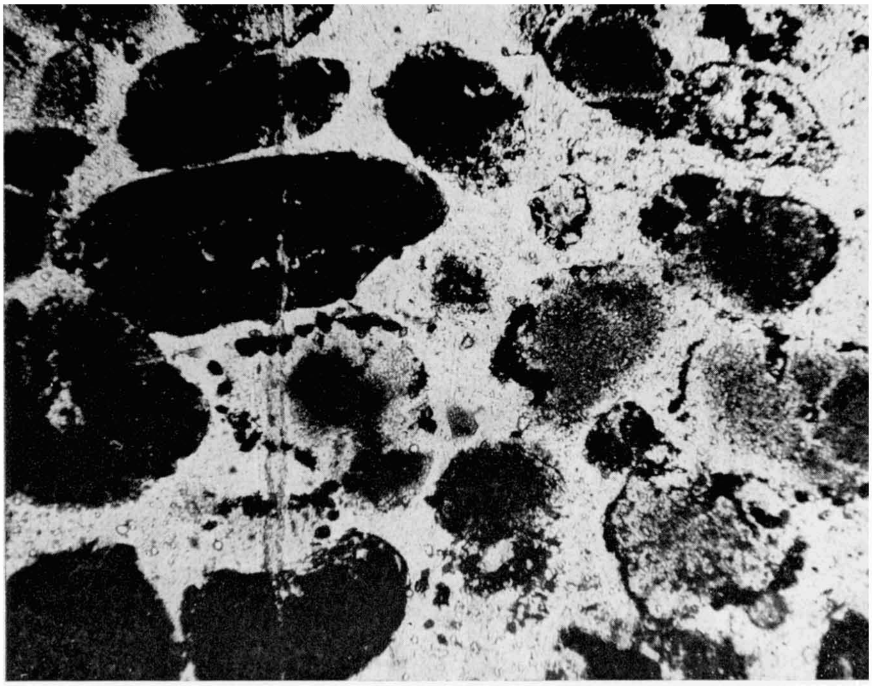
Tiny grains of what appears to be apatite are occasionally seen in the taconites.

Organic matter is present in many phases of the iron formation, but more particularly in well-bedded carbonate rocks and in the argillites. Brownish streaks and lenses in the carbonate are probably carbonaceous matter. Anthraxolite or a similar brittle hydrocarbon is associated with the algal concretions at Hillside, on the Whitefish River. Stylolitic surfaces, found in many outcrops at the contacts of cherty and carbonate-rich beds, are coated with carbonaceous material.

Texture and Sedimentary Structures

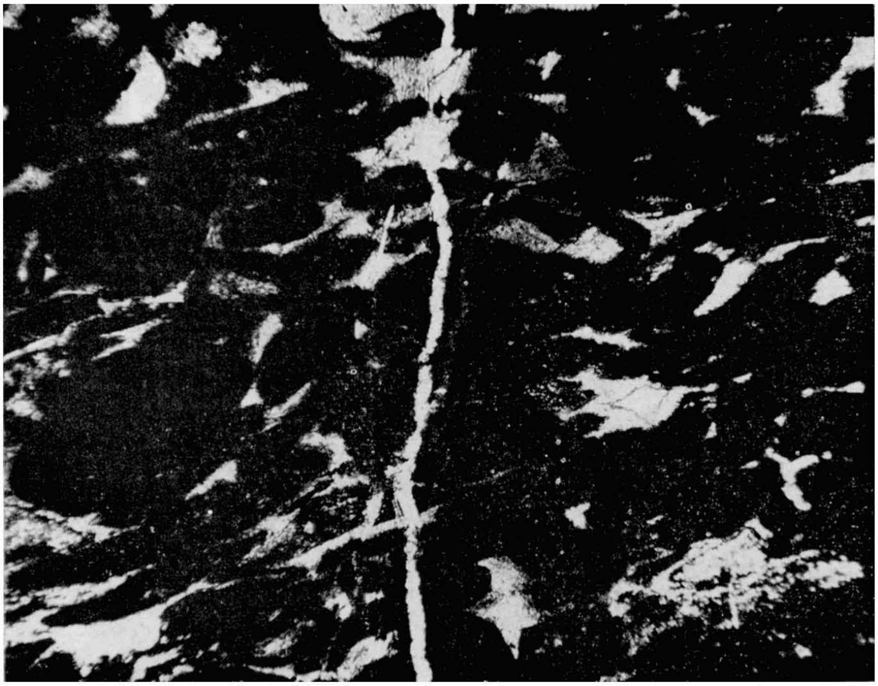
TACONITES

The taconites are characterized by their granule texture. The granules are fairly uniform in size, generally 0.5–1 millimetres in diameter. They are mostly oval or slightly flattened in shape and are sometimes described as oölites, but they lack the concentric pattern of the latter. They are composed of oxides, carbonate, chert, silicates, or various combinations of these minerals. (See accompanying photos.) Many of the chert granules are enclosed in a multiple border of greenish or brownish chert. Others have borders, cores, or patches of hematite or magnetite. The silicates also may make up entire granules or may occur as wisps and patches within chert or chert-oxide granules. Silicate, chert, and chert-silicate granules of the taconites on the McIntyre River, Neebing River, and Pitch Creek generally differ somewhat in their shape, being angular rather than rounded. (See photo, p. 29). In most sections of taconites, occasional composite granules or fragments are found enclosing several granules of normal size. Chert granules showing this feature sometimes enclose the smaller ones within single or multiple coloured rims such as are shown by those of normal size.

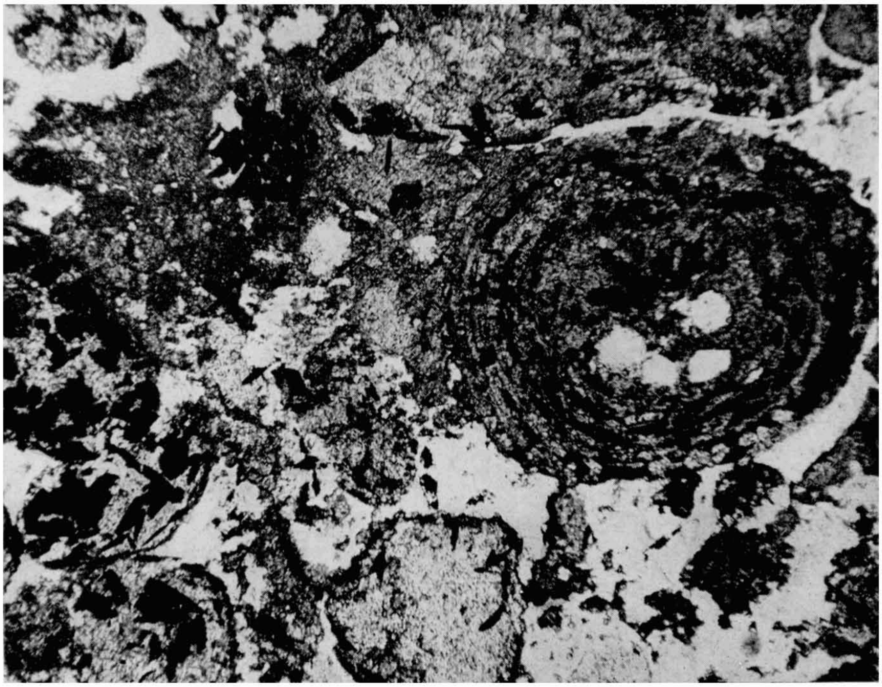


Taconite with granules of iron oxide (opaque) and chert (indicated by iron oxide dust). Plane light.

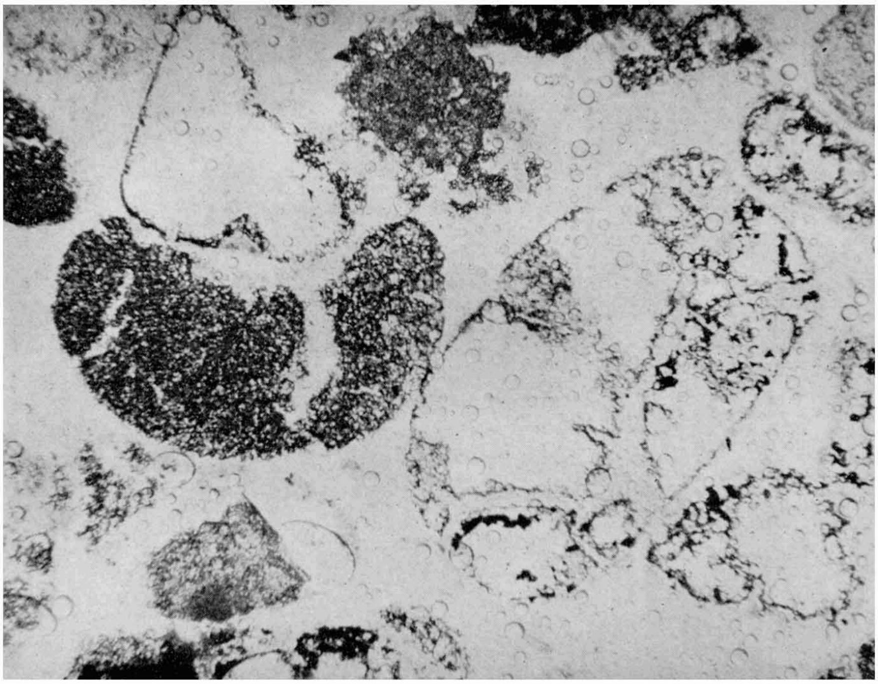
Taconite showing hematite granules and chert granules with blades of hematite. Plane light.



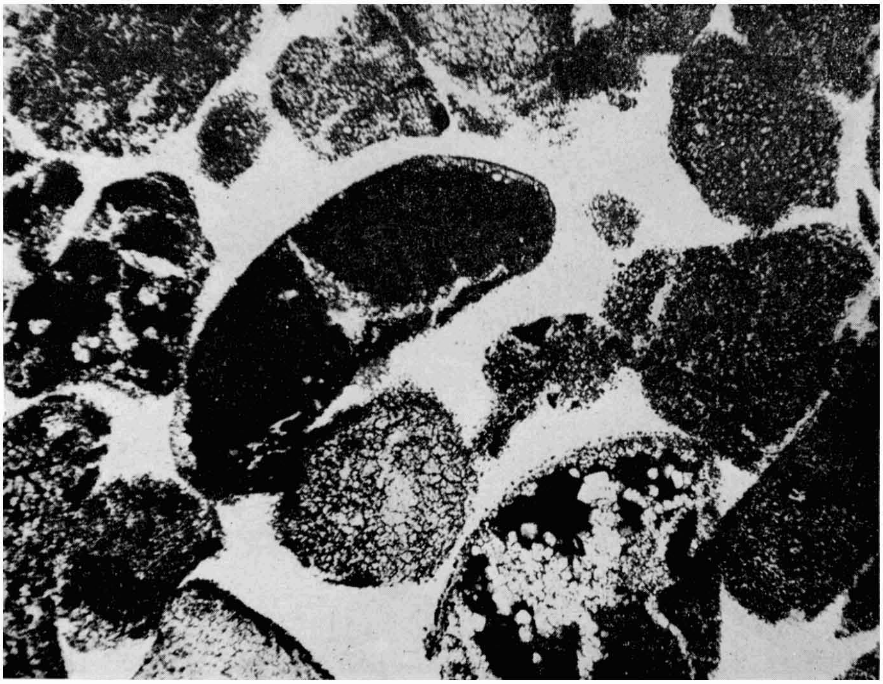
Hematite granules, showing flattened character, enclosed in chert. Plane light.



Oölite of chert and hematite with granules of chert and hematite. Plane light.

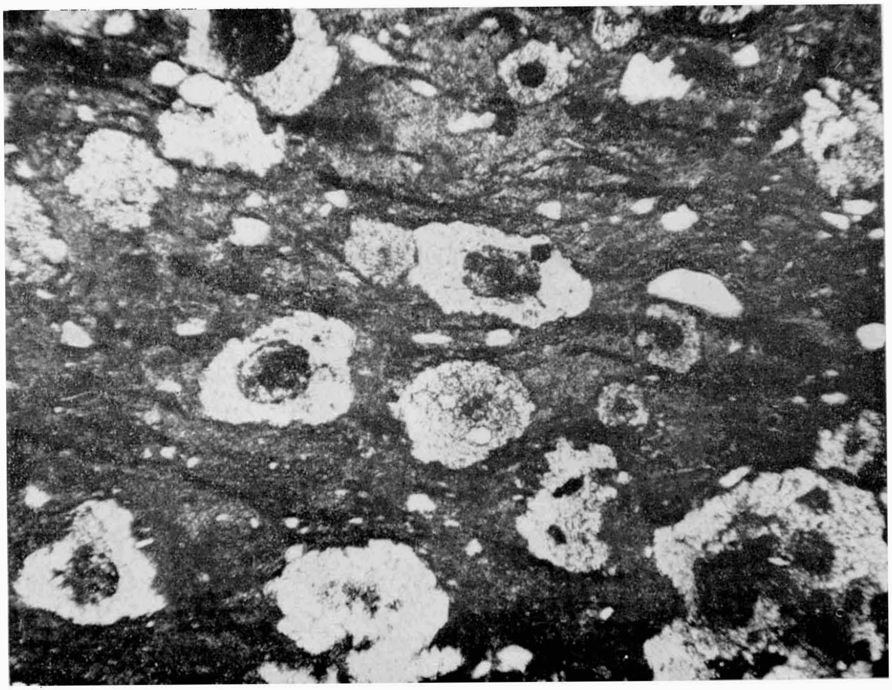


Granules of carbonate (dark) veined with chert, and granules of chert, replacing carbonate, and retaining traces of veins, which cut carbonate, before replacement by chert. Plane light.

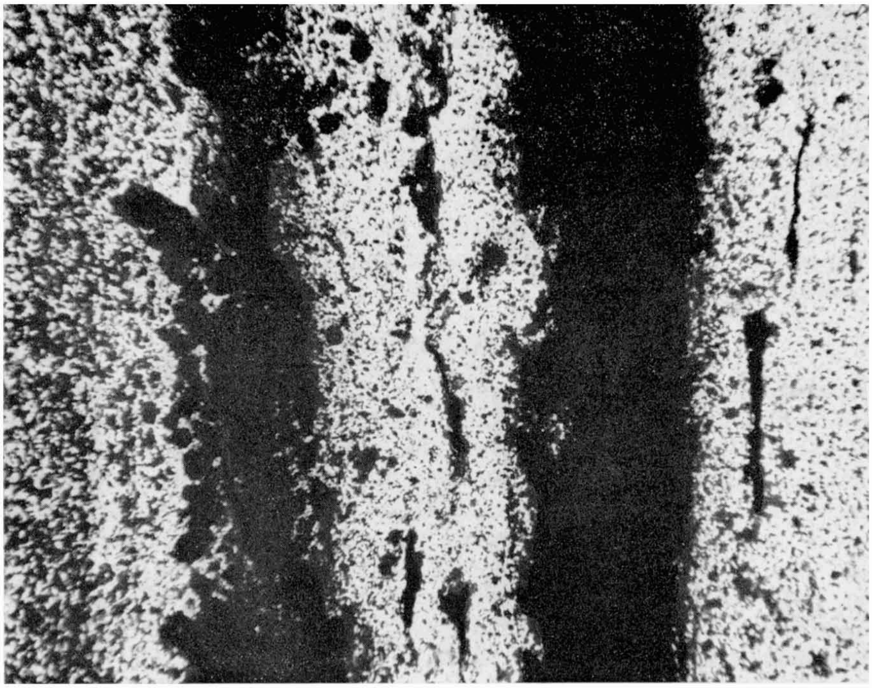


Taconite showing granules of iron silicate, silicate and chert, and chert, in a matrix of recrystallized chert. Plane light.

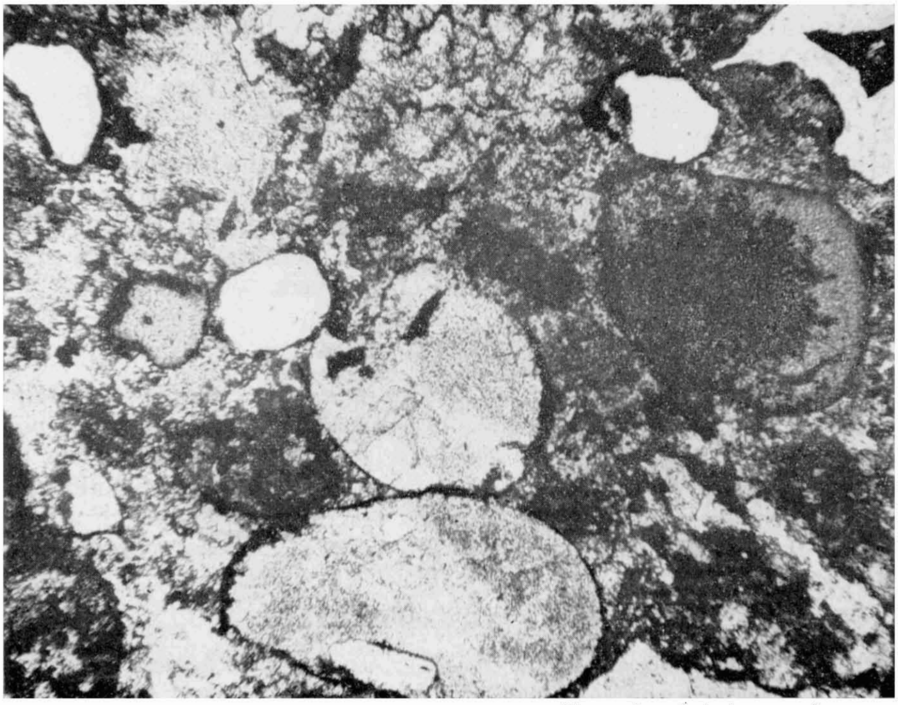
Taconite with angular, shard-like fragments. Plane light.



Shaly iron silicate with spherulitic carbonate grains from layer between taconite lenses.. Plane light.



Thin bedded chert-carbonate; opaque bands are oxidized carbonate. Spots in chert are cores of spherulitic structures. Plane light.



Intraformational conglomerate, Upper Gunflint, Current River. Rounded dusty grains are carbonate. Clear grains and patches are quartz (some clastic). Dark to opaque grain may be volcanic. Matrix largely carbonate. Plane light.

No general paragenetic relationship can be given for the minerals in the granules. Chert is frequently found to replace carbonate (see photo p. 29), but carbonate crystals are often found encroaching on chert granules. Hematite occurs in chert granules in relationships that suggest that it has recrystallized, often forming quite large plates, but it is questionable if this indicates a replacement of the chert by the iron mineral. It probably involves only redistribution. Similar relationships are shown by magnetite.

Thin shaly layers between lenses of taconite and wavy-bedded taconites are composed of silicates and fine-grained carbonate, or spherulites of carbonate. (See photo p. 30.)

THIN-BEDDED CARBONATE AND CHERT

Successions of alternate thin beds of chert and carbonate are typical of the Upper Gunflint south of Loon Lake and of other areas such as the Current River and Kakabeka Falls. Locally they are also components of the Lower Gunflint, for instance, east of Hodder Avenue and in McIntyre township. Both carbonate and chert beds are very fine-grained, although in some samples, coarse euhedral crystals of carbonate fringe and replace the chert layers. Chert layers usually contain some carbonate, and carbonate layers contain some chert. In thin section, both chert and carbonate beds contain tiny spherical bodies, which contain a brownish core, possibly an organic stain. These bodies have a characteristic radiating appearance. (See photo, p. 31.)

Typically, the only structure of this facies is its thin lamination and regular bedding. In a few exposures, the carbonate has flowed and recrystallized, brecciating and enclosing angular fragments of chert. Rarely, as for instance south of Kakabeka Falls, chert occurs in lenticular pinching and swelling beds, around which the carbonate shows evidence of differential compaction, suggesting that the chert is a primary deposit.

MASSIVE CARBONATE BEDS

Carbonate beds a few inches to about one foot thick are found in many Lower Gunflint sections. Some are fairly massive fine-grained carbonate; others are coarser and composed of euhedral grains, with a matrix of chert, organic matter, oxides, etc. The tops of some carbonate beds are marked by stylolitic seams separating them from the overlying chert layers.

FRAGMENTAL BEDS

Fragmental beds occur in many Gunflint outcrops. (See photo, p. 31.) The fragments include carbonate, chert, argillaceous material, granules, and possibly volcanic rocks. Cross-bedding is visible in some clastic beds. They clearly indicate an environment of active, even violent, current or wave action. These are readily distinguished from the breccias described above, which are due to flow of the carbonate, since they contain fragments of carbonate, argillite, etc., as well as chert.

CHERT AND JASPER BEDS

Although most beds of chert and jasper, apart from the chert layers in the thin-bedded chert-carbonate facies, are lenticular taconites, there are a few persistent beds of uniform thickness, up to 1–1½ feet, such as on the Neebing River north of Arthur Street.

Metamorphism of the Gunflint Iron Formation

In general, the iron formation has been subjected to relatively mild metamorphism, as indicated by the fine grain of chert, carbonate, and iron silicates and by the preservation of chalcedony, hydrocarbon residues such as anthraxolite, and the many delicate structures described and illustrated in this report. Some typical silicates, such as minnesotaite and stilpnomelane, are regarded by most investigators as metamorphic, although some believe them to be primary or diagenetic constituents of the original sediment.

Where the iron formations are cut by diabase sheets, there has been variable recrystallization, and some new minerals have formed. At some contacts of the iron formation, metamorphism has involved little more than recrystallization of carbonate, chlorite, etc., with loss of original textures. A specimen from beneath the diabase on Green Point contains diopside, phlogopite, and tremolite, in addition to carbonate, chlorite, and apatite. A sample of iron formation underlying diabase near the east boundary of Marks township is made up of fibrous amphibole, epidote, chlorite, stilpnomelane, quartz, and magnetite. In general, the iron formation underlying the diabase appears to be enriched in magnetite, particularly west of Kakabeka Falls.

Argillites underlying diabase have been recrystallized, with the formation of biotite. In carbonate layers in the argillite, diopside, amphibole, and in places small grains of garnet have been formed. Quartz and carbonate form streaks and stringers in the metamorphosed phases. Mention has already been made of albitized argillites locally produced at the upper contact of the diabase.

Sedimentary Facies in the Gunflint

Reference has been made to variations in lithology of the Gunflint iron formation, indicating varying conditions of deposition, that is, facies variations. (Figure 9.) In a few places, gradations from one facies to another can be observed in the outcrop. Most such changes, however, can only be inferred from variations in what are presumed to be beds of similar age in separate outcrop areas. A fuller treatment of the facies of the Gunflint than is possible here is given by Goodwin.[1]

BASAL CONGLOMERATE FACIES

This facies developed during the initial advance of the sea over the peneplaned and weathered surface of pre-Animikie formations. Weathered material was removed, and resistant quartz and iron-formation pebbles accumulated, mixed with quartz sand or chlorites and clays, which sifted down between them.

ALGAL REEF FACIES

Although widespread in occurrence, this facies is not quantitatively important. It occurs at the base of the Gunflint, or near it, and also at the base of the Upper Gunflint,[2] in the western part of the range. Presumably these structures accumulated where the water was relatively free from sediment, well-oxygenated, and active.

TACONITE FACIES

The silicate-chert taconites are the most typical of this facies. The predominance of ferrous silicate suggests reducing conditions. Wavy, lenticular bedding, composite granules, and similar features suggest active currents and

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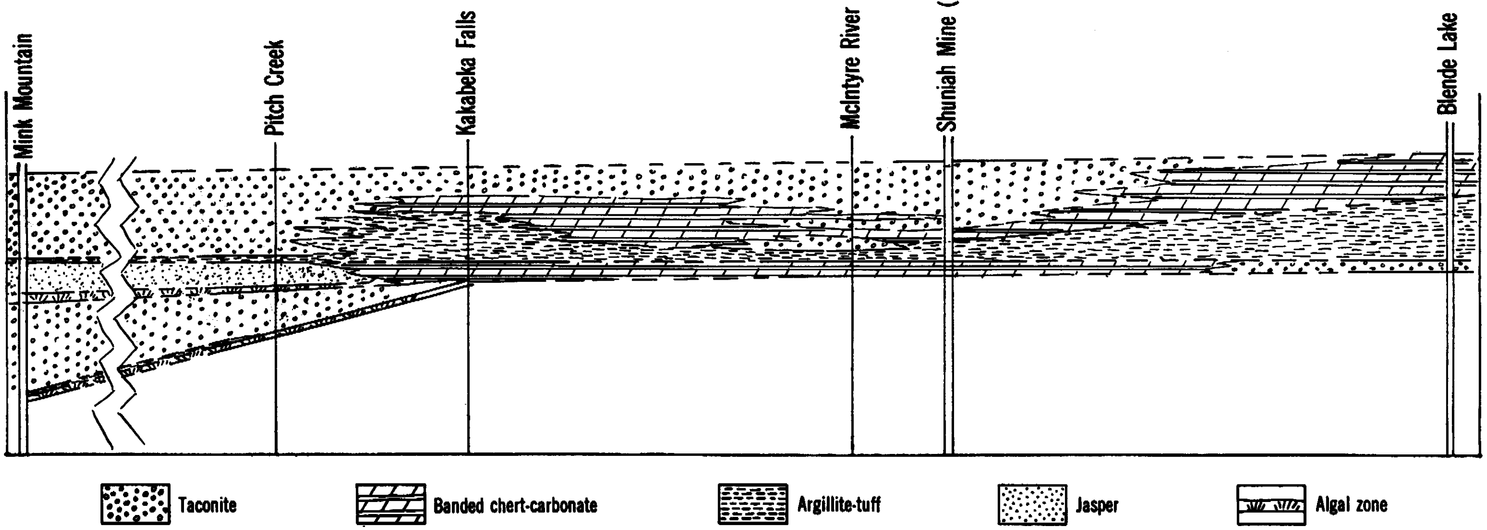
[1] A. M. Goodwin, "Facies Relations in the Gunflint Iron Formation," *Economic Geology'* Vol. 51, No. 6, 1956, pp. 565–95.

[2] A. M. Goodwin, *Stratigraphy of the Gunflint Iron-bearing Formation*, Ph.D. Thesis, University of Wisconsin, 1953, p. 7.

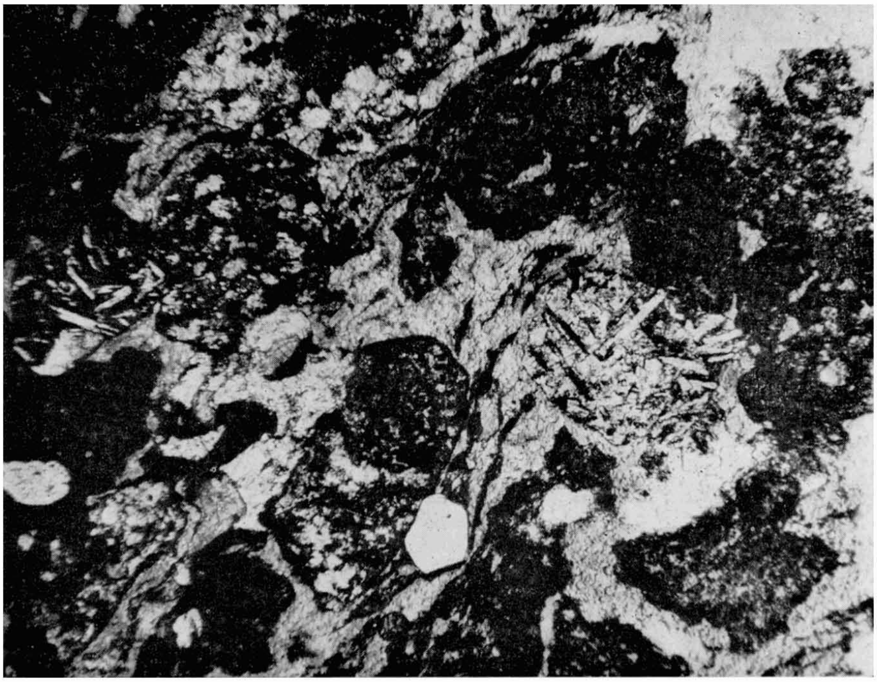
O.D.M.712



Horizontal scale: 1 inch to 8 miles
Vertical scale: 1 inch to 400 feet

Figure 9—Cross-section showing the distribution of the principal facies, from Mink Mountain to Blende Lake.

wave action. The reducing conditions must therefore have resulted from an abundance of organic matter, although little trace of it is evident in outcrops of this rock. Deposition is presumed to have been in the form of colloidal gels of iron silicate and chert, either by inorganic or organic processes; these gels shrank, cracked, and were broken up and transported in varying degrees by current or wave action. Carbonate may have been precipitated with this material, under similar conditions. Magnetite probably formed under less strongly reducing conditions, and hematite under strongly oxidizing conditions. Current action probably resulted in some admixture of granules from varying local environments, so that minerals such as hematite and iron silicate may occur in the same taconite lens.



Volcanic fragments in a carbonate matrix; basalt fragments and opaque vesicular fragments. Plane light.

CARBONATE FACIES

Siderite, ferroan dolomite, and other carbonates are widely disseminated throughout the Gunflint, and locally make up considerable thicknesses of the formation. They are usually interbedded with cherts. Locally, as in the Current River, they have undergone reworking to form breccias and conglomerates.

The principal carbonate sections represent tracts of the basin of deposition that were, at least for a time, free from clastic sediments and ferruginous and siliceous colloids. Organic matter is present in only some of the carbonate beds.

CHERT-CARBONATE FACIES

This facies is best developed south of Loon Lake. The uniform thin bedding and small-scale lamination are indicative of the quiet conditions to be expected in deep, sheltered waters. The rhythmic alternation of chert and iron carbonate apparently results from recurrent variations in the rate of deposition of one or both constituents, rather than alternating deposition, since there is usually some chert in the carbonate bands and some carbonate in the chert bands. Clastic material is typically absent, but at Kakabeka Falls, transitions from this facies to argillaceous rocks are evident.

ARGILLITE-TUFF FACIES

The argillite-tuff facies represents a spread of argillaceous material throughout the entire Gunflint Range. In the east, tuffaceous, calcareous, and argillaceous layers are all represented. Except for a few tuff layers at Kakabeka Falls (see photo, page 35) and some limestone beds, bedding is thin and slaty. Organic matter is locally abundant, for instance in the section at Kakabeka Falls. The incursion of argillite throughout the Gunflint, coinciding with tuffaceous contributions, probably represents rejuvenation of stream erosion connected with volcanism and is a precursor of the much more extensive and thicker Rove formation. To the west of Kakabeka Falls, the unit decreases rapidly in thickness, being largely replaced by slaty carbonates and taconites.

Chemical Composition

Complete chemical analyses are not available for the Gunflint iron formation or for individual phases of the iron formation. Iron assays are given in the next section of this report. Many spectrographic analyses have been carried out by Bradshaw[1] on carbonates, cherts, taconites, and argillites of the Gunflint. The elements determined included B, Cr, Co, Ni, V, and Rb. Only in the argillaceous rocks were these elements present in quantities sufficient to be measurable. Some of these results are listed in the accompanying table.

AVERAGE TRACE-ELEMENT CONTENT DETERMINATIONS

Element	Mean	Standard Deviation
	parts per million	parts per million
Animikie argillites:		
Cr	147	135
Co	12	14
Ni	15	13
V	205	146
B	39	42
Rb	147	203
Animikie cherty iron formation:		
V	63	63

Most other elements studied in the iron formations, except in the argillites, occur too erratically to be averaged.

Assays of Gunflint Iron Formation

Several assays of diamond-drill cores obtained from drilling done by M. A. Hanna Company, south of Loon Lake in 1923, were kindly made available by the company. Five-foot sections of the Lower Gunflint ranged from 3.56 to 17.95 percent Fe, and from 36.4 to 53.1 percent SiO_2. The thin-bedded chert-carbonate rocks ranged from 5.32 to 16.68 percent Fe, and from 31.90 to 49.6 percent SiO_2; CaO ranged from 11.52 to 21.60 percent, and MgO from 3.29 to 3.92 percent.

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[1] B. A. Bradshaw, *Petrological Comparison of Lake Superior Iron Formations,* unpublished Ph.D. Thesis, University of Toronto, 1956.

Chip samples were taken by the author at a number of localities, to obtain some idea of the over-all grade of different parts of the Gunflint. In a railway cut in the Upper Gunflint, west of the Blende River bridge, 15 feet of chert and ferruginous carbonate, measured normal to the bedding, yielded 21.47 percent Fe, 0.37 percent S, 0.96 percent P_2O_5, and only a trace of Ti. A sample, 11.5 feet long, above the preceding sample, averaged 20.43 percent Fe, 0.29 percent S, 0.89 percent P_2O_5, and a trace of Ti. Similar material from Deception Lake is reported by Bartley to have given 16.56 percent Fe and 39.25 percent SiO_2. A chip sample, taken by the author, from an outcrop of the Lower Gunflint on the north side of highway No. 17, 30 chains northeast of the Loon Lake road, gave, over a vertical distance of 16 feet, 15.75 percent Fe, 0.37 percent P_2O_5, and a trace of Ti. From a zone of carbonate underlying diabase, on the east side of the small lake south of Chert Lake, the author took two chip samples; one, over 4 feet 2 inches, gave 3.94 percent Fe, and the other, 8 feet below, over 3 feet, gave 4.97 percent Fe.

Chip samples were taken by A. M. Goodwin of the metamorphosed iron formation underlying the diabase caps of the three hills north of Pitch Creek and near the east border of Marks township. Assays were as follows:

	Fe percent
South hill	31.62
Centre hill	30.18
North hill	28.73

These samples were taken over a few feet of iron formation immediately underlying the diabase.

Apart from those supplied by M. A. Hanna Company, the assays quoted were made by the Provincial Assay Office, Ontario Department of Mines.

Concentration of Iron in the Gunflint Iron Formation

No extensive zones of direct-shipping iron ore, comparable with those of the Mesabi range in Minnesota, have been discovered in the area mapped. Some zones of apparently enriched iron formation do occur, but all appear to be small in extent. Considerable work was done over half a century ago. Smith[1] has reported on the results of this work as follows:

> The concentration appears to have been determined by two main types of structural conditions:
>
> (1) In the one case, the lower iron-bearing horizon is found lying on the south slopes of the graywacke-granite hills, with a comparatively uniform flat dip to the south. During the deformation which the series has undergone, sufficient movement occurred, both across and along the beds, to fracture and open them up, and thus produce conditions favorable for groundwater circulation.
>
> The areas illustrating this type of structure include that portion of the Animikie area lying north and south of the Canadian Pacific railway, and west from Bittern Lake about two miles, and the area south of Loon Lake and west of Deception Lake. In the latter area the iron formation is exposed practically at the surface, there being but from one to ten feet of overlying drift. In the former, the lower horizon is generally capped by 10 to 35 feet of diabase. As the thickness of the lower horizon in this district is not great (50 to 60 feet), the question of commercial bodies of ore depends largely on the horizontal element. In both areas exploratory work has been done by test-pitting and diamond drilling. The result of the work thus far done shows that over the greater part of these areas the lower iron horizon has been extensively altered to iron oxide, but that associated with the layers showing the greatest concentration a considerable amount of lean silicious material is present, either as lenses in the hematite or as layers interbedded with it. Thus the average sample of any considerable vertical section is low grade.

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[1] W. N. Smith, "Loon Lake Iron-Bearing District," *Annual Report*, Ont. Bur. Mines, Vol. XIV, 1905, pt. 1, pp. 259, 260.

Analyses of samples taken every three inches from four exposures representing vertical distances of six to eight feet each are given below. These are from the natural exposures which showed the greatest observed concentration, and include both the hematite and associated silicious material.

Fe	P	S	SiO_2
percent	percent	percent	percent
45.81	0.020	0.024	31.91
45.22	0.017	0.028	33.13
30.76	0.160	0.058	35.06
30.21	0.256	0.036	37.11

(2) The second structural condition which determined concentration is that of severe local deformation. This is mainly shown at or near the fault planes, where the movements have produced closely folded and brecciated rock masses. Here the conditions were again favorable for the circulation and work of ground water.

This phase of deformation is best illustrated in the Animikie area lying along the fault plane north of Deception lake and extending eastward to Silver lake, the area east of Deception lake, and that portion of the Animikie area located south and east of Bittern lake. On the above properties at various places both the upper and lower horizons of the iron formation are exposed. In these areas diamond drill holes have been put down, but the main work has been by test-pitting and driving short drifts into the iron formation on the hill sides. As in the previous case, the iron formation is found to be largely altered to iron oxide, but here also the layers showing the maximum concentration are frequently interbanded with lean material, or in the more brecciated phases contain masses of chert irregularly through the ore.

Silver[1] has also reported assays, by A. G. Burrows, from the areas described by Smith, but he does not report the nature of the samples, whether grab, character, chip, or channel samples:

	Fe	S	P
	percent	percent	percent
Tunnel E of Deception Lake	31.03	0.09	0.167
Stripping east of Deception Lake	31.91	0.06	0.321
Wiley's Pit No. 2 [near Beck siding ?]	35.11	0.067	0.016
Cliff of Flaherty's [east of Deception Lake]	27.64	0.088	0.195
Flaherty's tunnel [east of Deception Lake]	40.45	0.021	0.021

A brief discussion of the geology of the area and a few assays are also given in the report of the Iron Ore Committee, 1923, on pages 181–82. The following quotation is taken from this report:

> . . . The properties on which exploratory work has been carried on are known as the *Flaherty-Knobel* [extending from Deception lake to the east end of Silver or Sheen lake], *Marks-Wiley* [one block northeast of Beck siding, the other extending from Loon station to southwest of Deception lake], and *McConnell* properties [on both sides of the Canadian Pacific railway, extending from the west end of Loon lake to 3 miles west of the lake; a part of this property is now held by S. Rosenblatt, Fort William]. In these areas numerous diamond-drill holes have been put down and a considerable amount of trenching and test-pitting has been done in search for iron ore. . .
>
> . . . The following analyses are representative of the grade of ore occurring here:

	No. 1	No. 2	No. 3	No. 4
	percent	percent	percent	percent
Iron	26.51	31.24	40.20	19.68
Silica	34.78	30.86	44.76	61.04
Sulphur	0.06	0.06	0.04	0.13
Phosphorus	0.04	0.08	0.06	0.06

> A diamond-drill hole penetrating the ore-bearing strata in reaching a depth of 45 feet, cut two bands of ore with thicknesses of 6½ feet and 1¾ feet, respectively, three bands of lean ore with thicknesses varying from 3 to 5 feet, and three bands of ferruginous chert with thicknesses varying from 6 inches to 3 feet. . . .

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[1] L. P. Silver, "The Animikie Iron Range," *Annual Report*, Ont. Bur. Mines, Vol. XV, 1906, pt. 1, p. 168.

Dominion Bessemer Ore Company Property—About 4 miles to the southwest of the above described area lies mining section location No. 5, in the Township of McGregor, which was operated in 1909 by the Dominion Bessemer Ore Company and from which two cargoes of ore were shipped before the close of navigation. An ore-loading dock was built, also a tramway from the dock to the ore body about one mile inland. Operations ceased at the end of the year and were not resumed.

The ore on this property occurs in two varieties: as hard, greyish, fine-grained hematite; and as friable, brown oxides of iron. The ore-beds are associated with quartzose and sideritic rocks, with a prevailing dip to the southeast of about 50°; they attain in places a thickness of 6 feet, but a thickness of more than 3 feet is not common. Frequently the ore beds thin rapidly. In the better ore beds high-grade ore occurs in segregations with the result that where a whole bed is mined the average iron content of the ore, after cobbing in the quarry, is likely to be below present furnace requirements.

Average analysis of stock-pile samples taken while mining operations were in progress, are reported as follows:

	No. 1 Grade	No. 2 Grade
	percent	percent
Iron	44.30	37.60
Silica	22.60	23.00
Sulphur	0.015	0.275
Phosphorus	0.015	0.024
Manganese	1.50	4.00

The improbability of finding large tonnage and the reported inferior grade of shipments made from mining operations, have deterred further exploitation.

A number of drill holes were put down by M. A. Hanna Company on the McConnell property in 1923. No sections of ore grade were encountered. The range of assays obtained is reported in the previous section.

Two short adits underlying diabase just north of the Canadian Pacific railways, west of Bittern Lake, on the McConnell property, were examined briefly and sampled by the author. The mineralization consists of carbonate, fine-grained hematite, which is often slickensided, and chert. The bedding is irregular. A chip sample, taken by the author normal to the bedding over a length of 5.5 feet, on the southwest wall of the main or north adit, averaged 34.29 percent Fe. A 16-inch sample, taken about 2 feet from the top of the adit, averaged 19.66 percent Fe. A chip sample, for 5 feet above the adit opening, in the rock face, averaged 54.09 percent Fe. A 4-foot 4-inch sample, from the south side of the entrance of the adit near the railway, gave 43.63 percent Fe. All these analyses were made by the Provincial Assay Office. Selected samples, taken from the north adit by G. M. Hutt of the Canadian Pacific Railway, gave 65.26 percent Fe and 6.60 percent SiO_2, and from the south adit, beside the railway tracks, gave 58.96 percent Fe and 15.40 percent SiO_2. These assays were provided by M. W. Bartley.

Economic Potential of the Gunflint Iron Formation

The primary purpose of the present survey was to search for evidence of natural enrichment of iron formation. Apart from the fairly restricted zones west of Bittern Lake as described in the previous section, and an occasional narrow band near Iron Lake, no evidence of enrichment was observed. "Iron ores" are reported by Van Hise and Leith[1] as small, irregular bodies along faults north of Deception Lake and extending eastward to Silver Lake, and south and east of Bittern Lake. Due probably to filling in and weathering of old workings, these zones are no longer recognizable. Considerable attention was given to the

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[1] C. R. Van Hise and C. K. Leith, *The Geology of the Lake Superior District*, U.S. Geol. Surv., Monograph No. 52, 1911, p. 207.

faults encountered during mapping, but nothing was seen to indicate enrichment of the iron formation near them.

It would of course be premature to say that no enriched zones occur in the iron formation. Large areas, for instance in McIntyre township, and near, and west of, Kakabeka Falls, are covered by drift and have not been tested by drilling. No trace of enriched ore is to be seen either in visible outcrop or in boulders in the drift.

The possibility of locating concentrating ore must also be considered since this type of iron ore is becoming more important as a source of furnace feed. Most concentrating plants at present are based on the magnetic separation of magnetite from iron formation in which it is the principal iron mineral. No sections of the iron formation northeast of Port Arthur that contain enough magnetite are known. West of Kakabeka Falls, iron formation, immediately underlying the diabase sheets, is sufficiently rich in magnetite to be considered. Investigations so far made on this material show that very fine grinding is necessary to free the magnetite sufficiently to obtain a large enough concentrate of satisfactory grade. This, with the fact that most of this magnetite-enriched iron formation must be recovered from beneath a thick diabase sill, make this source of iron ore unattractive at present. Since most of this type of material is found west of the area described here, the reader is referred to Goodwin's report for further details on grade and concentration tests. Assays, from the three hills located north of Pitch Creek in Marks township, have already been given. This is the only considerable occurrence of magnetite-rich iron formation found by the author northeast of Whitefish Lake.

The banded chert-carbonate of the Upper Gunflint, in the vicinity of Chert Lake and Blende Lake, is of relatively low grade and unsuited for iron ore as it stands. Measurements of a section in a railway cut on the Canadian National railway indicate about 40 percent chert bands and 60 percent carbonate. Presumably the chert and carbonate layers could be readily separated by gravity methods, which might produce a carbonate concentrate with enough iron to be amenable to sintering, but no investigation has been made of the feasibility of such treatment. The presence of considerable chert mixed with the carbonate layers, and the variable iron content of the carbonate, make this material less attractive for such purposes than it would be otherwise.

In general, prospects for the development of iron mining in the Gunflint do not appear good at present. Nothing so far discovered promises economic grade and tonnage.

Gunflint Iron Formation of the Whitefish Lake Area, District of Thunder Bay

BY

A. M. Goodwin[1]

INTRODUCTION

This report[2] deals with the Gunflint iron-bearing formation occurring in Jean, Hardwick, Strange, Lismore, and the south half of Lybster townships, District of Thunder Bay. More specifically, the map area extends from Silver Mountain, which is 32 miles southwest of Port Arthur, westward for 14 miles to Mink Mountain, and is about 4 miles wide. Attention is directed to the stratigraphy and iron ore potentialities of the Gunflint formation.

Typical cuesta topography formed by gently-dipping diabase sills, looking eastward across Whitefish Lake.

The results of this work and that of Dr. Moorhouse (see preceding report) are shown in the eight maps in the case at the back.

The area has been the scene of a sporadic search for iron and silver ores for the past 65 years. Silver ore of considerable value was removed from Silver Mountain and vicinity prior to 1903, but there has been no recent exploitation. In many localities, the iron-bearing rocks have been examined by surface work and drilling, but no commercial deposits have been discovered.

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[1] Postgraduate Student, University of Wisconsin, 1952.

[2] *See also* A. M. Goodwin, "Facies Relations in the Gunflint Iron Formation," *Economic Geology*, Vol. 51, 1956, pp. 565–95.

The present survey was conducted during the 1952 field season by a two-man party using pace-and-compass methods assisted by air photographs. Information was plotted on air compilation maps on a scale of 4 inches to 1 mile.

Acknowledgments

It is a pleasure to acknowledge the co-operation of M.W. Bartley, Port Arthur, who was in charge of commercial exploration work in the map area at the time of the survey. Dr. Bartley was very co-operative in providing drilling, assay, and concentration test records.

Lawrence Hobbs of University of Western Ontario ably assisted during the season.

Means of Access

The map area is readily accessible from Port Arthur by means of the Silver Mountain road. Numerous wagon roads and trails lead northward from this road into the principal areas of rock exposures.

Previous Work

The first systematic geological investigation of the map area appears to have been that of E. D. Ingall[1] in 1887, who briefly described the iron-bearing rocks exposed in the vicinity of Silver Mountain and Whitefish Lake.

In 1926, J. E. Gill[2] presented the results of his studies of the stratigraphy of the Gunflint formation in the area extending from Gunflint Lake, on the International Boundary, northeastward to Silver Mountain. His report provides a detailed and accurate section of the iron-bearing formation there.

T. L. Tanton,[3] in 1923, described iron prospects at Mink Mountain. In 1931, he published the results of investigations in the Thunder Bay district, in which the present map area is briefly described.[4]

In addition to these geological records, there are records available of considerable exploratory work on the iron-bearing rocks by interested individuals and mining concerns.

Considerable surface work was conducted in the vicinity of Mink Mountain prior to 1926 by local residents, of whom J. McGugan appears to have been the most prominent.

In 1943, Gunflint Iron Mines Company Limited sectioned the iron-bearing formation in the area adjoining Mink Mountain with eight vertical diamond-drill holes. In 1952, L. K. Johnson Explorations, of Duluth, Minn., conducted extensive exploration of the formation in the area between North Lake, 16 miles southwest of Mink Mountain, and the town of Nolalu, 4 miles northeast of Silver Mountain.

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[1] Elfric Drew Ingall, "Mines and Mining on Lake Superior, Part I," *Annual Report*, Geol. and Nat. Hist. Surv. Can., New Series, Vol. III, 1888, Report H.

[2] J. E. Gill, "Gunflint Iron-Bearing Formation, Ontario," *Summary Report*, Geol. Surv. Can., 1924, Part C, pp. 28–88.

[3] T. L. Tanton, "Iron Formation at Gravel Lake, Thunder Bay District, Ontario," *Summary Report*, Geol. Surv. Can., 1923, Part C, pp.1–75.

[4] T. L. Tanton, *Fort William and Port Arthur, and Thunder Cap Map-Areas, Thunder Bay District, Ontario*, Geol. Surv. Can., Memoir No. 167, 1931.

Topography

The maximum relief in the area is about 450 feet and is due to the presence of diabase sill rock that has resisted erosion and now stands above the surrounding flat-lying terrain in the form of large round mesas such as Mink, Sun, Marny, and Silver mountains, or as east-west trending cuestas such as Divide Ridge.

The southern and western parts of the area drain southward by tributaries of the Pigeon River, which enters Lake Superior at Pigeon Point. Elsewhere, drainage is eastward by the Whitefish River, which joins the Kaministikwia River, and thence flows through Fort William to Lake Superior.

Exposures of iron-bearing rock are scarce in the low-lying country adjoining streams and lakes because of drift cover. Beneath the diabase capping of hills and ridges, however, the rocks are well exposed.

GENERAL GEOLOGY

All the consolidated rocks of the area are considered to be Precambrian in age. Glacial till of Pleistocene age, and unconsolidated debris, form an extensive mantle over low-lying parts of the area.

The oldest rocks in the area are granite and granite gneiss with inclusions of chlorite and mica schist, upon which rest, in angular unconformity, gently dipping sedimentary and volcanic rocks, within which numerous diabase sills have been emplaced.

TABLE OF FORMATIONS

CENOZOIC	
Pleistocene and Recent:	Till, gravel, sand, and clay.
	Unconformity
PRECAMBRIAN	
Keweenawan:	Diabase and related rocks.
	Intrusive Contact
Animikie:	Rove formation. Gunflint iron formation.
	Unconformity
Algoman Type:	Granite, granite gneiss, with inclusions of chlorite and mica schist.

Precambrian

ALGOMAN TYPE

Algoman-type granitic rocks exposed along the north margin of the sedimentary rocks consist predominantly of normal, pink granite and granite gneiss. The texture ranges, without recognized distribution, from conspicuously gneissic to coarsely pegmatitic.

Numerous inclusions of chloritic and micaceous schist, and gneiss of various shapes and sizes, occur within the granite.

ANIMIKIE

Sedimentary and volcanic rocks of the Animikie rest upon Algoman-type granitic rocks with major angular unconformity. These formations are intruded by diabase of Keweenawan age.

The Animikie consists of two formations: the lower being the Gunflint iron formation, and the upper, the Rove argillite formation. The sedimentary, and locally volcanic, rocks making up the formation dip gently south at an average angle of 5 degrees.

Gunflint Iron Formation

The Gunflint iron formation consists mainly of sedimentary rocks that are unusually rich in iron. The average thickness of the formation is 475 feet. The distribution, lithology, and economic aspects are considered in detail later in this report.

The north-facing escarpment of Divide Ridge.

Rove Formation

The Rove formation consists typically of thin-bedded, black to dark-grey argillite. There are very few exposures within the map area. Argillite, with an approximate thickness of 200 feet, underlies the capping sill on Silver Mountain, and there are exposures up to 30 feet thick beneath the capping rocks on Mink, Sun, and Marny mountains. South of the map area, however, there are great thicknesses of argillite that probably amount to several thousand feet.

KEWEENAWAN

Rocks of the Keweenawan within the map area consist of diabase intrusives.

Remnants of diabase sills, typically about 100 feet thick, form the capping rock on the larger hills and ridges within the map area. The largest exposure is on Divide Ridge, which lies immediately north of Whitefish Lake; it is 6 miles long and 2 miles wide. The diabase sills dip gently southward, conforming more or less to the attitude of the enclosing sedimentary rocks.

All the principal exposures of flat-lying diabase rock in the map area are considered to be remnants of an original single sill, now segmented by faulting and erosion.

A single diabase dike was observed within the map area, transecting the basement complex north of Whitefish Lake; its age, relative to the Animikie rocks, could not be determined here. Elsewhere in the Thunder Bay district, however, diabase dikes that transect Animikie rocks are common, and it is presumed that the dike mentioned is of the same age.

Cenozoic

PLEISTOCENE AND RECENT

Unconsolidated sand and gravels are widespread and in places very thick. Most of the material is unsorted and appears to represent glacial debris; along the river banks, however, there has been considerable reworking and sorting.

The thickness of the debris ranges from a thin discontinuous mantle of boulders on top of the diabase-capped hills to sand and boulder deposits up to 250 feet thick, such as occur on the southeast side of Mink Mountain.

STRUCTURAL GEOLOGY

The Animikie sedimentary rocks are essentially flat-lying and rest upon a granite terrain of low relief. The principal disturbance has been due to normal gravity faults, which are common throughout the area.

Folds

Except for local variation in attitude, the beds of the Gunflint iron formation dip gently south at an average angle of 5 degrees. A typical variation occurs in the beds adjoining fault planes, where it is common to find local, but intense, folding.

Gill has drawn attention to local folding and brecciation in the uppermost beds of the Gunflint formation on Mink Mountain,[1] and has emphasized the extreme brecciation of the chert beds. Folding and deformation of this type are attributed to violent volcanic disturbances that occurred towards the end of the deposition of the iron-bearing rocks.

Faults

There appear to be two principal systems of normal gravity faults within the map area. One system strikes approximately N.70°E; the other, generally northward. The age relationship between them was not determined, as individual faults cannot be traced with certainty for more than a few miles.

One example of an east-trending fault is located between Silver Bluff and Divide Ridge, in which the north side appears to have moved down about 100 feet relative to the south side. Another example is the fault southeast of Mink Mountain, where the south side has moved down about 250 feet.

The north-trending system is illustrated by the two faults, one on either side of the North River, that together have formed a downfaulted block, or graben. Movement has been about 200 feet.

A fault is indicated between Silver Bluff and Silver Mountain. The diabase capping rocks at both localities are at the same elevation, but whereas the capping rock at Silver Bluff is underlain by iron-bearing rocks of the Gunflint formation, there is 200 feet of Rove argillite beneath the capping rock of Silver Mountain. Thus, there has apparently been a vertical displacement of at least 200 feet, the east side having moved down relative to the west.

There are probably many other faults in the area but with such limited vertical movement that they are not readily discernible.

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[1] J. E. Gill, *op. cit.*, pp. 39, 40.

GUNFLINT IRON FORMATION

The Gunflint iron formation is a sequence of sedimentary, and locally, volcanic rocks, with a total thickness of about 475 feet. The formation is characterized by an unusually high iron content, as well as by a variety of textures, the granular texture of the taconite rock being most distinctive. The textural and mineral terms common to this formation have been well described by Gill[1] and readers interested are referred to his report for details.

The general stratigraphic relationships of the formation have been determined by field observations and drilling records. Tables I and II present pertinent drilling records; the location of the holes is shown in the accompanying sketch map.

TABLE I—DRILLING RECORDS
(L. K. Johnson Explorations, 1952)

Member	Thicknesses Encountered in Drill Holes							
	No. 1 (feet)	No. 2 (feet)	No. 3 (feet)	No. 4 (feet)	No. 5 (feet)	No. 6 (feet)	No. 7 (feet)	No. 8 (feet)
Upper Limestone..	5.0							
Upper Taconite....	175.0	63.0		34.3	132.5			
Upper Shale.......	8.2	8.3		5.5	16.5			
Upper Jasper.....	64.5	35.7	40.0	63.9	58.0			
Upper Algal chert.	22.3	6.0	19.4	15.3	8.5		18.0	
Lower Taconite...	196.7	208.5	187.1	204.8	194.0	108.7	231.0	153.0
Lower Shale.......	11.3	5.5	16.5	11.5	9.0			3.5
Lower Algal chert.	2.4		15.3	3.6	13.0	3.0	3.7	13.6
Basal Conglomerate		2.0						
Total.........	485.4	329.0	278.3	338.9	431.5	111.7	252.7	170.1

No. 1—SW. corner of Mink Mountain; T.B.44177—720 ft. N.87°30'W. from No. 2 post.
2—S. of Burnt Bridge on Whitefish River; T.B.44120—1,060 ft. N.18°W. from No. 4 post of T.B.44117.
3—S. shore of Sandstone Lake; T.B. 43828—700 ft. W. from No. 1 post and 200 feet S. of North Line.
4—NE. corner of Unit 4, Divide Ridge; T.B.44384—150 ft. NW. from No. 2 post.
5—S. shore of Iron Range Lake; T.B.43718—300 ft. W. and 150 ft. S. of No. 1 post.
6—Between Iron Range and Sandstone lakes; T.B.43762—400 ft. S. and 200 ft. W. of No. 1 post.
7—W. of North River; T.B.44444—700 ft. W. and 50 ft. S. of No. 1 post.
8—NW. of Nolalu; T.B.44487—25 ft. N. and 100 ft. W. of No. 2 post.

Stratigraphy

The Gunflint formation is divided into lower and upper cycles. Each cycle contains a sequence of members, most of which are common to both. The uppermost member, a limestone bed, is unique to the formation and marks the top of the iron-bearing rocks. (Table III).

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[1] op. cit. pp. 41–43.

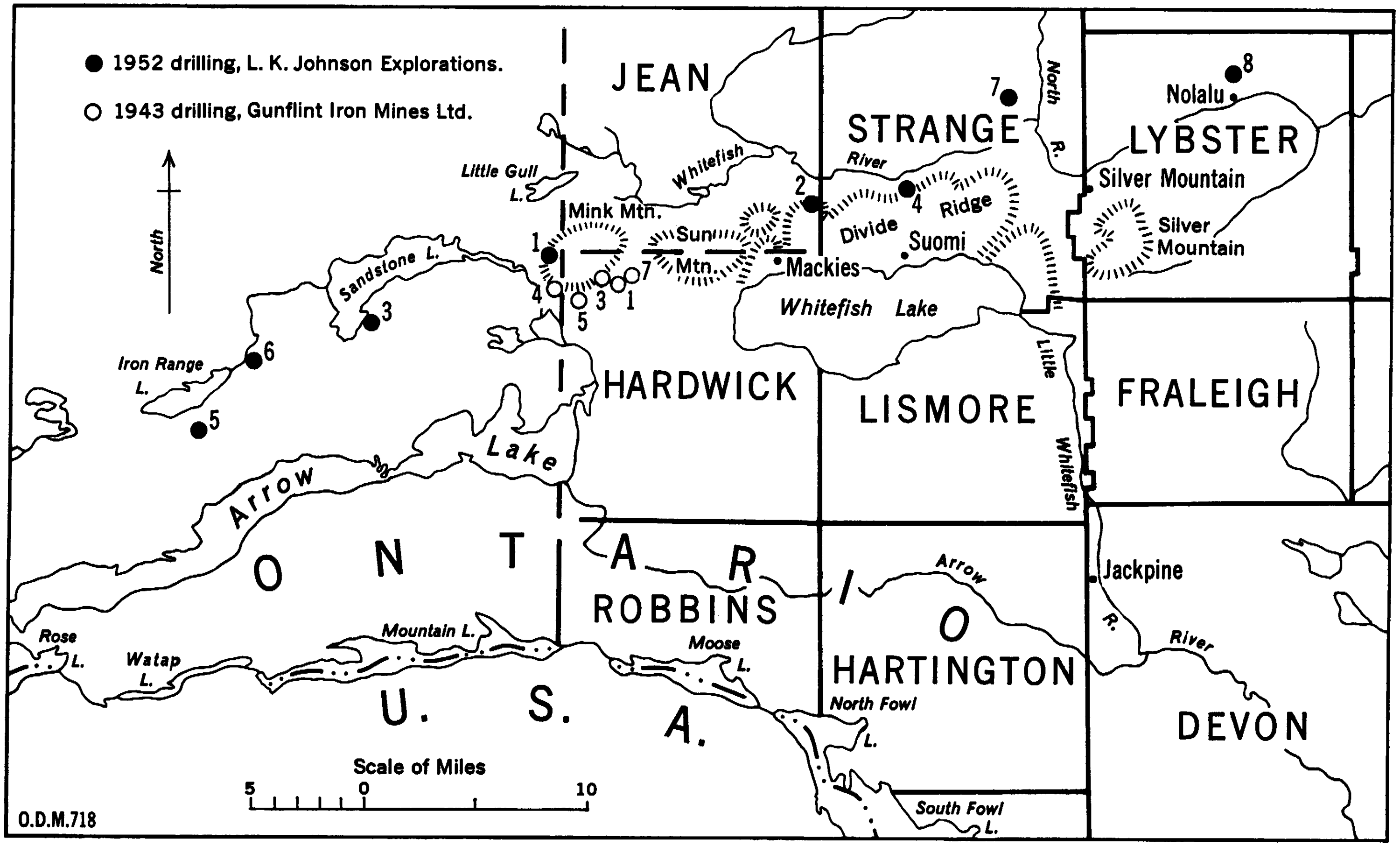

Figure 10—Sketch map showing location of diamond-drill holes.

TABLE II—INTERPRETATION OF SELECTED DRILLING RECORDS

(All drill holes are located south of Mink Mountain)
(*Gunflint Iron Mines Limited, 1943*)

Member	Thicknesses Encountered in Drill Holes				
	No. 1 (feet)	No. 3 (feet)	No. 4 (feet)	No. 5 (feet)	No. 7 (feet)
Overburden	234	226	146	212	179
Upper Taconite	18	7		52	113
Upper Shale	5	2.5			5
Upper Jasper	51	54.5	44.5		53
Upper Algal chert					
Lower Taconite	206	38	182.5		60
Lower Shale	32				
Lower Algal chert					
Basal Conglomerate					
Total	546	328	373	264	410

No. 1—27 chains S. and 19 chains W. of NE. corner of lot W-281.
3—18 chains S. and 22 chains W. of NE. corner of lot W-281.
4—27 chains S. and 18 chains W. of NE. corner of lot 56-X.
5—18 chains S. and 20 chains W. of NE. corner of lot W-280.
7—20 chains S. and 28 chains W. of NE. corner of lot W-280.

TABLE III—GENERALIZED SECTION—GUNFLINT IRON FORMATION

Cycle	Member	Thickness (feet)	Equivalent—Gill's Section
Upper Gunflint(1)	Upper Limestone	5– 20	
	Upper Taconite	150–180	Division 5
	Upper Shale	5– 16	
	Upper Jasper	40– 64	
	Upper Algal chert	8– 22	Division 4
	Lava flow locally	0– 40	
	Total Upper Gunflint	250–350	
Lower Gunflint	Lower Taconite	150–210	Division 3
	Lower Shale	4– 20	Division 2
	Lower Algal chert	2– 15	Division 1
	Basal Conglomerate	0– 1	
	Total Lower Gunflint	210–240	
	Total thickness of Gunflint iron formation	460–540	

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(1)The Upper Gunflint in this report includes the Upper Jasper, Upper Algal Chert, and Lava Flow, which have not been recognized at or east of Kakabeka Falls, and the Upper Shale which has been classed as a distinct unit in the report by W. W. Moorhouse.

BASAL CONGLOMERATE MEMBER

The basal conglomerate is well exposed along the north fringe of the iron formation, where it forms a thin skin on top of the basement complex. The thickness of the conglomerate is seldom more than one foot, even where completely preserved, and is usually only a few inches.

The pebbles of the conglomerate are formed of white vein quartz, milky white chert, and occasionally jasper. Most pebbles are ½–1 inch in diameter, although several with diameters of 6 inches were observed, and the majority are well rounded. The matrix consists of sandy quartz grains with considerable admixed chloritic material.

Reef-like mound of algal chert (left) resting on granite basement (right).

LOWER ALGAL CHERT MEMBER

Algal chert rests directly upon the basal conglomerate, or where this is absent, upon the granitic basement. There are excellent exposures north of Burnt Bridge on the Whitefish River. The total thickness of the member ranges from 2 to 15 feet.

The algal chert is commonly in the form of reef-like mounds, which are roughly elliptical in plan view and average 10 feet long, 4 feet wide, and 2 feet thick. The chert forming the mounds is finely contorted in the manner typical of algal structures. Small brown, white, and red granules are often closely associated. The algal chert typically grades upwards into green and white banded chert with massive texture.

LOWER SHALE MEMBER

The Lower Shale member outcrops in only a few places because of the soft nature of the rocks. The best exposures observed are on the ridge near the south shore of Little Gull Lake where a maximum thickness of 18 feet is exposed. Drilling records indicate that the member thins eastward. At Nolalu, on the east border of the map area, it is 3.5 feet thick.

The shale is soft, black and typically fissile. Thin-section examination reveals much fine-grained clastic material together with carbonaceous matter. Bands of grey to black chert, commonly flecked with pyrite, are present near the top of the member.

LOWER TACONITE MEMBER

Rocks of the Lower Taconite member are exposed along the north slope of Mink Mountain, on the banks of the Whitefish River, and on numerous small hills and ridges north of this river. The thickness of the member ranges from 150 to 210 feet and is remarkably uniform throughout the map area.

Typical algal structures of the Lower Algal chert member.

Weathered rocks of the member are characterized by a shingly appearance due to numerous closely spaced parting planes, rusty colour, and finely granular texture. The thickness of the beds can only be determined in very fresh exposures because of the strong tendency for parting. An individual bed is lenticular; the maximum thickness is 6–15 inches, and the lateral extent is up to 50 feet. The beds are separated by very thin partings usually no more than 2 inches thick.

Under the microscope, the typical rock of this member is seen to consist of small granules up to 2 millimetres in diameter, in a fine-grained chert or carbonate matrix. The granules consist of a mixture of fine-grained chert, a green silicate mineral (probably greenalite), and iron oxide. The iron oxide is commonly an intimate mixture of hematite and magnetite, or near the weathered surfaces, the hydrated equivalents. The oxides often form the rims of granules. The matrix to the granules is fine-grained chert or ferruginous carbonate. Where the carbonate is present the granules are not well formed.

Carbonate nodules are common in certain beds. In cross-section, the nodules are characteristically round and occasionally slightly elliptical. They range in diameter from a fraction of an inch to 1 inch and average ¼ inch. The individual nodule when fresh is typically composed of salmon pink, finely crystalline carbonate, commonly with a rim of greenalite (?). The carbonate is rusty weathering, the colour being yellow, orange, brown, or black, depending on the degree of oxidation and hydration.

Shingly granular rocks of the Lower Taconite member.

There is a variation in the relative proportions of chert, greenalite, hematite, and magnetite, within the unweathered beds of the member. Some beds are unusually rich in the iron oxide minerals, whereas adjacent beds contain a high proportion of chert and greenalite. However, no large-scale mineral zoning was recognized, and there is here no attempt to subdivide the member.

UPPER ALGAL CHERT MEMBER

Rocks of the Upper Algal chert member are exposed on the west and east flanks of Mink Mountain, beneath the diabase sill of Divide Ridge, along the banks of the Whitefish River, and within the North River downfaulted block. The thickness of the member ranges from 8 to 22 feet.

The beds of the member are divided into the following groups, in descending order:

Group	Feet
3. Coarse granular ferruginous chert	2– 6
2. Algal-oölitic chert, lava flow locally	4–50
1. Granular chert with jasper veinlets	2–10

Group 1

The beds of this group are 2–10 feet thick. They are predominantly cherty with abundant red, grey, and black granules. The granules are formed of chert and iron oxides, the latter an intergrowth of hematite and magnetite. The matrix is predominantly fine-grained chert.

The beds are characterized by jasper veinlets. These veinlets are up to 1 inch thick; some are parallel to the bedding planes, but the majority are subhorizontal to vertical.

Group 2

The algal group is characterized by finely banded, red and white algal chert. In places, there are three distinct beds of algal banding, each being about 4 inches thick, and separated by 6–12 inches of granular chert; elsewhere, only one algal bed was observed, the thickness ranging from 1 to 6 feet. Intimately associated with the algal bandings, there are unusually coarse red and black oölitic granules up to ¼ inch in diameter; these are typically concentrically banded and consist of chert, hematite, and magnetite, the iron oxides being usually intermixed and concentrically interbanded with the chert.

Basic flow rock is exposed intermittently in a belt ½ mile wide, which extends from the northeast corner of Mink Mountain northward for ¾ mile to the south bank of the Whitefish River. Here, the base of the lava rests upon 7 feet of granular chert, which in turn grades downward into magnetite-bearing greenalite taconite rock of the Lower Taconite member.

Near an abandoned cabin on the east side of Mink Mountain, the flow rock is in contact with, and appears to plunge beneath, red granular chert. Within 50 feet of this contact, there are scattered outcrops of algal-banded chert.

Thus the flow rock occupies a stratigraphic position within, and slightly above, the base of the Upper Algal chert member.

The flow rock contains pillow-type structures up to 2 feet in diameter, which are commonly encased in a rim of red and green chert up to ½ inch thick.

Amygdules are common in the upper 10 feet of the flow rock. The filling is white chert, jasper, or a greenalite-like mineral. The amygdules range up to ⅛ inch in diameter. There is commonly a bleached zone surrounding each amygdule, up to ¼ inch in diameter, from which the iron appears to have been removed.

Hematite-bearing veinlets were observed in the flow rock. A typical veinlet is 1 inch thick and follows sinuous joints in the lava. The vein material is red and has a distinct granular texture. Thin-section study reveals oölitic granules formed of concentrically banded red hematite and chert up to 5 millimetres in diameter, in a fine-grained chert matrix.

There is a scattering of large boulders containing considerable amounts of hematite and magnetite, distributed over the area that is apparently underlain by flow rock. The boulders are up to 6 feet in diameter, and typically contain hematite and magnetite in the form of large granules up to ¼ inch in diameter, and lenticles as much as 2 inches long. Under the microscope, the granules and lenticles are seen to consist of an intimate intergrowth of specular hematite and magnetite. Commonly, magnetite forms most of the core of a granule, the proportion of hematite increasing towards the border. The matrix to the granules consists of chert, often radiating, with a sprinkling of earthy red hematite.

Some boulders contain zones up to 1 foot in diameter that consist of granular specular hematite with sparse matrix. It forms a spectacular rock, consisting as it does of abundant, closely packed "globules" of steel-grey hematite. Thin-section examination reveals granules up to 5 millimetres in diameter that consist largely of hematite with some intermixed magnetite and fine-grained chert. The sparse matrix is chert.

The iron-bearing boulders are restricted to the area designated above, so far as is known. Since the rock has not been observed in place, its stratigraphic position cannot be determined; however, its unique character, restricted distribution, and close association with basic flow rock, suggest a close genetic association. Accordingly, the boulders are interpreted as remnants of a rock unit that was originally situated immediately above the flow rock.

Group 3

The beds above the algal chert group are similar to those below it. They consist of chert with a coarse granular texture; there is often hematite and magnetite associated with the chert. Jasper veinlets similar to those in the rocks of Group 1 are present, but in smaller numbers.

UPPER JASPER MEMBER

Beds of this member are well exposed in numerous test pits and adits along the east and west sides of Mink Mountain. There are also good exposures beneath the capping sill of Divide Ridge. The member ranges in thickness from 40 to 64 feet.

The lower beds of the member are characterized by granules and small lenticles, or beads, of jaspery chert; this grades upwards into beds consisting of thick lenses of granular jaspery chert with shaly partings.

The granular or beaded jasper beds are 2–6 inches thick and consist of many small jasper granules and beads in a dark-red, very finely granular matrix. The typical jasper bead is lenticular in form and is up to ¼ inch in length; it is well rounded and elongated parallel to the bedding.

Thin-section examination reveals that the beads are irregularly shaped granules consisting of a core of fine-grained chert and a green silicate mineral (greenalite?) with a rim of intermixed hematite and magnetite. The matrix to the beads is composed of fine-grained chert speckled with earthy red hematite.

Large jasper lenses occur in the upper beds of this member; these are 4–8 inches thick, and 2–10 feet long, and are all elongated parallel to the bedding planes. An individual lens often pinches to a fraction of an inch before swelling again to maximum thickness, continuing thus laterally for many yards. There is often a succession of lenses along a particular horizon.

The jasper lenses consist of abundant, close-packed, small red granules in a chert matrix. All lenses observed have a granular texture. Not all granules are red; occasionally a lens has a local concentration of green granules or a general intermixture of red and green. The granules are seen in thin section to consist of chert with red iron oxide or a greenalite-like mineral, the colour of the granule varying accordingly. There is an increase of green granules relative to red granules towards the top of the member, and the uppermost lenses are predominantly green.

Both red and green chert lenses are separated by fine-grained shaly material, some with recognizable clastic matter.

The rocks of this member grade upwards by increase in shaly material to shale of the overlying member.

UPPER SHALE MEMBER

The Shale member is exposed in the same localities as the underlying Jasper member. It ranges in thickness from 5 to 16 feet and is persistent throughout the map area.

The member consists largely of black, fissile shale. Locally, small concretions are present; they are generally 2–3 inches in diameter and composed of black sideritic carbonate.

Upper part of Upper Shale member. Thick pisolite bed below hammer head, jasper lens immediately above handle.

A prominent feature of the Shale member, and a good horizon marker, is the presence of a pisolite layer near the top of the member. The layer is 9–18 inches thick. It consists of pisolites averaging ⅛ inch in diameter that are somewhat flattened along the bedding plane. They weather characteristically to a rusty brown colour and are easily noticed against the background of black shale.

Thin-section examination reveals that an individual pisolite consists of fine-grained, angular clastic material in a greenish clay matrix. The tabular clastic fragments tend to be oriented with their long dimension perpendicular to the radius, thus developing a crude concentric banding.

The shale grades upwards within a vertical distance of 2 feet to the granular rock of the overlying member.

UPPER TACONITE MEMBER

Upper Taconite beds are exposed beneath the capping sills of the hills and ridges of the area. There are particularly good exposures on the north face of Silver Bluff. The member is 150–180 feet thick.

The typical rocks of this member consist of thick-bedded granular chert with shaly partings.

The chert layers are commonly green in colour, due to abundant greenalite granules. The thickness of the chert layers ranges from 5 to 24 inches. An occasional layer is of uniform thickness, but most are noticeably wavy banded; such bands pinch and swell within a lateral distance of 10–20 feet. The thinner chert beds are often segmented into discreet chert lenses, 5–10 inches thick and up to 20 feet long. Within a vertical section, chert lenses are arranged so that the thick part of a particular lens rests in the hollow formed by the tapered extensions of subjacent lenses. The plan view of a lens is typically circular to elliptical, so far as was determined.

Lenticular chert beds with their shaly partings of the Upper Taconite member. The chert is granular.

In all cases observed, lenticular, or wavy-banded chert has a distinct granular texture.

Under the microscope, the fresh material is seen to consist of granules formed of greenalite intermixed with some chert and iron oxide, in a matrix of fine-grained chert.

The shaly partings that separate chert beds range in thickness from 1 to 12 inches, most commonly about 4 inches. The partings are dark-brown to black and very fine grained. They consist of an intermixture of ferruginous carbonate, magnetite, and occasional fragmental grains.

Beds within 80 feet of the diabase sills have a considerably higher magnetite content than normal. In such beds, the magnetite grains are up to 3 millimetres

TABLE IV—PARTIAL CHEMICAL COMPOSITION, LOWER TACONITE MEMBER

(All figures are percentages)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18
Iron (Fe)	19.27	25.09	31.81	34.41	26.94	25.00	25.00	25.97	31.16	28.57	26.97	23.33	20.74	20.09	22.98	22.18	26.86	25.48
Silica	53.99	46.36	44.60	42.40	51.80	45.60	45.60	54.80	43.40	59.10	44.08	46.24	46.44	51.41	46.71	46.61	37.14	39.68
Phosphorus	nil	nil	0.027	0.021	0.021	0.061	0.061	0.014	0.023	0.020	0.015	0.009	0.005	0.006	0.010	0.009	0.012	0.009
Sulphur	0.11	0.08	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Manganese	0.27	0.32	0.21	0.31	0.19	0.71	0.71	0.12	0.21	0.31	......	......	......	......	......	......	......	......

No. 1—Falls on Whitefish River, W. of Burnt Bridge.
2—Small hill, NE. of Burnt Bridge.
(*Nos. 1 and 2 by Ont. Dept. Mines, Provincial Assay Office, 1952.*)
3–10—Pits and trenches on NW. flank of Mink Mountain.
(*Nos. 3—10 from M. W. Bartley, 1951.*)
11—Small hill NE. of Burnt Bridge.
12, 13—Falls on Whitefish River, W. of Burnt Bridge.
14—Roadside outcrop, W. of North River.
15—1943(?) drill core, W. side of Mink Mountain; 20–40 feet.
16—1943(?) drill core, W. side of Mink Mountain; 40–60 feet.
17—1943(?) drill core, W. side of Mink Mountain; 60–100 feet.
18—1943(?) drill core, W. side of Mink Mountain; 100–125 feet.
(*Nos. 11–18 from L. K. Johnson Explorations, 1952*).

TABLE V—PARTIAL CHEMICAL COMPOSITION, UPPER JASPER MEMBER AND UPPER TACONITE MEMBER

(All figures are percentages)

	Upper Jasper Member					Upper Taconite Member												
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18
Iron (Fe).......	24.44	24.16	24.84	24.37	28.36	26.68	28.61	32.24	26.89	23.95	26.41	29.89	39.85	32.34	30.36	33.89	34.08	33.91
Silica..........	50.49	51.14	44.66	39.17	......	54.60	56.52	44.96	49.16	51.41	46.50	43.96	33.24	28.36	42.78	35.89	38.07	35.69
Phosphorus.....	nil	0.41 (P_2O_5)	......	......	......	0.17	0.26	0.009	0.008	0.014	0.015	0.060	0.025	0.083	0.141	0.178	0.154	0.138
Manganese.....	0.08 (MnO_2)	0.03	......	......	......	0.15	0.17	......	......	......	......	......	......	......	......	......	......	......
Sulphur........	0.52	0.16	......	......	......	0.17	0.10	......	......	......	......	......	......	......	......	......	......	......

No. 1—Large pit; NW. flank of Mink Mountain.
2—N. face of Divide Ridge; NE. corner, Unit 3.
(Nos. 1 and 2 by Ont. Dept. Mines, Provincial Assay Office, 1952.)
3—Drill core—Hole No. 1; average of six 5-foot sections, 262–92 feet.
4—Drill core—Hole No. 2; average of seven 5-foot sections, 240–75 feet.
5—Drill core—Hole No. 5; average of four 5-foot sections, 220–40 feet.
(Nos. 3–5 from Gunflint Iron Mines Ltd., 1943.)
6—N. face of Divide Ridge; NE. corner, Unit 4.
7—N. face of Silver Bluff.
(Nos. 6 and 7 by Ont. Dept. Mines, Provincial Assay Office, 1952.)
8—S. shore of Addie Lake.
9—SW. shore of Addie Lake.
10—N. face of Divide Ridge; NW. corner, Unit 1.
11—E. face of Divide Ridge.
12—N. face of Divide Ridge; NW. corner, Unit 3.
13—Fire Tower outlier.
14—N. face of Silver Bluff; 0–24 feet below diabase.
15—N. face of Silver Bluff; 24–94 feet below diabase.
16—W. side of Mink Mountain.
17—NW. face of Divide Ridge; 0–8 feet below diabase.
18—NW. face of Divide Ridge; 8–18 feet below diabase.
(Nos. 8–18 from L. K. Johnson Explorations, 1952.)

in diameter; they occur in both the chert layers and shaly partings, but more abundantly in the partings. Bands up to 5 inches thick, rich in magnetite, were observed; however, cherty material is usually intimately associated.

The upper 20 feet of this member consists locally of beds that have been highly contorted and brecciated. The rock now consists of chert fragments, up to 6 inches thick and 2 feet long, within a matrix of magnetite, secondary iron-bearing amphibole minerals, and calcite. The chert of the fragments is commonly dark-grey to black and finely laminated. The rock appears to have consisted originally of thinly interbanded chert and ferruginous carbonate.

UPPER LIMESTONE MEMBER

The Limestone member is exposed immediately north of the abandoned railway on the south slope of Sun Mountain; the thickness is estimated to range from 5 to 20 feet.

The limestone is typically dark-grey to black and very fine grained. It is easily confused with the finer-grained phases of diabase. There are usually thin interbandings of grey-to-black massive chert up to 2 inches thick.

Chemical Composition

Sufficient partial analyses are available to determine with considerable accuracy the average composition of potential ore-making beds of the Gunflint iron formation. The members considered in this respect are the Lower Taconite member, Upper Jasper member, and the Upper Taconite member. The other members of the formation are relatively thin and contain less iron. Tables IV and V present the available analyses of the three members.

The rock samples from which the analyses were determined represent a fairly wide distribution within each member in respect to both thickness and lateral extent. A study of the tables reveals the essential chemical uniformity within each member. The average iron and silica content of the three members calculated from the above analyses is as follows:

TABLE VI—AVERAGE IRON AND SILICA CONTENT

Member	Number of Analyses	Fe	SiO_2
		percent	percent
Lower Taconite	18	25.71	46.44
Upper Jasper	20	25.50	46.36
Upper Taconite	20	30.70	43.16

Economic Considerations

Since the average composition of the iron-bearing rock contains too much silica for its use as ore material, searchers for ore material look for parts of the iron-bearing rock that have been concentrated by natural processes or are amenable to commercial beneficiating methods. The evidence is examined with this in mind.

POSSIBILITIES OF NATURAL CONCENTRATIONS

There is no direct evidence that natural concentrations of ore material have formed within the map area. The iron-bearing rocks show little evidence of oxidation of the iron minerals and leaching of the silica content.

Rocks of the Lower Taconite member appear to have been weathered more than other parts of the formation, particularly in the ridges and mounds north of the Whitefish River. However, close inspection of the outcrops reveals that alteration is restricted to a rim 1–2 inches thick. The chemical analyses demonstrate that there has been little, if any, removal of silica and other impurities.

Outcrops and drill core of Upper Jasper rocks inspected give no indication of more than slight surface alteration, and hold little promise of large scale, natural concentrations. A 1-foot bed of soft hematite ore, assaying 52 percent iron and 3–8 percent silica, was reported to have been encountered at a depth of 250 feet, in the region south of Mink Mountain, by Gunflint Iron Mines Limited, in 1943. Thus, local concentrations of soft ore are possible within this member at depth.

The Upper Taconite rocks show the least signs of oxidation and leaching. The member typically occupies a high topographic position beneath diabase sills of considerable thickness, and oxidizing activity may have been restricted for this reason.

It is possible that rocks of the Upper Taconite member that formerly overlay the diabase sill underwent oxidation and leaching of impurities before removal. Such iron-enriched material might have been concentrated in low-lying areas, such as Whitefish Lake and vicinity, and thus protected from erosion. However, there is no direct evidence that such a concentration exists. On the contrary, an erosional remnant of Upper Taconite rock, overlying sill rock on the north shore of Whitefish Lake, shows no sign of extensive oxidation and leaching.

It is possible that concentrations of iron-rich material occur along fault planes. Here again, with one possible exception, there is no direct evidence of such a process of enrichment.

This exception occurs ½ mile southeast of the falls on the Whitefish River, in lot 4, concession IV, Strange township, where, in the farmyard of Mr. Youman, there are scattered fragments of possible fault breccia. The material is rusty weathering, and consists of angular jasper fragments up to 2 inches in diameter in a dark-brown, powdery matrix. The partial analysis of this material is as follows:

	Percent
Fe	20.01
SiO_2	51.80
Al_2O_3	1.84
CaO	4.15
MgO	1.16
TiO_2	0.35
MnO	0.19
S	0.03
P	0.071
Ignition loss	0.35

Although the material is far from ore grade, it is possible that richer iron-bearing zones occur elsewhere. Fault zones that might repay investigation lie between Silver Bluff and Divide Ridge, between Silver Bluff and Silver Mountain east of North River where the iron-bearing rocks abut on granite, and southeast of Mink and Sun mountains.

Several analyses were obtained of the granular hematite-magnetite-bearing boulders described on page 52. They are listed below.

	Sample			
	No. 1	No. 2	No. 3	No. 4
	percent	percent	percent	percent
Fe	51.94	57.36	11.75	59.08
SiO_2	20.00	19.95	32.31	14.20
P	0.031	0.023	nil	0.034
MnO	0.21	0.15	0.89 (MnO_2)	0.19
Al_2O_3	....	0.33	....	....
S	....	0.010	0.06	....
Ca	....	0.75	....	....
Mg	....	0.10	....	....

Samples Nos. 1, 2, and 3 are natural material.
Sample No. 4 is magnetic concentrate.

The high silica content and apparently restricted distribution of the boulders render them of no value.

POSSIBILITIES OF MATERIAL AMENABLE TO BENEFICIATION

To be of value as concentrating material, the iron-bearing rock must be of appropriate chemical and textural composition and readily available in large quantities, and iron-bearing rocks of the Lower and Upper Taconite members were considered with this in mind.

Lower Taconite Member

There are widespread exposures of Lower Taconite rocks in the general area north of Mink Mountain and Whitefish River. Thicknesses up to 230 feet have been encountered in drill holes. Furthermore, the material is relatively soft and friable, and is exposed over a large area without capping rock to hinder extraction.

Samples of the Lower Taconite rock have been tested with magnetic tubes. Table VII shows the results of test made on material ground to minus 100- and minus 200-mesh. The tests show that in general the over-all recovery by magnetic separation is not high, and the concentrate is prohibitively siliceous, even at minus 200-mesh grinding.

The concentrate, of course, consists principally of the magnetic portion of the total iron content of the rocks. It may prove possible to obtain a higher grade concentrate by using roasting and flotation processes. However, the intimate relation between iron minerals and silica does not suggest that such a concentration is feasible without unduly fine grinding.

Upper Taconite Member

The analyses of Upper Taconite rocks indicate that they contain more iron and less silica than the Lower Taconite rocks, and the magnetite content in proximity to diabase sills is considerably higher. However, a deterrent to the possible use of such material is its location beneath capping sills of diabase up to 200 feet thick, which would probably have to be removed before extraction; moreover, there are no known exposures, or near-exposures, of Upper Taconite rocks not capped by diabase.

Table VIII gives the results of magnetic concentrating tests, run on rocks of this member at minus 100- and minus 200-mesh.

TABLE VII—MAGNETIC TUBE TESTS, LOWER TACONITE ROCKS

(Sample Nos. 1–4 are respectively equivalent to Nos. 15–18 in Table IV.)

	minus 100-mesh						minus 200-mesh					
	Magnetic Concentrate				Non-magnetic Tails		Magnetic Concentrate				Non-magnetic Tails	
Sample No.	Percentage Weight of Sample	Total Iron	Phos-phorus	Fusion Silica	Percentage Weight of Sample	Total Iron	Percentage Weight of Sample	Total Iron	Phos-phorus	Fusion Silica	Percentage Weight of Sample	Total Iron
		percent	percent	percent		percent		percent	percent	percent		percent
1.............	24.83	38.87	0.010	35.40	75.17	17.73	14.28	54.44	0.009	19.64	85.72	17.74
2.............	24.43	34.68	0.009	38.46	75.57	18.14	11.51	50.08	0.008	23.08	88.49	18.55
3.............	25.21	48.07	0.010	23.30	74.79	19.71	15.13	59.92	0.009	12.20	84.87	20.97
4.............	18.23	52.26	0.010	16.91	81.77	19.51	12.64	62.26	0.009	9.00	87.36	20.16

TABLE VIII—MAGNETIC TUBE TESTS, UPPER TACONITE ROCKS

(All iron determinations are total assays; all silica determinations are fusion assays.)

	minus 100-mesh						minus 200-mesh					
	Magnetic Concentrate				Non-magnetic Tails		Magnetic Concentrate				Non-magnetic Tails	
Sample No.	Percentage Weight of Sample	Total Iron	Phos-phorus	Fusion Silica	Percentage Weight of Sample	Total Iron	Percentage Weight of Sample	Total Iron	Phos-phorus	Fusion Silica	Percentage Weight of Sample	Total Iron
		percent	percent	percent		percent		percent	percent	percent		percent
1............	43.81	49.68	0.014	26.30	56.19	18.64	36.48	55.50	0.012	15.50	63.52	18.88
2............	35.28	47.60	0.014	29.22	64.72	15.60	29.03	51.95	0.012	22.78	70.97	16.64
3............	18.40	51.76	0.021	17.79	81.60	17.68	14.38	54.13	0.022	15.33	85.62	18.88
4............	48.49	38.66	0.026	35.62	51.51	14.88	39.55	43.42	0.026	29.83	60.45	15.28
5............	38.37	50.66	0.075	21.36	61.63	16.96	33.51	54.77	0.062	16.73	66.49	17.35
6............	22.91	49.20	0.189	19.47	77.09	27.20	16.24	51.63	0.163	17.70	83.76	28.48
7............	22.73	46.08	0.165	23.45	77.27	22.72	17.32	49.94	0.150	19.49	82.68	23.44
8............	30.17	50.24	0.038	24.50	69.83	35.36	23.51	53.16	0.044	20.20	76.49	35.76
9............	53.31	49.33	0.064	25.74	46.69	12.94	47.23	53.61	0.066	22.97	52.77	13.30
10............	35.11	45.58	0.168	27.32	64.89	22.13	27.11	50.36	0.189	23.00	72.89	22.92
11............	32.48	52.10	0.144	16.62	67.52	25.41	30.17	54.01	0.144	16.40	69.83	25.47
12............	40.96	49.00	0.152	23.64	59.04	23.44	35.24	50.93	0.147	17.36	64.76	24.65
13............	43.77	54.21	0.180	12.66	56.23	18.07	40.86	56.77	0.168	12.05	59.14	18.08

Nos. 1–5—Equivalent to Nos. 8–12 in Table V.
6, 7—SE. shore of Prelate Lake, below the diabase.
8–10—Equivalent to Nos. 13–15 in Table V.
11, 12—Equivalent to Nos. 17–18 in Table V.
13—Equivalent to No. 16 in Table V.

The results demonstrate that the magnetic concentrate is low in total recovery, low in iron, and high in silica. It is also significant that the finer grinding has not resulted in an appreciably richer concentrate, demonstrating the intimate association of iron and silica within the rocks of this member.

CONCLUSION AND RECOMMENDATIONS

The average chemical composition of the iron-bearing rocks of the Gunflint iron formation within the map area, the apparent lack of oxidation and leaching, and the negative results of magnetic concentration tests, are not encouraging for the discovery of ore material within the map area.

It is possible that natural concentrations of ore material occur in the low-lying areas in the vicinity of Whitefish and Round lakes, or along fault zones.

However, the economic future of the iron-bearing rocks appears to depend upon a process that will produce a commercial concentrate. More detailed experimental investigation might reveal such a process.

The rapid development of beneficiating methods suggests that future improvements might be sufficient to bring the iron-bearing rocks of the Gunflint iron formation within the range of commercial exploitation.

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