The Sudbury Nickel Field

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REPORT OF

THE BUREAU OF MINES, 1905

VOL. XIV. - PART III.

THOS. W. GIBSON, Director

THE SUDBURY NICKEL FIELD

BY

A. P. COLEMAN

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REPORT OF
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VOL. XIV **Part III**

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THE SUDBURY NICKEL REGION

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Introduction

During the past three summers field work has been carried on by the Bureau of Mines of Ontario, in the Sudbury nickel region, with the object of determining in detail the boundaries of the nickel-bearing rock, and of examining the geological relationships of the known ore bodies, special attention being given to working mines. The field work and the preparation of the previous reports on this region, as well as of this final report, have been entrusted by Mr. T. W. Gibson, Director of the Bureau of Mines of Ontario, to the present writer. It is intended that this report shall sum up as completely as may be our knowledge of the geology of the region, of its ore deposits and minerals, and of the mines which have been operated.

The field work has been done by the writer and various assistants, especially Mr. M. T. Culbert, who deserves particular mention for his quickness of apprehension and skill as a field geologist. The compilation of the accompanying maps also is mainly the work of Mr. Culbert, though much assistance has been obtained from the officers of the Surveys branch of the Department of Crown Lands, who furnished copies of the township maps of the region; and from the work of Drs. Robert Bell and A. E. Barlow, of the Geological Survey of Canada, whose published maps have been of the greatest assistance.

The surface plans of mines have been made partly by myself and my assistants, taking advantage, however, of any existing plans furnished by mine managers or surveyors. The plans of underground workings have been provided mainly through the courtesy of mine owners and managers. In the preparation of these plans for publication Mr. W. E. H. Carter, until lately Secretary of the Bureau of Mines, has been very helpful.

Valuable aid has been given by prospectors, miners and others connected with the nickel mining industry in all parts of the region, but special thanks are due to Mr. A. P. Turner, President of the Canadian Copper Company, and Mr. John Lawson, who has charge of their mines.

The Sudbury nickel field has long been known as the most important source of that metal in America, if not in the world, but the work of the last three years has brought out more and more strikingly the unique character of this mining region. It has been proved that all the ore deposits of any economic importance are at or near the outer margin of a huge laccolithic sheet of eruptive rock a mile and a quarter thick, 38 miles long and 17 miles wide. This sheet is now in the form of a boat shaped syncline, with its pointed end to the southwest and its square end to the northeast. The rock composing this sheet is norite at the outer (and lower) edge, merging into granite or grano-diorite at the inner (upper) edge. The ore bodies are round the margin of the norite or along dike-like offsets from it, and have evidently segregated from the rock while still molten, though they may have undergone later rearrangement by circulating water.

It is common to find ore deposits associated with eruptive rocks in such a way as to suggest that the eruptive furnished the ore; but in a large majority of the examples described the ores themselves have been transported and deposited by circulating water. In the Sudbury region, however, there is good reason to believe that the ore accumulated at the edges of the eruptive sheet while it was still fluid enough to permit the segregation and sinking of the heavier ingredients, probably, in part at least, under the action of gravitation. At a later time, however, there was in many deposits a considerable amount of water action, particularly in those along offsets. The conditions just mentioned are of very great interest, both from the geological and the economic side, and the evidence regarding them will be given in detail at a later stage.

While special attention was paid to the great eruptive sheet and its ore bodies, the adjoining rocks also have been collected and to some extent carefully studied and mapped; but this work has been subordinated to the main object of the investigation. It has been found that everywhere the laccolithic sheet rests on ancient, mainly crystalline, rocks which have hitherto been mapped and described as Laurentian and Huronian, while its upper surface underlies a series of later rocks which Dr. Bell suggests may be Cambrian in age. This inner rock series consists entirely of sediments, mainly ordinary clastics, such as conglomerate, slate and sandstone, but near the base including much pyroclastic materials, volcanic ash, lapilli, etc. These stratified rocks have been bent into synclines and anticlines during the formation of the main syncline. The underlying more ancient rocks present much less regularity, and their relationships are less certain. The rocks mapped as Huronian are chiefly sediments such as quartzite and graywacké tilted into positions more or less approaching the vertical, and often recrystallised into schists. With them are basic eruptives of great variety, including lava flows and an older, more basic, norite than that of the nickel-bearing rock. The rocks mapped as Laurentian include granite and gneiss younger than the Huronian, but older than the nickel-bearing eruptive and the overlying sediments. The youngest rocks of the region are the laccolithic sheet connected with the nickel ores and certain still later dikes of olivine diabase and granite.

It will be seen that the region presents a wide range of interesting features to the mining engineer as well as to the geologist, and the recent developments in the way of mining operations and the making of wagon roads and railroads enable one to study its southern side in a very satisfactory way; but the northern half is still forest covered for the most part and rather inaccessible.

The mining community and prospectors are accustomed to speak of two nickel ranges, the main or southern one, and the northern one. Our mapping proves that there is really only one range, which is continuous with the outer edge of the sheet of nickel-bearing rock. However in a modified sense the two ranges may still be distinguished, since the extreme west and the extreme east of the laccolithic sheet have not yet disclosed ore bodies of importance. In a general way there are more numerous and larger ore bodies, so far as known, on the southern than on the northern range, though there is great irregularity in this respect on both ranges.

As will be shown later the topography of the region has very close relations with the arrangement of the laccolithic sheet and its adjoining rocks, so that the surface forms of the area give aid in studying its geology.

PREVIOUS GEOLOGICAL WORK IN THE REGION

Nickel ore was first found in what is now the Sudbury district in 1856 by Murray who obtained it near the present Creighton mine, where Salter, an early land surveyor, had noted great disturbance of the compass. Dr. Sterry Hunt analysed the material, finding in it nickel and copper.[1] No further discoveries of nickel ores were made until the Canadian Pacific railway was constructed in 1883, when the ore body of the Murray mine was disclosed; and in the following year the Stobie, Copper Cliff and other deposits. The mineral which attracted attention was however the copper pyrites and not the pyrrhotite, and the deposits were valued only for their copper contents, as the name of the famous "Copper Cliff" mine suggests. It was not till three or four years later, when some thousands of tons of ore had been shipped for treatment from the latter mine that the value of the nickel ore was recognized.[2]

In the Geological Survey report for 1890 Dr. Bell's report on the Sudbury mining region appears as part F, including the results of his field work from 1888 and 1890, as well as those of Barlow and various other assistants; and in the same year the Report of the Royal Commission on the Mineral Resources of Ontario contained a number of references to the region by Dr. Bell and others.[3] In the following year Dr. Bell contributed an account of the ore bodies of the region to the Report of the Bureau of Mines,[4] and the same volume contained the first statistics of the production of nickel ore. Since then the nickel contents of the matte have been reported year by year, and various references are made to the mines and their geological relationships by mining inspectors and geologists, as well as accounts of the metallurgy of nickel and its value in the manufacture of armor plate, etc. It was in 1891 also that Garnier, the discoverer of the New Caledonian nickel ores, published an important account of the Sudbury nickel mines;[5] while in the following year another French mining engineer, M. Levat, described the treament of the Sudbury ores, comparing them with those of New Caledonia.[6]

In the same year the real character of the nickel-bearing rock was discovered by Baron von Foullon, who found hypersthene and diallage in specimens from the Murray mine, proving that it belonged to the norite variety of gabbro instead of being diorite, as former students of the region had named it.[7]

In 1893 the present writer showed that the country rock of certain nickel deposits on the northern range contained diallage and enstatite, and so should be classed with the gabbro family;[8] and somewhat later Dr. T. L. Walker, in an Inaugural Dissertation on the Sudbury Nickel District, proved that where unweathered the nickel-bearing rock contains hypersthene and hence is norite, as von Foullon had stated. He made another still more important observation, that this basic rock passes by insensible gradations into syenite and granite.[9] The present writer had found micropegmatite associated with the nickel-bearing rock but had not observed that the one passed into the other.[10] To Dr. Walker belongs also the credit of first recognising the field relationships, showing that the transition from norite to pegmatite was from southeast to northwest near the Murray mine; but in the reverse order near Onaping, so that the basic edge was on opposite sides of the two nickel ranges.

That the ore is really a very basic segregation from the margin of the eruptive mass with which it is associated was brought out in 1894 by Dr. Adams, who followed the theory proposed by Vogt for the Scandinavian nickel deposits.[11]

1 Geol. Sur. Can., 1853-6, pp. 180 and 189.
2 See Dr. Bell in Bur. Mines, 1891, p. 89
3 Pp. 23, 67-8, 88, 100, 404-5 and 433-5.
4 Pp. 88-90.
5 Mem. Soc. des. Ing. Civils, 1891.
6 An. des Mines, 1892, Tome I, 2 Livraison; see also translation in Bur. Mines, 1892, pp. 149, etc.
7 Jahr-b. d. k. k. geol. Reichsanstalt, Vienna, 1892, pp. 223-310.
8 Rocks of Clear lake near Sudbury, Can. Rec. Sc., Apr. 1893, p. 344.
9 Quar. Jour. Geol. Soc., Vol. LIII, pp. 40-46.
10 Can. Rec. Sc., 1893, p. 345.
11 Can. Min. Rev., Jan. 1894, p. 8.

In 1901 Dr. Barlow gave a brief account of the rocks of a portion of the southern nickel range, in which he described excellently the norite and its gradation into micropegmatite.[12] Later his large scale maps of the Copper Cliff and Victoria mines regions have appeared, and a further summary report on rocks of the region in 1902.[13] In the latter year the first detailed report of the Bureau of Mines was prepared, taking up especially the working mines of the southern range, of which maps and plans were published; and in 1903 the work of mapping the northern nickel range was nearly completed.[14].

In 1904 Dr. Barlow's admirable final report on the region was published as Part H of the Geological Survey report for that year. It is much the most complete account of the region yet given, and should be referred to by anyone desiring a full knowledge of the geology, and also of the economic development of the Sudbury district. Several useful maps of parts of the district are published with the report.

In the foregoing review of the literature of the subject only reports and papers of a geological nature have been referred to. Many papers have been published on the mineralogy, metallurgy, and mining of the district; but these will be noted in later portions of this report.

It will be seen that the region has attracted much attention and has been studied in whole or in part by many geologists. It was, however, a very difficult region for geological work in earlier days, being rugged and forest covered, and in most parts unprovided with the canoe routes which facilitate geological work in so many parts of northern Ontario. The real field relationships could only be determined by following up in detail the basic edge of the eruptive, thus proving that it is continuous and not merely a series of larger or smaller bands of basic eruptive rock.

The map constructed by Dr. Bell and his assistants was in some respects surprisingly accurate and served an excellent purpose in its time, though later work under more favorable conditions has thrown new light on many points and has given the clue to the general relationships.

TOPOGRAPHY

The topography of the Sudbury district is very closely bound up with its geology, the great laccolithic sheet especially influencing the land forms. The ancient Huronian and Laurentian rocks outside the eruptive sheet have a varied, but generally rugged and hilly, surface, the harder quartzites and granites rising as steep hills or ridges, while the softer rocks make the low ground, largely covered with old lake deposits or by lakes and swamps.

The nickel-bearing eruptive varies considerably in different parts, and these variations express themselves in very different types of topography. The basic phase of the rock yields readily to weathering, while the acid phase is a very resistant rock. The basic edge has had little effect on the rocks with which it is in contact, the so-called Huronian and Laurentian, so that the topography outside the basic edge depends on original differences in the character of the Archean rocks themselves. On the other hand the acid edge has powerfully metamorphosed the overlying sediments, turning them into very crystalline and durable rocks. Half a mile inward from the acid edge the tuffs and slates are much softer; but in the centre of the syncline there are thick sandstones of a more resistant nature than the slate.

The relationships just sketched furnish an explanation of most of the topographic features, which may now be discussed briefly. The exposed surface of the eruptive along the southern edge of the syncline is often four miles wide and averages more than three miles in width, of which the outer half is basic and weathers rapidly. Along the northern side the width varies from three miles to less than one mile, averaging nearly two miles, of which less than one-half is basic as a rule, and in places the basic portion is almost lacking.

12 Geol. Sur. Can., Sum. Rep., p. 143, etc.
13 Ibid. 1902, pp. 252-267.
14 Bur. Mines, 1903, pp. 235-299; and 1904, pp. 192-224.

The topography in general is then as follows: the country outside the syncline has the somewhat rugged and irregular mixture of hills and valleys of rather moderate heights and depths usual in Archean regions. The basic edge of the southern nickel range follows, with low, gently accentuated surfaces for a width of about two miles; after which comes a belt of quite precipitous hills belonging to the acid edge. The adjoining metamorphosed conglomerate and tuff makes a narrow band of very precipitous hills, often having unscalable cliffs. The inner, softer tuffs and slate make the floor of a wide valley, followed by hills of sandstone in the middle of the syncline, much lower however than the other hills referred to before.

Approaching the northern nickel range, after a flat valley representing the slates and softer tuffs, one finds once more a very mountainous band of country formed by the metamorphosed tuffs and the acid eruptives; then a narrow valley, often filled with a lake or muskeg, at the basic edge; followed by the irregular Laurentian hills to the north.

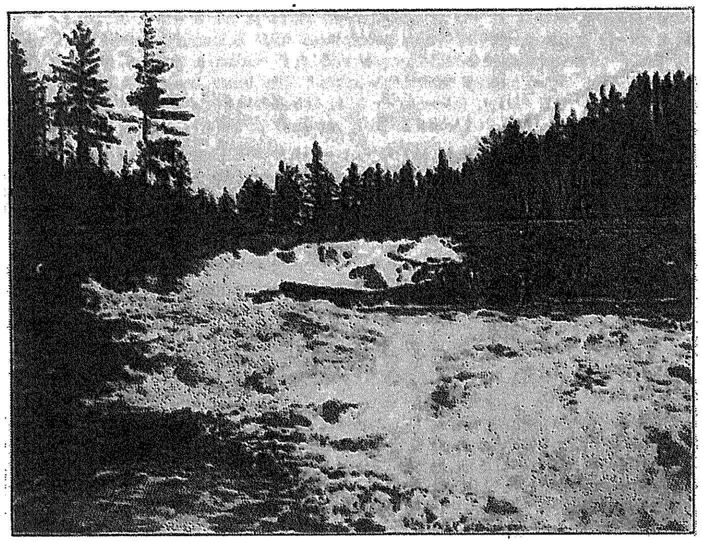
The contoured portion of the map accompanying this monograph illustrates graphically the relationships just referred to, so that detailed description is unnecessary. It should be remarked however that this section was chosen because of the convenience of the railway bench marks in working out the levels, and the railway has naturally selected the easiest passes into and out of the flat central valley. The acid edge near Azilda presents a much less rugged appearance than is usual in other parts of the range.

Although the country along the acid edge is so precipitous and rough in character as to cause difficulty in running lines because of vertical or even overhanging cliffs, the total difference in altitude from the flat interior of the basin to the enclosing hill tops is not more than about 600 feet, so that the elevations can scarcely be called mountains. The highest points measured reach not much over 1,400 feet above sea level.

In general then there is an elongated central area of low ground with comparatively gentle hills running down its centre, surrounded by a margin of very precipitous hills rising from 200 to 600 feet above the plain. Then comes a valley about a quarter or half a mile wide on the northern side and two miles wide on the southern, succeeded by the irregular hilly country of the outside Archean. The interior plain as well as all the low ground to the south of the eruptive area is covered with lacustrine clay or sand, while the less frequent level ground to the north consists of sand nad gravel terraces at higher levels.

HYDROGRAPHY

In a region so recently ice-covered as northern Ontario the arrangement of the lakes and watercourses is of a very youthful character, very little filling of basins, or cutting down of rocky obstructions having taken place, and yet the old topography profoundly affects the drainage system. The main river of the district, Vermilion river, comes in from Archean country to the north as a singularly straight north and south chain of narrow lakes connected by swift water or rapids. As soon as the hilly border is passed by an evidently pre-glacial channel the river changes its character, flowing gently over drift sand and gravel at the northwest end of the interior basin to lake Onwatin, an expansion in the soft slates. It then turns west for twelve miles, and afterwards southwest for six miles, keeping to the band of slate almost to Larchwood, where it cuts across the low sandstone ridges, forming rapids and falls. Arrived at the southern band of slate it expands into Vermilion lake, a counterpart of Onwatin, as noted by Dr. Bell, turns east for five or six miles of placid water, and finally strikes southwest across the acid edge as lake-like stretches separated by rapids or falls. It receives one large tributary, the Onaping, which plunges as a succession of violent rapids and falls where it crosses the acid edge on its way from the north into the central plain towards its eastern end. It then turns east following the slate until it joins the Vermilion above Larchwood.



Fall on the Onaping over vitrophyre tuffs.

The smaller tributaries largely occupy the same band of slate, and it is clear that the whole drainage system is mainly controlled by the peculiar geological structure of the region.

With the exception of Onwatin and Vermilion lakes, which have in general flat low shores and are merely expansions of Vermilion river, the low central area of sedimentary rocks contains no important lakes, except Whitewater, which has its northern shore within the tuffs. All round the hilly edge of eruptive rock, however, we find typical "rocky lake" country with irregular steep shored bodies of water, such as Fairbank, Windy, Trout and Whitson lakes. Along the northern basic edge of the eruptive there are many small narrow lakes whose basins are due to the rapid decay of the norite between walls of granite and gneiss to the northwest and the acid phase of the eruptive toward the southeast. The wider valley of the southern basic edge has lower hills and more numerous openings toward the southeast, and its hollows are mainly filled with drift, so that there are few lakes along that side.

The lakes of the interior basin are shallow and have muddy shores, while those of the hilly border are often very deep with rocky shores and clear water. They stand usually a hundred or more feet above the valley, and the small streams which drain them are full of rapids and falls.

The Vermilion river and its tributaries in the interior valley have very meandering channels, and are engaged in carving down the old lake deposits to the base level of the

next lower outcrop of rock. In the rocky country on each side of the basin their channels are determined by the irregularities of the rocky valleys, where practically no cutting has been done since the glacial period except in the unevenly distributed boulder clay.

METHODS OF SURVEY

Different parts of the Sudbury district are in very different stages of development, the southern portion being well supplied with wagon roads and railways, and having a number of towns and villages, as well as cultivated farms in the clay covered flats and valleys. Most of the country near the great mines has been cleared and burnt over, sometimes more than once, so that the rock is excellently exposed, except where buried under old lake deposits. The northern range, on the other hand, is still largely a wilderness covered with woods and with few roads except those of the lumbermen, who are now removing the pine.

These differences are partly due to the richness of the mines in the southern range, but perhaps in an equal degree to the passage of the main transcontinental line of the Canadian Pacific railway through it. The latter circumstance has its cause in the gentler character of the country in the southern part, resulting probably to a considerable extent from the much greater width of the norite margin of the eruptive. Norite weathers quickly and where wide forms a comparatively level surface with gentle hills.

The town of Sudbury is southeast of the main nickel range, and from it radiate railways in various directions, the main line of the C. P. R. running roughly east and west through the district; the "Sault" branch turning off to the southwest; the Algoma Central running for eleven miles about midway between it and the main line, following the basic edge of the eruptive where various mines are at work; and finally a branch running north three or four miles to the Stobie and other mines not now working.

The whole district has been surveyed into townships six miles square, and the lines between the square miles have been run, as well as occasionally north and south lines dividing the square miles into halves. Unfortunately for the geologist many of these surveys are now old, and the lines have grown up or have been obscured by lumbering operations, or fire has actually destroyed all evidence of the surveyor's work, so that following the lines is difficult and often impossible. On this account much topographical work has been required to fix the geological relationships, especially the contacts of the inner or acid edge of the nickel-bearing eruptive with the overlying sediments. It was decided to determine the position of the acid edge at points not more than a half mile apart, the usual method being by pacing from corner posts to the point of contact, while the basic edge was mapped in a more detailed way, especially in the neighborhood of mines or ore bodies. The latter work was done partly by pacing and prismatic compass, or where there was local attraction, by dial compass; and partly by micrometer work. There are parts, however, especially toward the southeast corner of the boat shaped syncline and at its southwestern end, where swamps or drift deposits hide the solid rock and leave some uncertainty as to the line of contact. The longest stretch covered in this way is in the townships of Falconbridge and Maclennan, where there is a gap of a little over two miles.

During the field work in the southern part of the region railways were largely made use of as bases, and in several places there are good wagon roads which were of service in tracing the basic edge. For the basic edge on the northern range and for the acid edge everywhere, these modes of access were seldom available and the work was done by tramping through the woods, or, where possible, by canoes on lakes and rivers.

It was found that the township maps as well as the maps of mining locations are usually accurate in so far as lines which had actually been surveyed are concerned, but that the courses of rivers and the forms of lakes are commonly very badly mapped, and that many smaller lakes not cut by a survey line have been omitted altogether.

The levels of the region have been determined mainly by aneroid from fixed points such as railway stations and bench marks, White's Elevations of Canada being made use of. In order to give an idea of the topography of the country for a mile or two on each side of the Canadian Pacific railway from Murray mine to Windy lake has been contoured, the lines being placed 25 feet apart. The work was done partly by hand level and partly by aneroid, and except near the railway great accuracy of detail was not aimed at. Owing to lack of time and the smallness of the staff available it was not possible to contour the whole district, but elevations of many of the higher points and of the chief lakes are given on the map. As these were determined by aneroid, and often at long distances from the railway, their accuracy is only approximate.

CLASSIFICATION OF THE ROCKS

Underlying the sheet of nickel-bearing eruptive there are various sedimentary and eruptive rocks which have always been placed in the Laurentian and Huronian. The Laurentian was originally supposed to be the older of the two, but it is now known that it has, in many places if not all, an eruptive contact with the Huronian, so that its age must be later. The Laurentian consists wholly of eruptive rocks but the Huronian contains more sediments than eruptives. The oldest rocks of the district are the banded iron formation and the schists associated with it, but they nowhere occur in the neighborhood of the nickel ranges, though they are developed in interesting ways on the north shore of lake Wahnapitae not far to the east, and in Hutton and adjoining townships to the north. The iron formation consists of silica of a quartzitic or jaspery kind interbanded with magnetite, in Hutton township affording great bodies of fairly good magnetic ore.[15] These rocks have been placed in the Lower Huronian by the geologists of the Bureau of Mines, the equivalent of the Keewatin as lately defined.

Their relationship to the sediments south of the southern nickel range is not quite certain, but the latter are generally considered younger and have hitherto been put with the rocks of the original Huronian area as Upper Huronian, but by the new classification will be Lower Huronian.

The widespread sedimentary rocks south of the nickel range differ materially from those of the original Huronian, however, containing no bands of limestone nor red jasper conglomerate and very little white quartzite, and being generally more extensively metamorphosed. They include distinctly stratified graywacké or quartzite with slaty bands, probably with a synclinal arrangement, as suggested by Dr. Barlow, since there are two parallel bands with arkose between. The arkose, though apparently later than the graywacké and included in its syncline, shows very little evidence of stratification in most places, and is often so far re-crystallized as to look like felsite or fine-grained gneiss. It has frequently been taken for an eruptive, and has been spoken of as syenite, but its parallelism with the well stratified graywacké and its general field relations make it almost certainly a sedimentary rock. The slaty graywacké is often crowded with whitish or gray pseudomorphs after staurolite, and is what Dr. Selwyn named "rice rock." Occasionally the pseudomorphs are far too large for grains of rice, and reach four or five inches in length.

When the slaty graywacké lies beside large granite masses, as near the Frood mine, it may become more schistose, so as to form mica schist or fine-grained gneiss.

In some parts of the region, especially toward Whitefish and Worthington, there are pale gray and very cleavable slaty rocks without the coarser textured layers, probably of the same age as the rocks previously described.

North of Ramsey lake and in other places there are considerable areas of graywacké conglomerate, usually showing little evidence of stratification and consisting of a dark gray or black matrix enclosing angular or rounded pebbles and boulders of various rocks, such as vein quartz, quartzite and granite. In appearance they suggest a greatly metamorphosed boulder clay, and it is not impossible that they originated by ice action.

[15] See Bur. Mines, 1903, pp. 318-321; and 1904, pp. 216-221 and 222-224.

Though the relations of this conglomerate to the slaty graywacké are somewhat obscure, it appears to be younger, the quartzite boulders probably coming from harder quartzitic layers of the previously mentioned rocks.

A narrow, discontinuous band of undoubtedly water formed conglomerate, very like some parts of the typical Huronian conglomerate north of lake Huron, stretches for about two miles northeast and southwest near Stobie mine; and near by is a small hill of white quartzite like that near Lake Huron. Just how these rocks should be placed with regard to the more widely spread rocks is uncertain, but they have been tilted and faulted in the same way and are probably of the same general age, *i.e.*, Huronian.

All the older rocks of the region have been greatly faulted, the faults being very numerous but usually with a small throw; and in various places there are crush conglomerates along the planes of faulting. Dr. Barlow in his map of the Copper Cliff region indicates a series of close folds in the schistose rocks, and it is quite probable that most of the Huronian has been sharply folded by the elevation of neighboring Laurentian areas, but our work was not detailed enough to prove this relationship.

Eruptive Rocks in the Huronian

The sedimentary rocks described above are associated with green schists and various greenstones and other basic eruptives which seem to be of much the same age. The schists may be sheared diabases or gabbros, now reduced to chloritic and hornblendic rocks; but beside them or intermingled with them are hornblende porphyrite, with large crystals of hornblende, and white spotted rocks, perhaps once porphyrites containing feldspar crystals. In many places these rocks pass into a very fine-grained norite, entirely different in character from the nickel-bearing norite, and of course much older than that important rock. In a few places there are well developed "pillow structures" and amygdaloidal or concretionary forms that must be explained as resulting from surface volcanic flows. Hills made up of these various basic rocks extend for several miles along the southeastern edge of the main nickel range, from Blezard to Elsie, and they are found less extensively in several other parts of the region.

Other basic eruptives, such as hornblende porphyrite and gabbro, form long bands or sometimes small laccoliths entirely enclosed in the Huronian sediments and often tilting them up in such a way as to prove them later in age, as in the hill east of Sudbury and a ridge south of Copper Cliff. Though later than the sediments they are supposed to be older than the nickel eruptive, and may represent earlier effusions of the same magma, since small pockets of nickel ore occur in them.

Fine and coarse-grained granite also penetrates the arkose, in general older than the nickel-bearing rock, though one band of red granite near Murray mine seems to have been later. Some of the granite may even be a re-melted or re-arranged part of the arkose, though this has not been clearly proved.

At one point north of Sudbury a grayish quartz-porphyrite rises through the arkose, superficially very like the enclosing rock.

In general all these acid eruptives and many of the basic ones, though later in age than the Huronian sediments, are older than the nickel-bearing eruptive and the rocks which overlie it; and are considered to belong to the Huronian rather than to any later series.

The Laurentian

In addition to the medium and fine-grained granites mentioned above there are coarse granites and syenites often porphyritic, which merge into gneiss and have been placed in the Laurentian by most writers. There are considerable areas of these rocks from Copper Cliff west to Creighton mine, evidently younger than the green Huronian schists, since they contain patches and elongated strips of them; but generally older than the norite, which often grows finer-grained where it approaches them. Still farther to the west is a great area which has always been mapped as Laurentian, and this expands to the northward and forms the northwestern country rock of many of the ore bodies along the northern nickel range.

There is a good deal of variety in these rocks, most of which are granitoid gneisses of a dull flesh color. They may have the composition of syenite or of grano-diorite, and very commonly they include angular or tailed out masses of greenstone or green schist, sometimes of large extent. The gneissoid structure is sometimes parallel to the edge of the norite, but at different points it may be found striking in almost any direction, so that the schistosity is probably older in origin than the nickel-bearing rock, and not a result of that eruption, like the schistosity of the Huronian rocks just to the southeast of the main nickel range. There are probably granites of later age enclosed in the granitoid gneiss, but, so far as known, these are older than the nickel eruptive. A bright flesh red granite of coarse texture, cut by the Foy offset from the northern nickel range, is probably of this character.

Comparatively little time has been devoted to the Laurentian, and it should be stated that more or less greenstone or green schist, probably of Huronian age, and even a few small bands of the iron formation are covered by the Laurentian color. Comparatively large greenstone areas are known to exist west of Windy lake and east of Blue lake, near lake Wahnapitae, but lack of time prevented careful mapping of these tracts, and they are not separated from the Laurentian.

In our classification all the rocks referred to the Laurentian and Huronian are considered to belong to the Archean, while the rocks above them are looked on as probably of Animikie or later age.

Rocks above the Archean

The rocks next in age to the Laurentian appear to be the sedimentary series enclosed in the basin of the nickel-bearing eruptive, which probably represent approximately the Animikie of western Ontario. It is curious that these are nowhere found in contact with the two lower series, the Huronian and Laurentian, the eruptive sheet always separating the upper rocks from the lower, evidently because the division between the unmetamorphosed Animikie and the more crystalline Archean provided an easily invaded plane for the laccolithic magma to spread out in. When that took place the upper sedimentary deposits were in a sense floated off from their foundations.

The rocks here classed as Animikie may be subdivided into four formations, the Trout lake conglomerate, the Onaping tuff, the Onwatin slate and the Chelmsford sandstone, employing local names for the sake of convenience of description.

The Trout lake conglomerate with coarse pebbles or boulders of granite and other rocks is evidently basal and now rests everywhere upon the "acid edge" of the nickel bearing eruptive, which has profoundly acted on it by heated solutions, so that it is now the most resistant rock of the series.

The Onaping tuff is well displayed at the high falls of Onaping river, where the dark fine-grained volcanic sediments overlie the Trout lake formation; but the tuffs occur without a break all round the basin.

The Onwatin slate is black, carbonaceous, and very fissile, and lies between the tuff and sandstone, but is too soft to be well represented in the rock exposures.

The Chelmsford sandstone runs as low sharp ridges down the centre of the basin, being best represented at Chelmsford and Larchwood.

STRATIGRAPHY OF THE NICKEL BASIN

The great complication of the Huronian sediments and the eruptives penetrating them, as well as the interruption of Laurentian granitoid gneiss have made it impossible in the time at our disposal to work out with any definiteness the thickness and detailed relationships of the rocks lying below the nickel eruptive, though their probable succession in age has been pretty certainly determined. With regard to the eruptive sheet itself and the overlying sediments, much more is known and a fairly complete account of their relationships can be given. Though the eruptive is later in age than the sediments, it is convenient to begin with it as the lowest rock in the series.

The Sudbury Nickel-bearing Eruptive

The rock always found associated with the nickel deposits is found to be norite wherever fresh, as shown by von Foullon and Prof. Walker and confirmed by Dr. Barlow and myself; but it is very often weathered so as to have the composition of diorite. It has various shades of gray, generally dark along the most productive part of the southern nickel range, and passes insensibly into pale gray or flesh colored micropegmatitic syenite or granite towards the inner and upper edge. The width of the band is quite variable, running from four and one-fifth miles near the Creighton and Murray mines to five-sixths of a mile at the narrowest part near the northeastern corner of Morgan township. The average width of the southern side of the eruptive band is 3.1 miles, and of the northern 1.9 miles; and the total average width is 2.5 miles. Where the band is wide quite half of it is dark gray norite; but where it is narrower the acid (granitic) portion takes up more than half; and at the narrowest point the noritic phase is almost absent. What has been said of the basic portion of the rock applies in a general way to what may be called its most basic fringe, the nickel and copper sulphides. Roughly speaking, ore bodies are more numerous and larger where the whole eruptive is wide, and less numerous or absent where it is narrow.

The length of the boat-shaped eruptive sheet is 36.2 miles, and its greatest width 16.6 miles, the average width being 13.6 miles; so that the whole area, covered as well as exposed, is 495 square miles. The inward dip of the contact between the ore bodies, or the basic edge of the eruptive when ore is absent, with the underlying Huronian or Laurentian rock runs from 20° to 64°, and the average dip may be estimated between 30° and 45°. As the inward dip of the overlying sediments averages about 30°, this will be taken as the true average dip of the whole series of rocks.

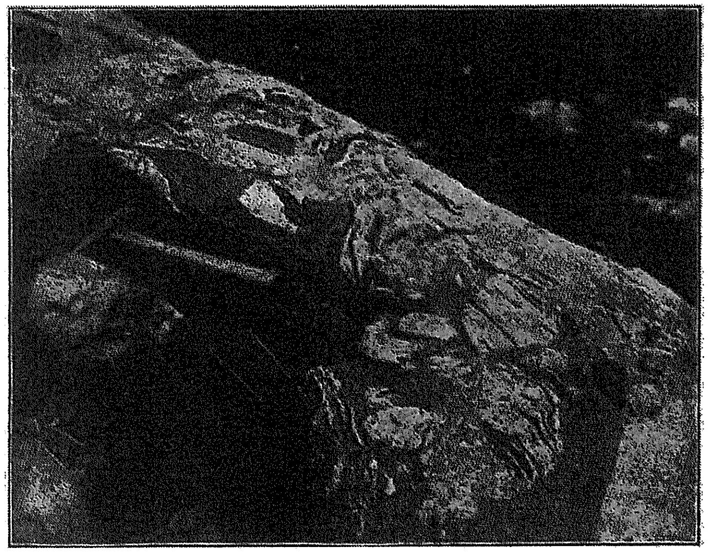
Accepting the dip at 38°, the eruptive sheet has an average thickness of 1.25 miles. If this thickness is retained in the parts hidden beneath the sediments, the total volume of the sheet is nearly 600 cubic miles; but probably the sheet is thicker in central parts, and certainly all the edges have lost greatly by erosion, so that the original volume must have been very much greater than 600 cubic miles. As the circumference of the basin is 80 miles, one mile added to its margin would increase the volume by 100 cubic miles, and in the beginning the total volume may have been 1,000 cubic miles or more. As the basin now stands the northwestern edge of the eruptive has an elevation of about 300 feet above the southeastern edge, perhaps due to more rapid weathering of the much wider basic part found along the southeastern side.

The basic edge sends offsets into the surrounding rocks for distances up to eight miles, in places continuous and dike-like, but often discontinuous and irregular; and the acid edge also projects into the overlying rocks, though none of the apophyses have been traced for notable distances.

The lower rocks have been greatly crushed and faulted, and coarse breccias have often been formed of the blocks, cemented with narrow bands of norite or with ore.

General Features of the Basin

The origin of the synclinal basin whose rocks, ranging from the nickel-bearing eruptive beneath, to the Chelmsford sandstone on top, have just been described is most easily explained by supposing that the source of the 600 or 1,000 cubic miles of eruptive magma now solidified as the great laccolithic sheet was immediately beneath the basin itself. As the magma welled up and spread out broadly beneath the originally horizontal sediments the floor of crystalline Archean rocks (Huronian and Laurentian) collapsed owing to lack of support and underwent great faulting and shearing, as may be seen in the complex system of fault planes and crush breccias displayed near Sudbury.

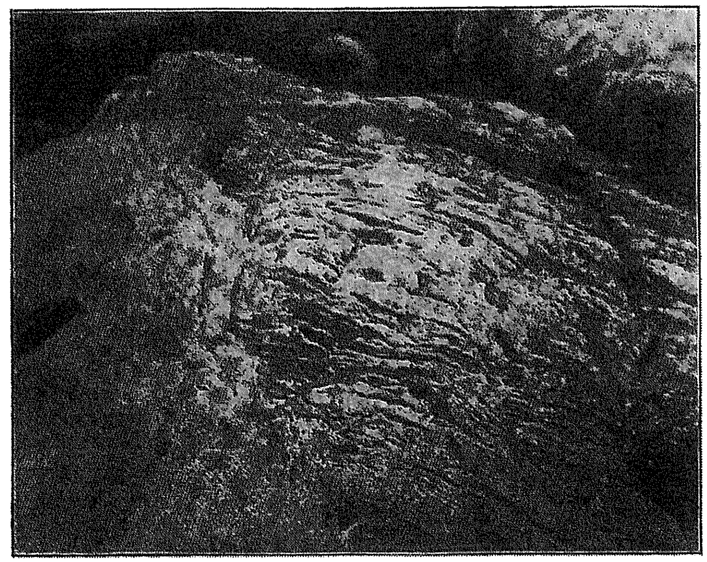


Crushbreccia, hill south of Creighton.

In a general way the sedimentary series of the basin was cushioned by the molten sheet more than a mile thick beneath it, so that faulting is not very prevalent in the upper rocks; but the gradual sinking of the substructure brought the uppermost layer that of the Chelmsford sandstone, into compression, causing gentle anticlinal folds or elongated domes.

The sources of the magma extended from northeast to southwest, so that the main effect of the collapse of the underlying Archean rocks was to produce compression at right angles to this plane. Hence we find a well marked slaty cleavage in all parts of the sediments which were not impregnated with materials from the eruptive and so hardened. The fissure from which the molten rock came was probably somewhat curved, being convex toward the northwest, so that the slaty cleavage in the southwest end of the syncline runs from 60° to 70°, while toward the east end it bends to 80° or even to southeast at the extreme corner.

In general the slaty cleavage is nearly vertical with a tendency to incline toward the southeast; but along that side this tendency becomes more marked until at the edge a well defined schistose structure is developed, dipping even 45° or 35° to the southeast and flattening the pebbles of the basal conglomerate, as on Whitewater lake. Since the eruptive sheet is nearly twice as thick on the southeast as on the northwest side (the width on the surface being 3.1 miles to 1.9 miles) the greater weight may have had an important effect in producing a more extensive collapse on this side, or else the sinking of the substructures was greater here, permitting a thickening of the sheet. The fractured and faulted and slickensided character of the country rock at



Fault hill, south of Creighton

the Creighton and North Star mines may be accounted for in this way. It is possible too that the peculiar broad bay-like margin of the acid edge between Gordon and Whitewater lakes and the projection of two long and important offsets from the basic edge, at Victoria mine and Copper Cliff, as well as the separate nickel-bearing band of Frood and Stobie mines, may be brought into connection with the great weight of the fluid or plastic magma at this part of the southern edge, where it is thicker than elsewhere.

After the eruption of the nickel-magma a long continued process of segregation took place, to some extent at least under the influence of gravitation, the sulphides sinking into depressions of the Archean substratum, and the more acid and lighter portions of the rock rising to the upper part of the sheet. The great thickness of the overlying sediments, estimated at 10,230 feet (with an average dip of 30°) was sufficient to render the cooling exceeding slow, permitting of a very perfect separation of the heaviest ingredients, which were also the most fluid, at the bottom.

Later Eruptives

As explained before, the nickel-bearing eruptive is younger than the series of sediments which rest upon it, but it is by no means the latest eruptive of the district. Penetrating its edge near Murray mine and Copper Cliff there are flesh-colored to gray medium-grained granites, and within the eruptive north of Murray mine and near Whitson lake, as well as in other places, there are pale or flesh-colored granitic rocks, probably later dikes or irregular bosses; so that the main laccolithic sheet was followed by more acid flows of a somewhat later age, but perhaps before the sheet had completely lost its heat.

Probably at a much later time, after the whole region had cooled down, fissures several miles in length and often more than 100 yards wide were opened through all the earlier rocks and filled with olivine diabase, the freshest rock in the region. This took place after even the most fluid and lowest portion of the nickel-eruptive, the pyrrhotite of the ore bodies, had completely cooled, for the dikes cross indifferently from it to the granitoid gneiss or the norite, but have a more glassy edge against the ore than against the other rocks, since the sulphides were better conductors of heat and chilled the dike more quickly.

These very numerous olivine diabase dikes remind one of the dikes and "Logan sills" of the Port Arthur Animikie and may be of the same age, Keweenawan, though there is no direct proof of this, since distinctively Keweenawan beds have not been found in the Sudbury district, the nearest point at which they are known being on the east shore of lake Superior 150 miles away.

Still later than the diabase dikes, and the latest known rocks of the district, except the Pleistocene, are some narrow granite dikes which cut the diabase itself about three miles west of Sudbury. These are probably post-Keweenawan. It is understood of course that all the rocks described are to a greater or less extent covered with boulder clay, moraines, kames and eskers, and that wide-spread beds of stratified clay, sand and gravel deposited in post-glacial lakes come later still; but none of the fossiliferous beds of the Palaeozoic touch the district so as to fix the upper time limit of the unfossiliferous rocks above described. The nearest Palaeozoic strata are the Cambro-Silurian beds of Georgian bay, 36 miles to the southwest.

The succession of rocks in time is given in the following table:

Table of Formations

PLEISTOCENE		Sand and clay.
KEWEENAWAN		Latest granite dikes. Olivine diabase dikes. Granite. Sudbury nickel-bearing eruptive.
ANIMIKIE		Chelmsford sandstone. Onwatin slate. Onaping tuff. Trout Lake conglomerate.
ARCHEAN	Laurentian	Granitoid gneiss.
	Huronian	Acid and basic Huronian eruptives. Ramsay Lake graywacké-conglomerate. Copper cliff arkose. McKim graywacké.

CHARACTER OF THE SUDBURY ORES

The ores of the Sudbury mining district are extraordinarily uniform, three sulphides only making up practically the whole of most of the ore bodies, and only two as a rule presenting themselves to the eye, pyrrhotite or magnetic pyrites, and chalcopyrite or copper pyrites. The third one, pentlandite, is much the most important, though commonly invisible in the ore except at a few of the richer mines, where it appears only occasionally.

The mineral present in much the largest amount is pyrrhotite, a sulphide of iron whose composition as given varies from Fe_8S_9 to $Fe_{16}S_{17}$. It is pale bronze with bright metallic lustre on fresh surfaces, but quickly tarnishes to brown, and very readily weathers, turning to a rusty mass, the gossan which is so characteristic of all the nickel mines. It almost never appears in crystals, though a certain platy character at a few mines suggests crystalline structure, and it may be from coarse to fine-grained. Its property of magnetism distinguishes it from other sulphides, since it is easily attracted by the magnet, while others are not, but the strength of its magnetism varies considerably in different localities, for reasons not certainly understood. The most highly magnetic ore of the region is found at Blue lake toward the northeastern end of the ranges, specimens from there having distinct polarity and attracting iron filings. In other parts the pyrrhotite is too feebly magnetic to do this, though it always shows a powerful effect on the compass or dip needle. Attempts have been made to locate ore bodies where hidden by drift or obscured in other ways by means of the dip needle or more delicate appliances, such as the Thompson-Thalén magnetometer, and a considerable amount of magnetic survey work has been done by Messrs. Nystrom, Kay, Miller and others, for the Mond Company, the Lake Superior Power Company and Mr. Thomas A. Edison. It cannot be said however that up to the present any very important practical results have been attained by this method of exploration.

In a few places pyrrhotite has occurred almost to the exclusion of copper pyrites, as at Gertrude mine, where there was so little copper in the ore that plans were made at the Sault Ste. Marie for roasting it, and reducing the resulting oxide directly to ferro-nickel; but even at the Gertrude, mining operations soon showed a considerable amount of chalcopyrite, making the ore unsuitable for that purpose.

Though the chalcopyrite is generally present in much less quantity than the pyrrhotite, occasionally, as at the Copper Cliff in early days, it may form the larger proportion of the ore. The two sulphides commonly occur together, the brassy lustre of the chalcopyrite distinguishing it from the bronze of the pyrrhotite, and polished surfaces of ore show quite irregular arrangements of the two minerals. They do not appear to be very minutely intermixed as a rule however, and it is not difficult to select fairly pure examples of each.

Pure pyrrhotite contains on the average about 3.21 per cent. of nickel in the Sudbury region, and pure copper pyrites, having the composition $CuFeS_2$, contains 34.5 per cent. of copper. Since the ores of the district produce on the whole about equal amounts of the two metals, the proportions of the two minerals in the ore must be about 10 parts of pyrrhotite to one of chalcopyrite.

The variations in the proportions of the two minerals even in the same ore body are sometimes wide, as at Copper Cliff, where the percentages obtained in different years present differences such as 4.65 copper to 4.46 nickel at one time and 7.81 copper to 2.87 nickel at another. The different mines vary even more widely from one another in this respect, the Creighton, for example, having nearly 5 per cent. of nickel to 2 of copper, in contrast to the percentage given above for Copper Cliff.

It is probable that the chalcopyrite is a little more mobile in the ore bodies than the pyrrhotite, since it is more commonly found filling fissures in the country rock, or as a film between slickensided surfaces of the later diabase dikes. It has been observed also that at Copper Cliff the ore body was richer in copper when narrow, and in nickel when wide, so that the relations to the adjoining rocks appear to have some influence on the distribution of the two minerals.

The third and most important mineral is pentlandite, a rich ore of nickel, having the composition (Fe, Ni) S, with a varying amount of nickel sometimes reaching 35 per cent. or more. It is not easily distinguished from the pyrrhotite in which it is embedded in fresh ore, the main difference being its rather perfect octahedral cleavage, but its brassy lustre on slightly weathered surfaces is characteristic. It has not been found in a number of the mines, probably because too finely disseminated; but at Creighton, Worthington, Evans and a few other deposits, it sometimes occurs with cleavages half an inch wide. As experiments carried out by several persons, including Messrs. Browne, Judson, Dickson and Ogilvie, have proved that with fine crushing a magnet will separate a more magnetic part with little nickel from a less magnetic part rich in nickel, it seems probable that most if not all of the nickel is contained in pentlandite, which is non-magnetic, and that the pure pyrrhotite would be found to contain little or no nickel.

Iron pyrites in both its varieties is not infrequent in the ore deposits, sometimes as distinct octahedral crystals enclosed in pyrrhotite, sometimes in larger quantities with no crystal forms and belonging to the variety marcasite. In the latter case it may contain a considerable percentage of nickel, as near the Worthington mine.

Several other compounds of sulphur and arsenic with iron and nickel occur in the deposits, but in such small quantities as to have no importance as ores, so that they may be left for consideration to the chapter on the minerals of the nickel region

RELATIONS OF ORE TO ROCK

It has already been stated that the Sudbury ore deposits are all connected with a single sheet of eruptive rock or its offsets, but it will be well to discuss the relations of ore to rock more in detail, since this has a very practical bearing for the prospector and miner as well as great theoretic interest for the geologist and mining engineer.

Prospectors long ago recognized that the ore is always associated with a particular kind of rock, diorite as it was generally called, though the work of von Foullon, Prof. Walker and others has proved that it is norite, a variety of gabbro, in which a rhombic pyroxene is important. On the ordinary weathered surface of the rock so easily attacked a sulphide as pyrrhotite practically never shows itself, being completely oxidised to limonite, whose rusty brown color is very characteristic. In the field, therefore, it is the burned-looking rock covered with gossan which attracts attention, and this has been so carefully sought for that every patch of it surrounding the nickel eruptive has been taken up by prospectors. The gossan varies in thickness from a mere film to deposits of limonite several feet thick, and almost important enough to be worked as iron ores. It is only where an impervious sheet of till has covered the fresh rock surface that the sulphides are still found fresh, and I have observed this only on a finely polished and striated surface at the Creighton mine, now completely removed. Even in the few years since mining began, the older strippings and the waste rock have been so weathered that fresh material can no longer be seen, and large fragments must be broken to show the unchanged sulphides.

In crossing the eruptive from the acid edge toward the basic edge little rusty holes like "pock marks" are the first indication of ore, and they may occur half a mile or rarely even a mile from the actual edge, with rock surfaces free from spots between. As the basic edge is approached, in most cases the spots are closer together or form blotches which unite into a sheet of gossan over ore bodies at the margin of the eruptive and for a short distance beyond over the country rock.

Ore bodies are not found everywhere along the basic edge, though one may walk for miles along that edge in places without an important break in the rusty band. There are however a few places along the circumference near Windy lake and toward the northeast of Morgan township, in the northern range, where no gossan or only a few of the pock marks are found, so that the distribution of ore is evidently very unequal. It will, of course, be understood that gossan does not everywhere mean an ore deposit of workable size, though a large area of gossan has nearly always been found to indicate an ore body worth developing.

The most satisfactory places for the study of the relations of ore and rock are naturaly the mines, and a number of geologists from various coutries have examined them with this point in view, most of them agreeing that ore and norite were parts of the same molten rock from which the ore segregated toward the edge; though a few think that the ores have been deposited by hydrothermal means by replacement of the rock-forming minerals of the norite. The evidence in favor of the theory of magmatic segregation is excellently given by Dr. Barlow in his report on the region.[16] The idea that ore bodies could be formed by the slow separation of the heavier materials at the edge of a molten rock mass was elaborated by Prof. Vogt of Christiania for the nickel ores of Norway, which have similar relationships to ours; but at about the same time Dr. Barlow expressed the same view of the Sudbury deposits, stating in 1891 that "the ores and the associated diabase were therefore in all probability simultaneously introduced in a molten condition, the particles of pyritous matter aggregating themselves together in obedience to the law of mutual attraction."[17] Dr. Adams applied Vogt's theory to the Sudbury deposits. Prof. Walker has supported the same explanation of the relationships, and the late Prof. Stetzner of Freiberg in Saxony in a letter to Mr. G. R. Mickle in 1892 makes the following statement as to these ores:

"Polishing one side of rather large pieces gives very pretty results. In the ore from the Vermilion mine one sees plainly—much more plainly than on the surfaces of fracture—the intergrowth of pyrrhotite, chalcopyrite and characteristic yellow lamellae which might be either millerite or polydymite. Morover on a polished surface like this the black rock inclusions in the sulphides show up plainly. The true nature of these inclusions and their relation to the ore is disclosed by the sections. One sees then that these black rock inclusions in no way are sharply divided from the sulphides but are connected with them by quite gradual transitions. Those of the Vermilion ore consist of quartz, brown mica, chlorite, hornblende and some epidote; those of the Murray ore of triclinic feldspar, augite, which is more or less decomposed, some brown mica and epidote. The intergrowth with the ore is such an intimate one that I cannot regard the black specks as fragments enclosed by the ore, but can see in them only formations which are of the same age as the ore. Similar relations of ore and country rock occur also in the Norwegian pyrite and in the pyrrhotite."

On the other hand there have been a few who oppose this theory, such as Posepny, who thought the presence of metallic sulphides in the magma of a molten eruptive rock an impossibility;[18] and H. W. Hixon, manager of the Victoria mines, who appears to share Posepny's view.[19] Dr. C. W. Dickson is one of the latest defenders of the theory of aqueous deposition, and his summing up of the points which favor that theory is probably the best that can be made.[20] He seems however to have been singularly unfortunate in the choice of his material for study, since he has selected almost without exception the brecciated rock material enclosed in the ore, and judging by his photomicrographs and descriptions, has not studied the opposite phase in which the norite is thickly speckled with the ore particles. Descriptions of such specimens will be given later under the chapter on petrography.

Dr. Dickson believes that almost all the evidence favors the work of water as the means of deposition of the nickel ores, but in this he is almost alone among the geologically trained students of the region, and is apparently opposed to the views of Prof. Kemp in whose laboratory he studied.

My own work convinces me that the theory of magmatic separation accords best with the facts, but that there has been some subsequent re-arrangement of the ores by solution and re-deposition in all the ore bodies, this being much more marked in offset deposits than in marginal ones. Many of Dr. Dickson's examples are from offset deposits, and naturally enough for one who had but a short time for field work in the region, he does not distinguish their characters from those of the marginal deposits, which point more clearly to an origin from the molten norite.

[16] G. S. C., Vol. XIV, Part H, pp. 123-132.
[17] Ibid. 1890-91, 128 S; also Ottawa Naturalist, 1891.
[18] Genesis of Ore Deposits, p. 146.
[19] Geol. Sud. Dist., Eng. Min. Jour., Dec. 29, 1904, p. 1022.
[20] Trans. Am. Inst. Mining Engineers, Vol. XXXIV, pp. 25-66.

Points favoring Magmatic Differentiation

Although the mode of formation of these and similar ore deposits has been widely discussed from various sides, so that most of the arguments for and against their igneous character have already been presented, the question is of so much interest that it is desirable to cover the ground once more; and to begin one may ask the defenders of the hydrothermal solution theory what is the real source of sulphide ores? The warm circulating waters must have obtained them from rocks of some kind, and at no very great depth, for open fissures are not possible at depths of more than a few miles. We know that the sulphides of the schists underlying the nickel eruptive are only slightly nickeliferous, and that the probable source of the ore must have been some heated mass of eruptive rock. If the original sulphides were obtained from a hot eruptive rock, they must have formed part of that magma, for there is no other source possible.

It has been shown there is reason to believe that the sheet of nickel eruptive is a mile and a quarter thick and that it is covered by about two miles of sediments, so that in the beginning its lower side, where the ores occur, must have been more than three miles below the surface. What theoretical improbability is there in supposing that the sulphides everywhere associated with the norite were an original part of the molten magma? If the solutions were obtained from molten, or at least heated, eruptive rock at a few miles depth, why should not such an eruptive as the nickel-bearing sheet more than three miles down bring the sulphides with it? This should be sufficient answer to Posepny, who believed that sulphides could not form part of a molten rock. We know that sulphides do form parts of such rocks, and there seems no inherent reason why from a mile and a quarter's thickness of magma sulphides enough to make the nickel deposits should not separate out, probably helped by gravitation.

The arguments for magmatic segregation in the Sudbury district may be given briefly as follows:

1. The ores are everywhere associated with the norite of a single eruptive sheet. No ore occurs without norite. No long stretch of the lower edge of the norite or its dike-like offsets is entirely devoid of ore.

2. Norite and ore are mixed in every degree from rock enclosing scattered particles of ore, to pyrrhotite-norite in which ore and rock are in equal amounts, and finally to almost pure ore with a few rock-forming minerals scattered through it. This relationship is found at every mine. Norite spotted with ore is sometimes found in bands a long distance from the nearest ore body and separated from the basic edge by rock free from ore.

3. The adjoining rock, granite, gneiss, greenstone or graywacké, is never spotted with ore, and separated bodies of ore are never enclosed in it, but veinlets of ore may penetrate the country rock, and almost always blocks of it are enclosed in the ore. The shattering and crushing of the country rock took place when the nickel-eruptive forced its way between the upper sediments and the lower crystalline rocks, and the heavier and probably more fluid sulphides filled all the spaces thus opened. There are often clean walls of country rock against large bodies of pure ore.

4. The freshest norite is generally close to the ore bodies and is often shotted with ore. The best preserved hypersthenes at the Murray, Creighton and Gertrude mines are in sections containing sulphides and not in specimens free from sulphides at a distance from the mines. No considerable amount of re-arrangement caused by water could have taken place without changing so susceptible a mineral as hypersthene into secondary minerals.

5. The marginal ore bodies show hardly a trace of hydrothermal or pneumatolytic action. There are seldom any of the minerals usual in deposits formed by water except very small quantities of quartz and calcite, and these are often in seams cutting the

ore and evidently of later formation. There is no banding such as one finds where cavities are filled with minerals deposited from solution; nor are there concentric structures about the rock fragments enclosed in the ore.

6. The deposits are extremely uniform, as shown by Dr. Barlow, a fact hard to account for in mines scattered along a length of 35 miles with entirely different country rocks on one side unless they have had a single source, the norite, which is as monotonous as the ores themselves.

7. The largest ore bodies are where bays of the norite project into the country rock or on offsets from such funnel-like bays; there is seldom a deposit of importance along a straight margin; and no ores are found on parts of the margin which project inwards instead of outwards. This is intelligible if the ore settled into the hollows under the molten sheet, but quite unaccountable if it was brought in solution from elsewhere along the channels furnished by the contact.

While the whole of the ore belonged originally to the magma of the eruptive sheet, some parts of it have been dissolved and re-deposited in all the mines, for instance in fissures in diabase dikes which cut the ore bodies; and the process of re-arrangement is more marked in offset deposits than in marginal ones. In them there are often small quantities of quartz and carbonates probably deposited by water. Finally there are a few deposits accompanied by little norite and containing arsenical compounds, nicolite and gersdorffite, such as the Worthington and Vermilion mines, which may have been formed principally through the action of heated water circulating along fissures at distances, sometimes miles, away from the edge of the great eruptive sheet.

TYPES OF ORE DEPOSITS

The Sudbury ore deposits have been described in various ways by different observers, as veins, or stockworks, or lenses, and there are examples that suggest all of these forms, though none of them seems really characteristic. Vein-like deposits with continuous well defined walls reaching for any distance are unknown, though a small outcrop of ore southwest of Copper Cliff somewhat suggests a vein. The brecciated rock enclosed in ore and the narrow seams of ore projecting into the country rock found at many mines, such as the Mount Nickel and Blezard, have some of the usual features of a stockwork, but this arrangement of rock and ore, though more or less present at the edge of the underlying country rock at all the mines, is not the most prominent feature, since it often passes into solid ore with hardly any rock at the larger mines. The term lens also is not entirely appropriate, since it implies a deposit thicker in the middle and narrowing in each direction, with fairly definite walls of country rock, conditions seldom found in the nickel district. On the whole then none of the names mentioned seem entirely suitable, and it is hard to suggest a good general term for the deposits.

Looking at the nickel ranges in a broad way two or three types of deposit seem pretty distinct, as suggested in a former report of the Bureau of Mines;[21] and this accords fairly well with Dr. Barlow's treatment of the question, since he also makes three types, though with somewhat different definitions.[22] The types of greatest importance may be spoken of as Marginal Deposits and Offset Deposits.

Marginal Deposits

The marginal deposits are found at the basic edge of the eruptive sheet along the contact with the underlying rock, and so have to the southeast on the southern range and to the northwest on the northern range a wall consisting of the older rocks, gneiss, granite, greenstone or graywacké. This is generally, however, very uneven and irregular, especially on the southern range, and often modified by faulting. On the northern range,

[21] 1903, pp. 278-280. [22] Geol. Sur. Can., Vol. XIV, Part H, p. 120.

as at the Levack mines, the gneiss of the foot wall dips southeast at from 20° to 40°, and the ore follows it as an irregular sheet. On the southern range the underlying rocks have generally been a good deal shattered and faulted, so that there is less regularity, the foot wall, if it may be so called, being rugged and much broken up, but having in the main northwestward dips of 40° to 60°. Fault planes, as at North Star, may, however, provide a well marked foot wall with a steep dip of 65° to 80°.

On the inward side toward the norite there is seldom anything which can be called a wall, unless some faulting has occurred, and the ore deposit practically blends into the norite, work being stopped in that direction when the mixture of ore and rock becomes too poor to exploit.

The marginal deposits then are irregular sheets of ore penetrating slightly and enveloping fragments of the foot wall and fading out on the hanging side into norite with too little ore to be workable. They always dip inwards toward the axis of the syncline. They may have any thickness from a few feet of solid ore with a corresponding thickness of mixed ore and rock to 250 feet of pure and mixed ore in all; and the length is equally variable but usually several times the thickness, in the case of the Creighton mine reaching several hundred feet. In fact one deposit may be connected by a fringe of ore along the edge of the norite with another a quarter or a half mile away, as the Murray mine is connected with the Elsie. How deep the ore bodies go on the incline in unknown, since the deepest workings are not beyond 172 feet (at the Blezard mine), though diamond drilling proves that the Creighton ore occurs at a depth of 400 feet, and its great open pit reaches 140 feet. Theoretically there is no reason why these ore bodies should not extend downwards indefinitely if the basin-shaped depression of the country rock continues, and it would be most interesting to have a few drill holes sunk at some distance in from the basic edge where an important deposit occurs in order to test the matter.

The marginal deposits include the Creighton mine, which may safely be called the greatest nickel mine in the world, having already produced probably more than 500,000 tons of rich ore, and, as it is supposed from the results of diamond drilling, having millions of tons in reserve.

Offset Deposits

Offset deposits occur on dike-like projections from the basic edge of the norite, and the type will be considered to include isolated ore bodies on small outcrops of norite which represent the continuation of an offset after a short interruption, in this respect differing from Dr. Barlow's classification, in which the separate ore bodies are put in a third type. In general character the ore bodies in isolated outcrops of the norite differ hardly at all from those on the dike-like projections from the main range, and we may safely assume that there are or were channels connecting them with it, either beneath the surface or above the present surface, through rocks which have since been eroded away.

The offset ore bodies are as irregular in form as the marginal ones, but they do not often show the one-sided arrangement forced on the others because of their position between the overlying norite and the underlying country rock. Often they are rudely cylindrical or oval with an elongation in the direction of the offset, and where the offset is narrow they may in places fill almost the whole width to the more or less complete exclusion of the norite. They are apt to occur at the end of a norite offset or where there is some obstruction of the channel, and very large chimney-like masses of ore may be found in small outcrops of norite, as at Copper Cliff or Stobie.

The best known of this type of mines is the Copper Cliff, where an irregularly oval body of ore, split in the lower part by a horse, has been followed down 1,000 feet, with an average width of 50 to 90 feet in one direction and 75 to 200 feet in the opposite one. The cylinder dips at an angle of 77½° toward the northeast. The neighboring mine to the north, No. 2, has also a cylindrical shape, but its section is much greater, about 120 by 280 feet, and its known depth only 400 feet. This ore body is nearly vertical with a slight inclination to the west.

The Stobie mine is an example of a very irregular offset deposit, large bodies of ore being loosely connected with one another at various levels. More than 400,000 tons of ore have come from it, and it is said to be far from exhausted.

In a general way, the offset deposits show the same mingling of ore and rock observed in the marginal deposits, fragments of country rock of all sizes being enclosed in ore, and intimate mixtures of ore and norite occurring on their rock dumps; there are however more evidences of the action of water, such as quartz and carbonates in small amounts, and even traces of other sulphides such as galena.

There should perhaps be a third type of ore deposit defined in which little or no undoubted norite is found and so much evidence of pneumatolytic action that its formation should be considered due almost entirely to the action of water, though the materials were derived from the norite. This division might include the Vermilion mine and possibly also the Worthington and one or two others in the same region.

A good deal of confusion has resulted in the past from the non-recognition of the difference in type of the two chief kinds of ore deposits, and Dr. Dickson's work, which appeared since the distinction had been made by the Bureau of Mines, is seriously injured by not observing it. To draw inferences from the earlier worked chimney-like ore bodies near Copper Cliff, with their nearly vertical attitude, relatively small amount of much altered norite, and considerable evidence of water action, and apply the results to the marginal type of deposits in quite unjustifiable; and can only lead to error.

THE SOUTHERN RANGE IN DETAIL

The special work done in the Sudbury district has naturally been the examination and mapping of the nickel ranges and their associated rocks, and this has been carried out in detail at the various nickel mines of the region, the parts of the area which are less important from the economic side receiving less attention. As our work focussed mainly on the basic edge of the nickel-bearing eruptive and its offsets, the only parts where valuable ore deposits have been found, it will be convenient to follow the basic edge of the eruptive in detail, describing the ore deposits and adjoining rocks and referring to the results of mining operations. The acid edge of the eruptive will also be sketched with its associations, but in a more summary way. As it has been found that the width of the eruptive has an important bearing on the number and size of ore bodies it is advisable to take up both edges of the sheet, the upper, or acid, as well as the lower, or basic, edge in order to give a complete account of the ranges.

Our work has proved that in reality the outcrop of the nickel-bearing sheet is continous round the whole basin, though hidden for a distance by gravel plains toward the southeastern corner, yet the custom of the region divides the known ore deposits into two ranges, the main or southern range and the northern range, and it will be convenient to follow this usage. We shall begin at the southwest end of the boat-shaped basin and work northeastwards along the southern range, and afterwards take up the northern range in a similar way. The ranges will be looked on as continuous, the norite edge being followed the whole way, though sometimes for miles no ore bodies are known to exist along it. The offsets will be described along with the main ranges, so as to give the relationships in the most comprehensive way, though in many cases the actual physical connection between the two may not be apparent on the surface.

It need hardly be said that the present nickel-bearing rocks are only a remnant of a sheet which formerly extended more widely in all directions and perhaps covered more than double its present area. That weathering and erosion have destroyed hundreds of cubic miles of the rock and millions of tons of the ore is evident from the present arrangement of things at the truncated edges of the sheet, so that we can now examine the condition of affairs at a depth of at least two or three miles below the original surface of the country. In the beginning the basic edge of the southern range was covered by the overlying eruptive sheet to a depth of nearly two miles, and above this we may suppose that the sediments of the Trout lake conglomerate, Onaping tuff, Onwatin slate and Chelmsford sandstone, reached a thickness of two miles. It is then the basement of the region, where much fracturing, faulting and settlement went on during the excessively slow cooling of the molten sheet, that is at hand for study, and many points will be more intelligible when this is borne in mind.

Sultana Nickel Mine

At the southwest end of the southern nickel range is the Sultana nickel mine, reached from Worthington on the Sault branch of the Canadian Pacific Railway, by a road about 7 miles in length. The deposit is on lots 7 and 8 in the VI concession of Drury township, and the same lots in the I concession of Trill. The houses and office used during the development of the property stand near the corner post between the lots just mentioned; and the strippings and other workings follow the foot of the hill in a direction 10 degrees west of north for about a quarter of a mile from the corner post, so that the actual workings are in lot 8 of Trill; but one or two small outcrops occur on the hillside at a distance of 9 or 10 chains south of the corner post also. Part of the deposit is therefore in Drury, and the known extent of the ore is three-tenths of a mile. It is probable that careful search would disclose ore still farther to the south along the edge of the hill, but the bush is thick and no other hints of gossan were found.

Most of the ore to the north of the camp is along the lower flanks of the hill, but an offset runs 9 chains to the west a little north of the corner post, and two large strippings at this point show ore at the hill top 117 feet above the flat at the bottom.

There are three shafts, respectively 13, 19 and 22½ chains to the north of the corner post, and beyond the last shaft the hill turns off to the west, and no more ore is to be seen. The deepest shaft is said to be down 110 or 120 feet; and there is a considerable quantity of ore on the dumps. A drill hole sunk a little to the east of the last shaft showed 36 feet of clay and sand, then norite followed by some ore, and finally greenstone with more or less ore. The dip of the rock surface between the shaft and the drill hole is about 40 degrees to the east.

In general the ore in this locality seems to lie in depressions of the hill as if it had settled into the lowest places. As the rocky hills bounding the swampy valley to the east and west seem to be converging toward the south, it is not unlikely that ore may be found beneath the swamp or drift in that direction, but up to the presnt none has been reported; nor is it known if an offset runs southwards into Drury township.

The rocks forming the hill west of the gossan are not Laurentian, as suggested on the old maps, but are more like Huronian, since they include green schist and diorite, with irregular patches of what appears to be norite penetrating them and showing on the flank of the hill toward the low ground. Much of the hill has the look of crush conglomerate.

The norite north of the Sultana is greatly mixed with older rocks, especially a flesh-colored arkose, and for half a mile in that direction, if it were not for the finding of the basic edge near the mine and the acid edge still farther north, one would be in doubt as to the relationship. There was a great amount of crushing and faulting of the older rocks with the eruptive toward this narrow southwest end of the boat-shaped trough; but the thickly wooded surface prevents a very complete study of the geology. Just west of the Sultana mine the boundary of the norite is hard to trace, but about a mile to the northwest it is clearly seen again not far from a wagon road, now fallen into ruin and grown up with bushes, on the way to the Trillabelle or Gillespie mine, and there appears to be a small bay of mixed Laurentian and Huronian projecting into the eruptive to the north of the Sultana.

To the east of the hill along whose slope the Sultana ore is found a wide swamp stretches across the valley toward what is called the Sultana East property, where gossan shows on a hillside facing northwest and runs round the end of the hill just within the township of Trill, and then enters the VI concession of Drury in lot 7, running a little south of east into the next lot. The hillside dips away into a swamp to the north, and gossan with small pits showing ore extends for about 230 yards. Between the outcrops on each side of the valley one low hill of gray norite rises above the muskeg, but no ore has been found there. The country rock of the Sultana east is greenstone mixed with coarse gabbro or anorthosite and a little gneissoid rock, so that it belongs to the Keewatin or Huronian. The northward slope of the hill, which represents the foot wall of the ore, is not far from 40°.

To the east of the Sultana the basic edge of the eruptive bends southeast, is not accompanied by ore, and consists of medium to coarse-grained norite with granite or gneiss to the south, a band of swamp usually separating the two rocks, and in lots 3 and 4 hiding the contact altogether.

The Chicago Mine

A mine variously called the Chicago, or Travers, or Ines, in lot 3, con. V of Drury township, is the next point where ore has been found. It is reached by the road from Worthington mentioned before and was formerly connected with the railway at that point by a curious overhead tramway with only one rail, from which buckets were suspended and drawn by horses.

The mine is on an offset at a distance of about a quarter of a mile from the basic edge, Laurentian appearing between, while the ore is enclosed in a very mixed Keewatin or Huronian rock consisting of greenstone, green schist, porphyrite and anorthosite. The workings include a small open pit and a shaft reaching a depth of 160 feet, and the pockets of ore do not seem to have been large, though some thousands of tons were roasted and smelted to matte at the mine, the products being trammed to Worthington and shipped away.

The houses connected with the mine are placed some distance to the north of the shaft house and smelter, near the basic edge of the eruptive, which consists of coarse gray norite.

Acid Edge in Trill and Fairbank

The acid edge of the nickel-bearing eruptive is best studied form a succession of small lakes which follow its margin and give good sections of its contact with the conglomerate and tuff. The edge runs north and south across Ross lake and an unnamed lake half a mile to the south, then turns east to Cameron lake, and continues east to the northwest corner of Fairbank lake. From Cameron lake to Sultana mine the eruptive is only two miles wide, but at Fairbank lake the width increases to four miles. Near the unnamed lake, and also Ross lake, the boundary rises as sharp hills nearly 300 feet high, and the sedimentary rocks seem to have been much crushed and faulted, probably because of the narrowness of this end of the basin. The basal conglomerate is prominent with very large granite boulders, and coarse white quartzite, dark gray cherty rock, and hardened tuff occur somewhat mixed with felsitic looking rocks. The acid edge itself consists of fine-grained dark greenish, schistose, material which is far from suggesting syenite or granite, but really consists mainly of micropegmatite.

The north shores of Fairbank lake are formed of the same dark green schistose phase of the acid edge, while farther south there are dark reddish syenitic looking rocks followed by gray norite south of the lake to the Chicago mine.

After touching the northwest bay of Fairbank lake the acid edge first runs eastwards and then northeast to Gordon lake, and at a peninsula toward its east end bends southward for fully a mile, after which it turns northeast once more from about the middle of lot 4, con. II, in the township of Fairbank. The boundary between the acid eruptive and the conglomerate is often very indistinct along this sharp southward bend, bands of rock without pebbles alternating without regularity with parts crowded with pebbles, the whole forming a belt a mile or more in width. The strike of the schistose structure, which is well marked in the acid edge as well as in the rolled out conglomerate, is 65° or 70°, and not parallel to the direction of the eruptive contact, a feature very seldom seen elsewhere in the basin. The dip of the schistosity is about 45° to the southeast; but the dip of the stratification, as somewhat vaguely shown by bands crowded with pebbles and boulders, is 25° or 30° to the N. W. It is likely that the great width of the conglomerate in this part is due to a flattening of the dip caused by faulting in the Archean supports of the eruptive sheet near Vermilion mine, as will be noted later.

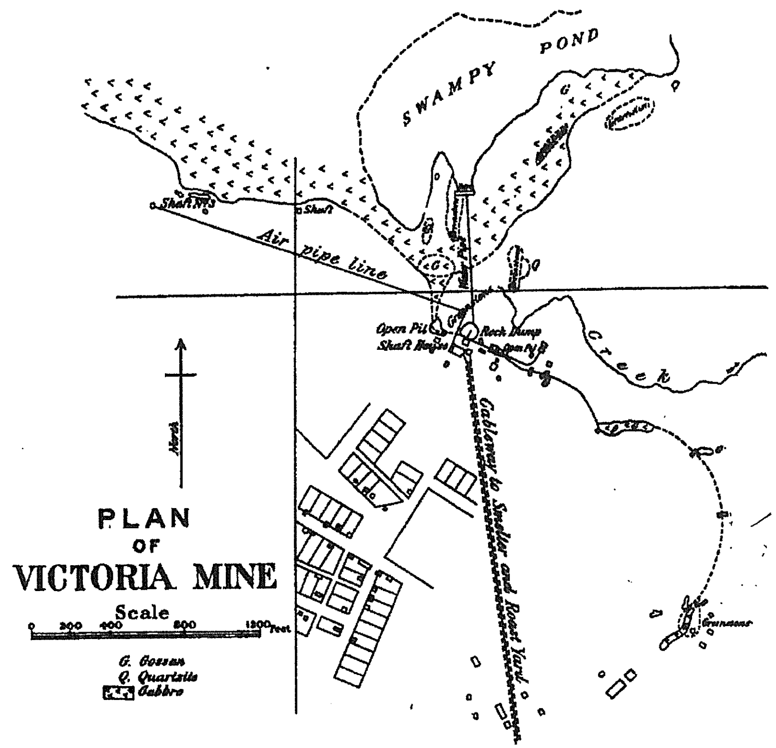
The Victoria Mine Region

Returning to the basic edge of the eruptive, it may be followed east from the Chicago mine to the boundary of Denison township, where for some distance it disappears under drift materials. The most westerly ore deposit in the township is in the south half of lot 11, con. V, or perhaps the north half of the same lot in the IV concession, the boundary lines being almost impossible to follow in this township. There are two large pits and several smaller openings or strippings disclosing a good deal of mixed ore, which lies against a hill of greenstone and green schist. To the north the low ground is largely swamp, but some coarse-textured norite occurs, sometimes crushed and sheared into conglomerate or squeezed into schist.

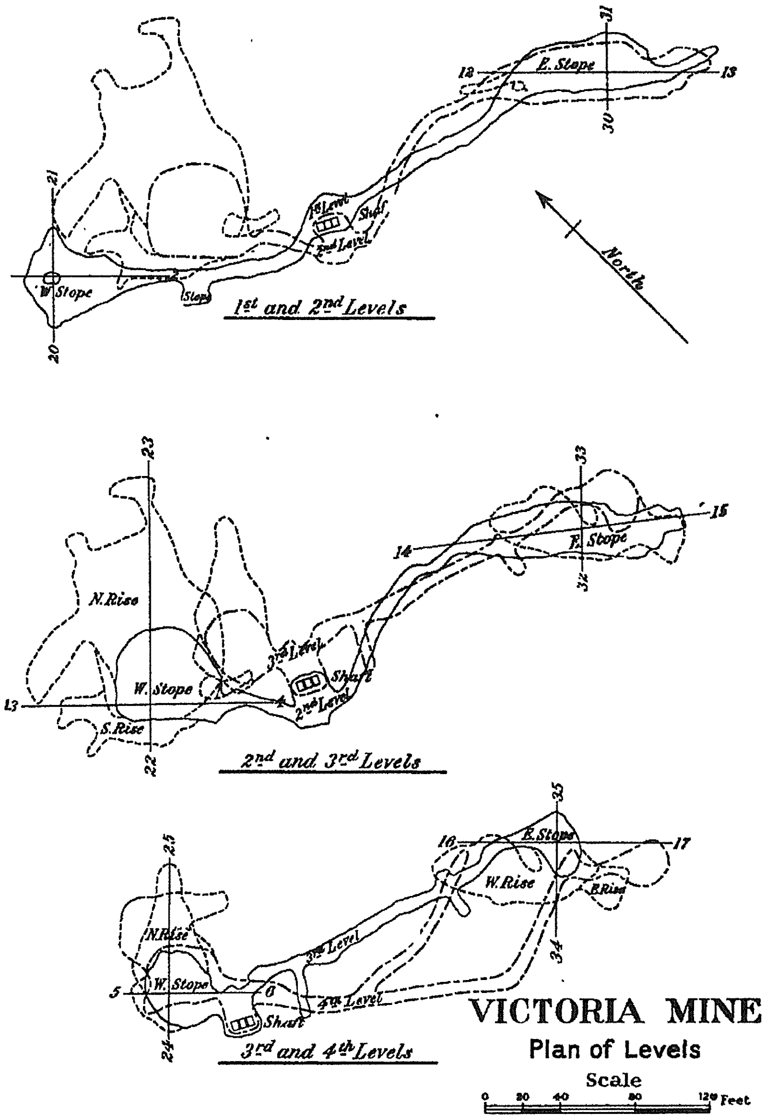
Victoria Smelter.

The schistose rock to the south has a dip of 70° or 80° to the south, and not far from the ore deposit there is a large quartz vein running parallel to the schistose structure. This has been mined to some extent to provide the silicious lining of converters at the Victoria smelter.

The basic edge turns northeast for a mile beyond this opening, though the boundary is mostly hidden under swamps, and then southeast to Victoria mine on lot 8 in the IV con. of Denison, much the most important mine in the western part of the

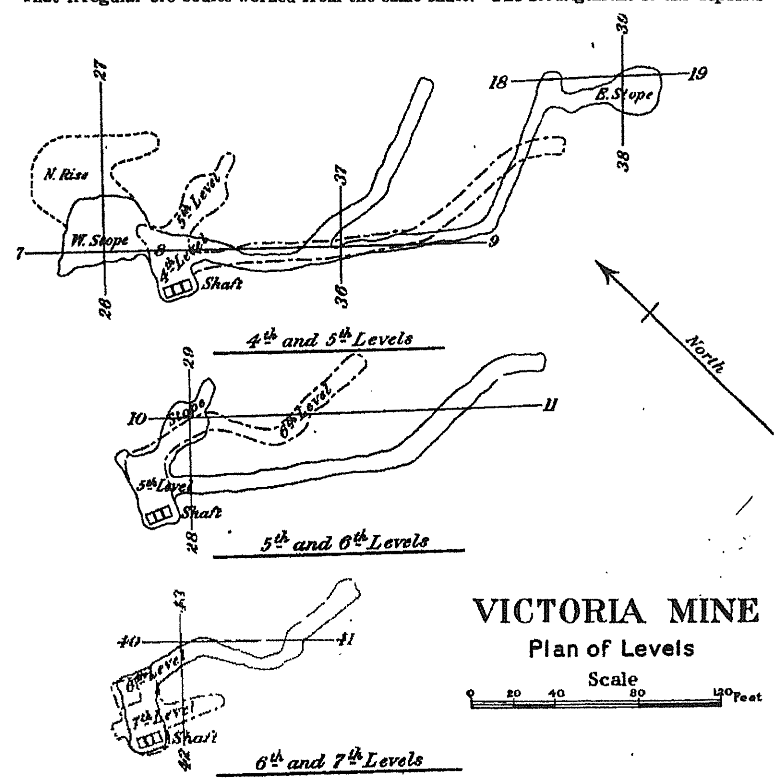


southern nickel range. At Victoria mine a long offset starts to the south and southwest including the Worthington mine, and another shorter one toward the southeast to the Vermilion mine; but both are more or less discontinuous, narrowing and widening or disappearing for a time altogether, so that they are hard to follow. The basic edge of the eruptive turns northeast for a mile beyond the Victoria mine, so that we may consider this ore body as lying at the end of a funnel which opens into the narrow offsets just mentioned. Ore deposits or gossan are found for half a mile northwest of the mine and also for some distance to the northeast, while to the north the usual coarse gray norite stretches for a mile or two. Several of the minor ore bodies have been opened up by the Mond Company by small shafts or test pits, but the main work has been done at Victoria mine itself, where the funnel narrows to its outlet.



The country rock to the southwest and southeast consists of various greenstones, such as diorite, hornblende porphyrite, and green schist, followed by chloritic slate interbanded with quartsite, and all these rocks appear on the dump at the mine, as well as fine-grained gabbro and actinolite rock probably resulting from its alteration.

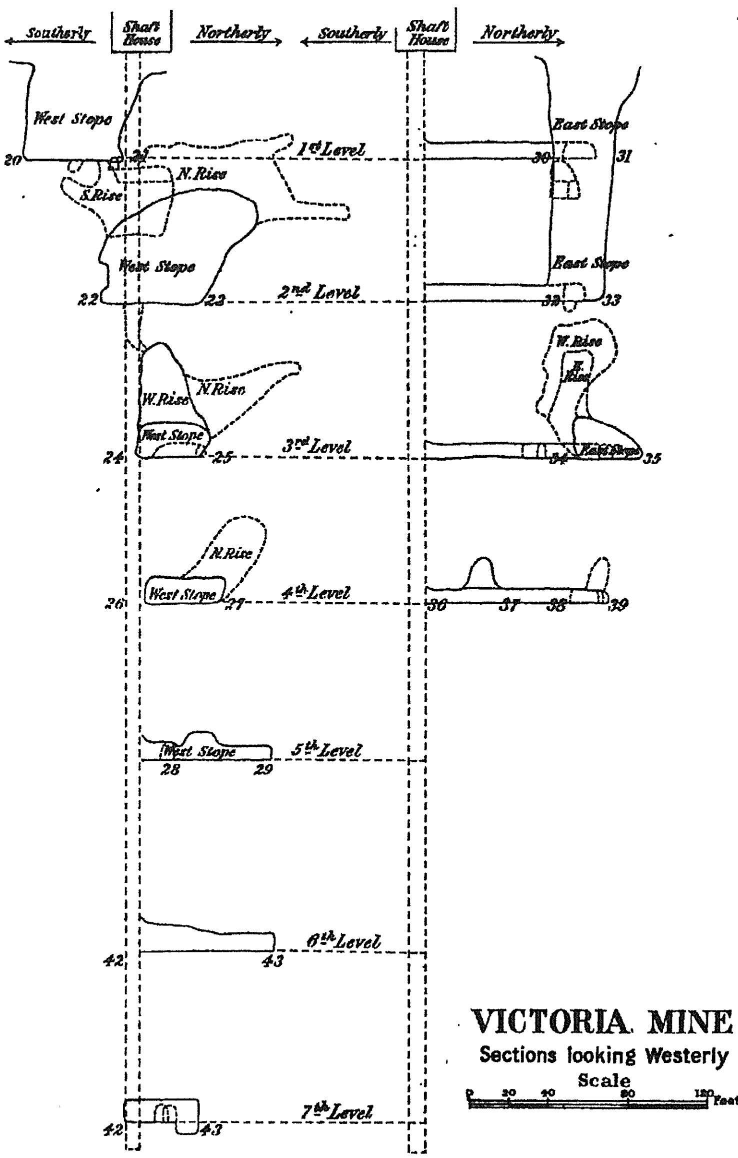
There are two large open pits near the shaft house, showing the rocks just mentioned, but mining is now being carried on by a shaft which reaches a depth of nearly 560 feet, and the ore is known by the results of diamond drilling to continue to 750 feet from the surface. As will be seen from the accompanying plans there are two somewhat irregular ore bodies worked from the same shaft. The arrangement of the deposits



of ore at Victoria mine is quite different from that which has been referred to at Sultana mine, since they occur apart from the main body of norite at the beginning of a narrow offset, so that neither wall of the ore bodies is of norite. In nickel ore deposits of this kind the dip approaches the vertical, while in the other kind it may be 45° or less, the ore resting on the Archean as a foot wall and blending upwards into the norite. The sides of the funnel to the northwest and northeast of the mine slope at an angle of about 45° into the swamp, or an artificial lake used as a water supply, and the gossan upon them represents ore bodies arranged in the marginal way, as contrasted with the main ore deposits at the mine, which are offset deposits.

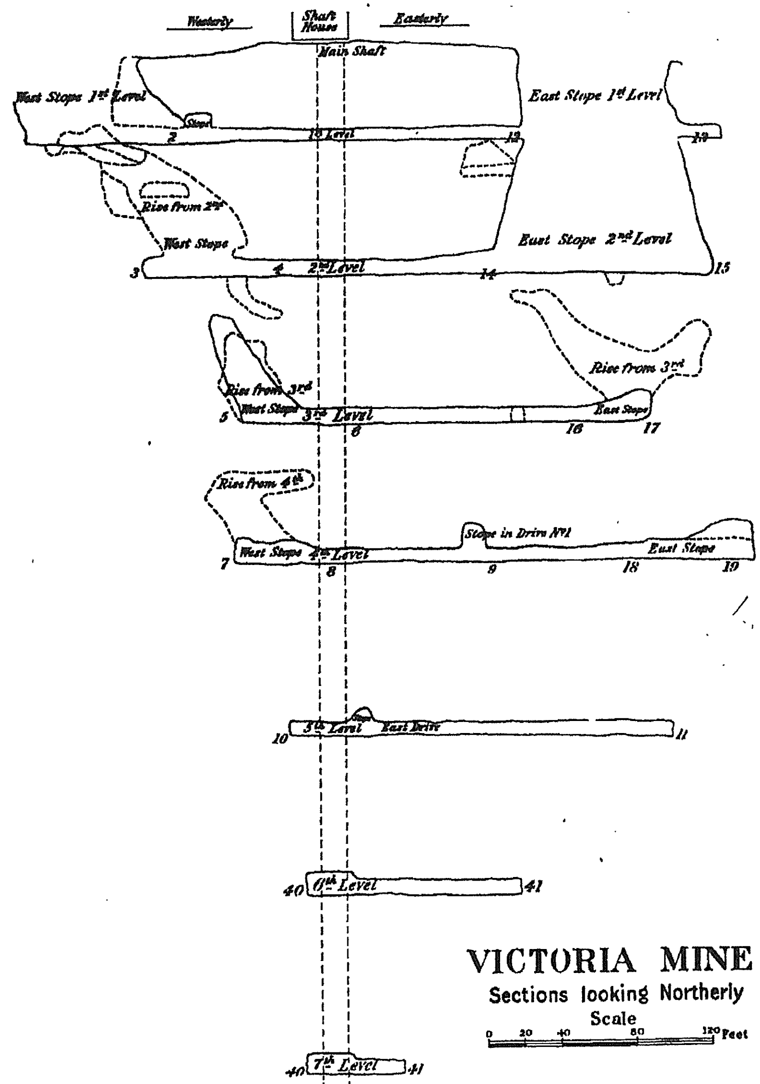
This mine has already furnished a large amount of ore, and is far from being worked out.

The offset beginning at Victoria mine runs southeast for a quarter of a mile, as shown by two small hills stained with gossan, and then bends southwest toward Worth-



VICTORIA MINE
Sections looking Westerly
Scale

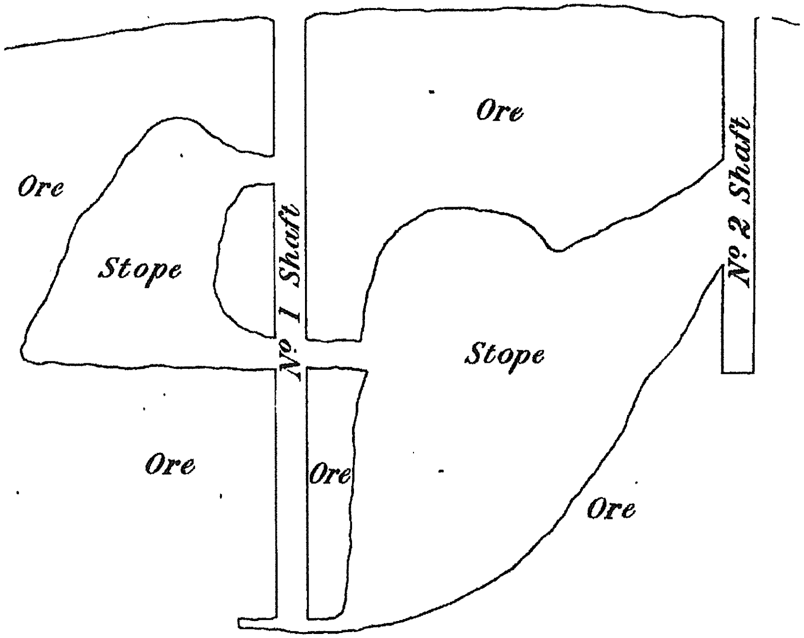
ington. It probably forks at the second hill, forming perhaps a subterranean connection with Vermilion mine to the southeast.



VICTORIA MINE
Sections looking Northerly
Scale

The Worthington Offset

The branch running southwest has been traced from the middle of lot 8, con. IV, in Denison township, to lot 3, con. I of Drury, a distance of 4½ miles, and probably extends a mile farther. The first part, as far as a swamp north of a small lake in lot 12, con. III, shows fine-grained norite more or less rusty, but with little ore; but beyond this small ore bodies have been found at various points, such as the O'Connor shaft, the Robinson drift, and the Totten mine, where a small shaft has been sunk. Here a broad band of diabase cuts the offset, but the rusty norite with small pockets of ore continues beyond and culminates in the Worthington mine, which several years



WORTHINGTON MINE

Scale

ago produced some thousands of tons of the richest nickel ore in the district. A quarter of a mile to the southwest is the Mitchener or Hamilton mine, and beyond this the band of rusty norite can be followed with certainty to a small lake near the southwest end of lot 3, con. I in Drury. On the other side of the lake rusty patches can be traced for some distance into the township of Lorne, but no undoubted norite is seen, quartzite, with some outcrops of greenstone being the rocks observed. There are patches of crush conglomerate along this line which may represent the fissure occupied by nickeliferous norite at Worthington and Victoria mines.

At the Mitchener mine the fine-grained norite is quite distinct, and is in a sense the matrix of a crush conglomerate containing angular or rounded masses of the

adjoining rocks, graywacké, quartzite, greenstone, etc. The norite has the characteristic spotting with blebs of ore, and a shaft has been sunk on a small deposit of solid ore.

The Worthington mine has not been worked for over eight years, and the geological relationships are not well displayed, but a small amount of rusty norite and rocks similar to those at the Mitchener mine are found on the dump, as well as actinolite. The norite masses are sometimes spotted with ore as in almost all nickel mines. The minerals found at this mine include pentlandite, niccolite and gersdorffite, three rich compounds of nickel, accounting for the high character of the ore; and the same minerals occur with pyrrhotite and chalcopyrite at several of the small pits and shafts to the northeast.

The Vermilion Mine

The other branch of the Victoria mine offset has not been traced, but the extraordinary ore deposit at Vermilion mine on lot 6, con. IV in Denison township, a mile to the east, evidently belongs to the nickel range, and so must be connected in some way with the rest of the deposits. This mine, with the Victoria mine, are marked out from all the others by containing in considerable quantities free gold and sperrylite, the arsenide of platinum. From a shaft 60 feet deep at Vermilion mine the richest ore in the district has been extracted, but the ore bodies are only small pockets, and may not prove of great value in spite of their high contents of nickel and copper and the gold and platinum they contain.

The rocks enclosing the ore are varied and do not include any typical norite, though a gray-green gabbro occurs and also rock spotted with ore. It is probable that these unusual ores reached their present position in large part by aqueous means rather than by the flow of molten sulphides and rock; but the final solution of the problem must be left till more extensive mining operations are carried on.

Certain general features of this important section of the nickel range should be noticed before passing on. The whole width of the eruptive is four miles, which is about the average for the southern range; and there is an extensive bay-like recession of the acid edge toward the northeast with a corresponding projection of the basic edge toward the southwest, ending in the long offset toward Worthington, the one apparently in some way bound up with the other. The whole region south of the nickel range is greatly broken up with faults which often manifest themselves as irregular belts of brecciation such as one finds along the Worthington offset, and this is most naturally explained by supposing a collapse of the Archean floor beneath this part of the range, perhaps because of the unusual load of liquid rock resting on it, or because the source of the magma was beneath it, removing its support. The main fractures resulting from this collapse afforded irregular channels through which the lowest layers of the magma (including molten ore) were forced, making breccias with a cement of norite or of ore and starting a circulation of heated water charged with mineral solutions which penetrated beyond the bounds of the molten rock itself. The presence of unusual ores and of such minerals as quartz and calcite indicate the action of water in re-arranging or in transporting and depositing the ore bodies.

Krean Hill to Gertrude

From about the middle of lot 6, con. V of Denison township the basic edge of the norite runs nearly due east to the boundary of the township, and then northeast across the Vermilion river to Gertrude. From the gossan northeast of Victoria mine to Krean Hill in the south half of lot 5, con. V, a mile and a half northeast of Vermilion mine, there is little evidence of ore along the contact except some rusty spots in the greenstone to the south. Beside greenstone, green schist and quartzite are found along the boundary, the direction of cleavage being 50° or 55°.

Krean hill rises as a sharp slope of gossany hillside which has been partially stripped for a quarter of a mile, and has been opened up by a few test pits. The coarse gray norite contains quartz and mica, and is blotched with spots of gossan where blebs of ore have weathered out, and the gossan increases till the surface of the rock is covered. The adjoining rock is mainly greenstone, often as large or small blocks with ore between. The ore is pyrrhotite of an unusually platy kind, cleaving with surfaces an inch square A vein of quartz near the west end of Krean hill contains a little free gold, but this is no doubt later than the ore as a whole.

Patches of gossan are seen along the edge of the norite from point to point for half a mile east of the main body, but no deposit of importance is found until the township of Graham is reached, where a shaft has been sunk by Mr. William McVittie, on lot 12, con. V. The rock south of the contact is mainly greenstone to the boundary of Denison, but farther northeast largely granite and gneiss.

On the east side of the Vermilion swampy country intervenes for half a mile, beyond which the boundary runs northeast to the township of Creighton, in lot 7, where it bends to the east toward Gertrude. Along this stretch there is little indication of ore, and the rock to the south is mainly gneiss or granite, with a mixture of greenstone. In many places the actual contact is hidden by muskegs, but along the line between lots 9 and 10 in Graham norite without ore meets porphyritic granitoid gneiss. The color of the nickel-bearing norite gradually becomes darker as one advances from the west end of the southern range, and the presence of grains of blue quartz and of scales of biotite attracts attention, but the composition of the rock as seen in thin sections does not vary much; the main difference beween the extremes being the presence of dusty particles in the feldspar giving it a deeper color.

Gertrude Mine

At a small creek on lot 5, con. I of Creighton township the first of the ore deposits of Gertrude mine shows itself, where a small tunnel has been run into the hill on the east. The norite is partly coarse and partly fine-grained, forming an irregular mixture, and the ore lies against greenstone and penetrates fissures in the latter rock. From this eastward more or less gossan and norite spotted with ore extends to the main workings about on the line between lots 3 and 4 and less than a quarter of a mile north of the boundary of Creighton. There are three shafts along the line of gossan, and various open pits, the most important one being the most easterly, where a body of very rich ore has been worked out. The whole extent of the gossan is about three-fifths of a mile, and the most important ore body is where there is a slight southward embayment of the norite edge. Diamond drilling north of the open pit near the eastern shaft discloses rich ore like that from the pit, and indicates that the foot wall dips from 67° to 55° toward the north. There are 20 feet of solid ore with 15 feet of mixed ore at a vertical depth of 120 feet. The pit to the south of the diamond drill holes appears to be a separate pocket, perhaps once an upward continuation of the sheet of ore disclosed by the drill cores, separated by a fault.

The rocks to the south of the contact are largely the older norite merging into greenstone, often brecciated at the edge of the ore bodies as if some crushing and faulting had taken place there. The rocks on the dump near the open pit include norite dotted with ore, greenstone, quartzite or graywacké, and masses of actinolite, probably an alteration product of the norite, and some well-rounded pebbles and boulders of rock are enclosed in ore. In early days the ore was mainly pyrrhotite, but later workings show considerable chalcopyrite as well, and sometimes also pyrite, occasionally in octahedral forms. A little quartz occurs with the ore, and seams of quartz are found in schistose greenstone south of the contact.

To the south of Gertrude there are rather low hills of greenstone of various kinds for nearly a mile, penetrated however by dikes of granite and irregular areas of

granitoid gneiss. The latter rock increases in amount southwards, until the proportions are reversed, and the rocks may be described as granitoid gneiss with many large and small inclusions of the various greenstones. The gneiss is evidently the later rock of the two.

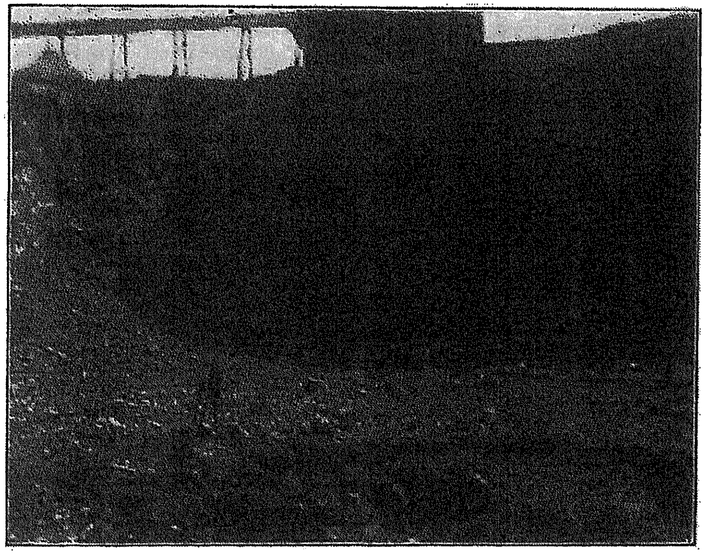
Just east of the line between lots 2 and 3 the edge of the norite turns north and then curves east and southeast toward a small lake at the west end of the Creighton ore body. Where the northward bend takes place there is a small offset to the south, on which some ore has been disclosed by stripping, but along the bend to the north little gossan and no ore has been seen. The rock projecting northwards here is mainly the fine-grained phase of norite, often referred to as "older norite," and greenstone, probably resulting from its re-arrangement, but there is also some granite and probably re-crystallized arkose At one point in lot 2 a vein of rusty quartz has been prospected by Mr. McVittie, who finds the ore to contain $4.50 in gold per ton.

The Creighton Mine

The most important nickel mine in the district, and one may safely say also in the world, is the Creighton; and it will be desirable to consider in some detail the character of the ore body and its relationship to the enclosing rocks. From the map it will be seen that the Creighton mine is not in Creighton township, but near the middle of lot 10, con. I of Snider, though the ridge of gossan-covered norite just to the north of the mine runs southwestward into lot 1 of Creighton. The position of the mine with reference to the margin of the eruptive is of particular interest, since it probably accounts for the unusual size of the ore body. The present great open pit is at the southeastern corner of the largest and deepest bay of the norite along the southern range, and the width of the eruptive is here at its greatest, 4½ miles. Here also we have the greatest width of the whole basin, as measured from Creighton to the Levack mine. This bay of the norite lies between the two great southern offsets at Victoria mine and Copper Cliff, but nearer to the larger one at Copper Cliff. We may suppose that the greatest amount of the fluid ore accumulated beneath the greatest thickness of overlying magma and was caught in the extreme end of the bay, which had no funnel-shaped outlet along a plane of faulting to allow the ore to escape and push up as separate ore bodies along an offset, as we find in the two cases mentioned. The theory given here is practically the view adopted years ago by some of the best prospectors of the region, though they contented themselves with the observation that one is most likely to find a good body where the "diorite" makes these bay-like projections.

The norite to the north of the mine is of the usual kind, coarse, dark gray, and containing blebs of quartz and flakes of biotite; but in many places it is more or less mixed with strips of greenstone squeezed into schist, or masses of what appears to be diorite; and near the contact granite, porphyritic granitoid gneiss, and arkose are enclosed also. Even hundreds of yards to the north some pitting of the surface is noticed, due to the weathering out of spots of ore, and this increases till the edge of the ridge facing southeast is reached, where much of the norite and the included blocks of other rocks is covered with gossan. This is not, however, uniform, but runs in short bands parallel to the edge of the hill, one band ending and another one beginning a little above or below, suggesting a corresponding banding of the blebs of ore in the rock. At the base of the hill is a narrow strip of swamp, ending toward the east in a small lake, and the large pit is between the two. Evidently the boggy depression represents ore which has been weathered and removed.

The rock to the southeast is coarse flesh-colored granitoid gneiss, often porphyritic, containing occasionally masses of greenstone and cut by finer grained syenite or gneiss. These rocks just beyond the open pit and the swampy strip which represents the westward continuation of the ore rise little above the flat, but one or two hundred yards beyond form steep and rugged hills much higher than the norite ridge to the northwest. The hill behind the village shows an extraordinary mixture of rocks, coarse porphyritic granite, well banded gneiss, hornblende schist, hornblende porphyrite and a medium-grained gray eruptive, the whole cut by faults which sometimes formed crush conglomerate or breccia containing several kinds of boulders.



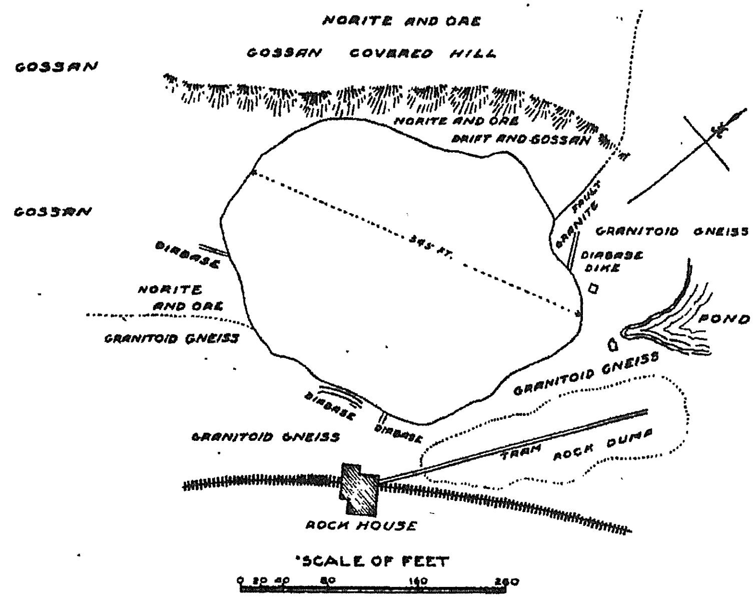
Creighton Mine, open pit, first level, August, 1904.

The great open pit of the Creighton mine affords the best opportunity for studying the intimate relations of ore and rock to be found in the region. The original pit was 60 feet deep and almost in solid ore, but as it was enlarged to the northeast, northwest and southeast more rock was encountered, as the ore body dipped northwest beneath a mixture of norite and ore. To the southeast is the irregular wall of coarse granitoid gneiss, which bends sharply in a direction a little west of north. During the past year a second level has been opened 80 feet below the first on the dip of the shaft, which is 60°, and toward the end of the summer a beginning was made at opening up the whole pit to that depth.

The open pit shows three main types of rock, the oldest, granitoid gneiss, with a very uneven surface forming a rectangular enclosure for the ore body, next in age norite mixed in all gradations with pyrrhotite and chalcopyrite, and finally diabase dikes, often very porphyritic, penetrating in various directions gneiss, ore and norite impartially. All of the rocks mentioned have undergone more or less faulting and crushing, and fragments of the two older rocks are often enclosed in ore as a sort of breccia, but not of the diabase, though the latter also has been fractured in places and faulted in a small way producing slickensided surfaces. The dikes have a fine-grained or compact selvage against norite and gneiss, and an almost glassy selvage against ore, showing that the ore was cold when the dikes were formed, and being a good conductor chilled the surface sooner than the rocks. The ore mixes in such a way with the norite that the conclusion cannot be avoided that the two materials

existed in a state of fusion together. From norite with disseminated specks of ore all transitions are met to ore containing tiny scattered crystals of feldspar, or less often the dark minerals; and thin sections prove that the rock-forming minerals are exceedingly fresh, even the hypersthene, which readily suffers change and is completely altered to secondary hornblende in the norite north of the mine. The mixture cannot then be the result of replacement of rock minerals by ore through the action of water.

On the other hand the ore is never intimately mixed with the granitoid gneiss, though it may penetrate it a little way as irregular seams, nor is it found in the diabase dikes, except as thin films between slickensided surfaces. That the ore was there in the beginning, arriving as an ingredient of the norite is very clear, but since then certain changes have taken place on a small scale by circulating waters. Part of the faulting shown by the older rocks may be later in date than the cooling



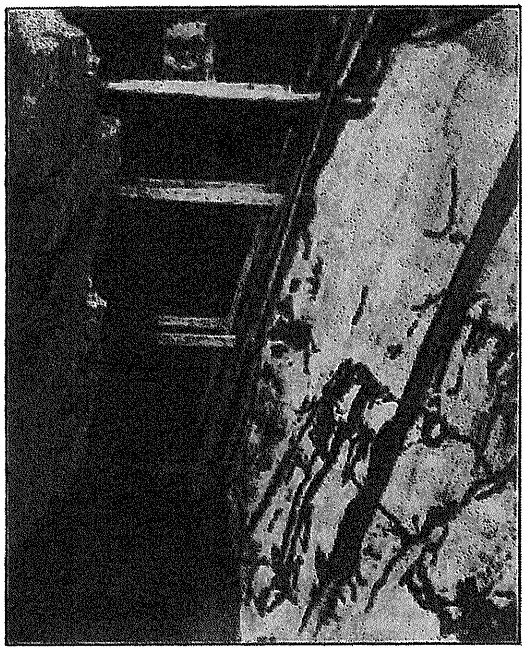
CREIGHTON OPEN PIT JULY 1905.

and consolidation of the ore, the latter, as the softer material, adjusting itself between the blocks. This may account for the curious "horse" of granitoid gneiss at the northeast side of the pit, which seems to have slipped down into the ore, though it might be equally well explained as slipping down into the pasty mixture of half cooled norite and ore before the final consolidation.

From the faulting and irregularity of the contact of the ore with the granitoid gneiss, it is rather hard to determine the original dip of the Archean surface over which the nickel-bearing norite spread, but drill holes to the northwest and west show that the floor dips in the main about 40° to the northwest. How far the great sheet of ore extends beneath the norite in that direction is unknown, though the results of drilling prove the existence of millions of tons. Up to the present the mine has produced about half a million tons of ore, and for some months of the past year averaged 18,000 tons; so that it is clearly one of the world's great mines. As the ore averages 5 per cent. of nickel and 2 of copper, the great value of the mine is apparent.

North Star Mine

The boundary between the norite and the Archean runs for half a mile a little west of north from the Creighton mine, then turns north and finally northwest to the North Star mine in lot 9, con. III of Snider township. Much of the country is low and swampy and the comparatively few outcrops of rock rise but little above the general level. The rock to the east and southeast of the norite is commonly coarse granite or syenite, flesh red to gray in color, and often porphyritic and gneissoid; but patches of greenstone occur also. Comparatively little gossan is seen at the norite edge, though there are frequently rusty blotches. Near the North Star mine there is rather more of the greenstone than usual, including a small area of "older norite" like that found near Gertrude and Creighton.



North Star, open pit.

The mine has hitherto been worked as a narrow open pit, but in the summer of 1904 a shaft was sunk to a depth of 170 feet, and lower levels are being opened. The dip of the ore body as seen in the open pit and shaft is unusually high 75° or 80° toward the northwest, and the foot wall is clean cut and slickensided, probably a fault plane. Capt. Corliss reports that on the hanging wall the ore fades out irregularly into the norite until finally there is only norite flecked with ore. Some curious well-

rounded boulders, as well as angular blocks of granite and greenstone, are enclosed in the ore, and a little quartz occurs as small seams in the ore near the foot wall. At one point a horse of granite runs diagonally across the ore.

The attitude of the Archean surface where unaffected by faulting is not evident at the North Star mine, and in this respect it presents an extreme example of what has already been noted at the Gertrude and Creighton mines, where faulting, crushing and slickensiding are marked features. The ore from the North Star, when free from rock matter, is richer than the average of the southern nickel range; so that the great Creighton mine with its unusually rich ore is flanked to east and west by smaller deposits, the North Star and Gertrude, having ore of a similar grade, the smaller deposits occupying only slight embayments of the norite edge, while the great ore body was accumulated at a deep depression of the norite into the Archean substratum.

From the North Star the line of contact of the norite continues for a mile northeastwards and then bends more to the east, but no ore deposits of importance occur until the Tam O'Shanter is reached at the northwest corner of lot 5, con. III of Snider township.

The norite edge to the northeast follows close along the railway track, and is of the usual kind, though somewhat sheared and schistose in places. Except for rusty spots there is little evidence of ore. The country in this direction becomes more hilly than near the North Star, the granitoid gneiss rising rather sharply in many places from the flat country occupied by the norite.

Acid Edge in Creighton

The acid edge of the nickel-bearing eruptive to the northwest of the mines just described is best reached by Vermilion river and a chain of small lakes including lake Emma, Moore lake and Whitewater lake, with Levy creek which connects them. The canoe route is seldom more than a quarter of a mile from the contact and each of the lakes lies upon the contact, giving opportunities to observe it.

The wide and vaguely bounded conglomerate south of Gordon lake has already been referred to as running south from that lake and then turning northeast toward the mouth of Levy creek, much of the region toward Vermilion river being covered with drift or muskegs so that outcrops of the actual contact are infrequent. The conglomerate on hills west of the drift-covered shore of the river is schistose with a strike of 45° and a dip of schistosity of 50° to the southeast; but the strike and dip of the sedimentation is probably entirely different, like that observed south of Gordon lake.

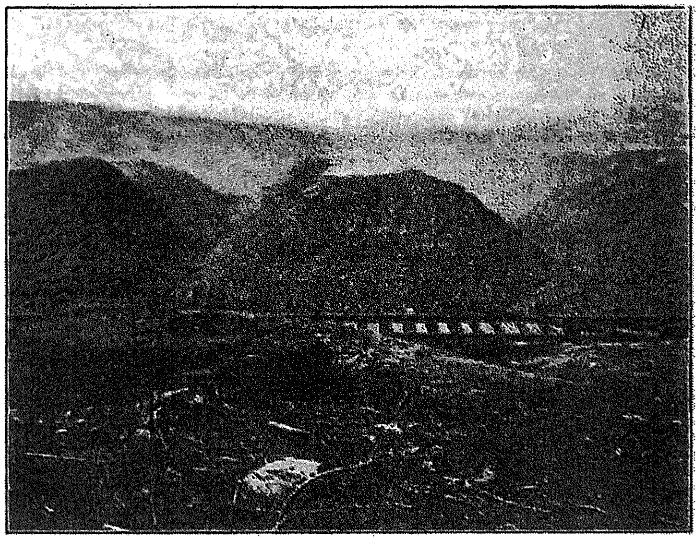
On both shores of Vermilion river near the mouth of Levy creek there is a somewhat narrow bank of clay rising about ten feet, followed inland by swampy land; and the contact of the acid edge with the conglomerate is first seen a quarter of a mile south of Levy creek, and about an eighth of a mile inland toward the west. A mile inland the edge is schistose, having a strike of 70°, and the schistose conglomerate has the same width with a dip of 50° to the southeast.

The characteristic tuffs are not found for more than a mile to the northwest at some distance inland from the river, where a steep hill of slaty tuff rises from drift and swampy ground. The tuff at this point contains numerous small pebbles of water-worn materials, and the cleavage strikes 60° and dips 45° to the southeast.

On the east side of the Vermilion the rock cropping out just to the south of Levy creek is schist conglomerate, and this extends southeast for a quarter of a mile where at a small lake schistose rock without pebbles forms the acid edge. At the rapid not far above the mouth of Levy creek the rocks exposed are hardened tuff, with a dike of fine-grained granite or felsite, but the stretch between this and the schist conglomerate is covered.

Levy creek between the Vermilion river and Emma lake flows between low clay banks with a few exposures of tuff rising little above the water's edge, and excursions inland show the acid edge at about a quarter of a mile to the south. On Emma lake the boundary crosses the southern bay where it joins the main water and runs eastward from the point of entry of the creek. The boundary is indistinct, as in most other parts of this region, since the conglomerate has been greatly metamorphosed; and the acid edge of the eruptive is squeezed into gray green schist much like some parts of the schistose matrix of the conglomerate. From Emma lake to Moore lake the contact lies in swampy ground a little south of the creek, and then crosses the southeast corner of the latter lake toward the western bay of Whitewater lake, the rocks and their relationships being similar to those already described.

Whitewater lake, which is two miles long and in places a mile broad, hides the boundary between the eruptive and the sedimentary rocks for the whole distance, and

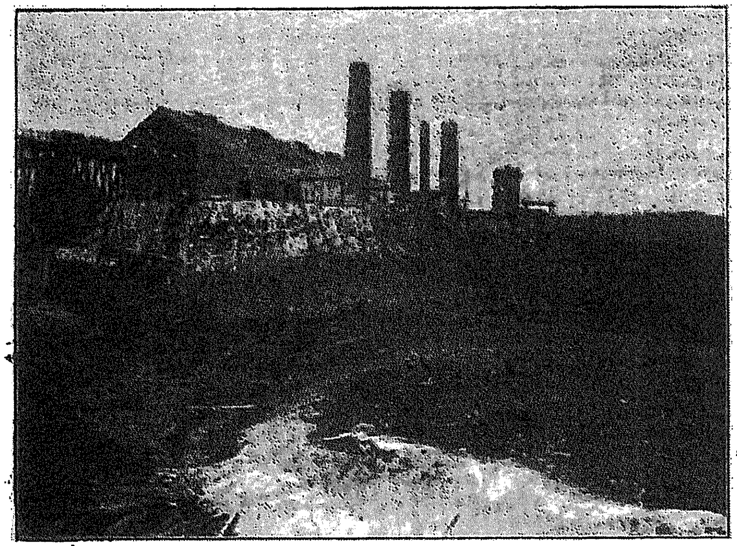


Roast heaps, Copper Cliff.

a broad low plain of clay on its northeast side prevents its demarcation with certainty in that direction for a mile to the north. The north shore and the islands which fringe it consist either of the basal conglomerate in a very schistose form, or in the deeper bays of tuff; while the south and east shores are of the acid phase of the nickel-bearing eruptive. Toward the west end of Whitewater lake both shores rise as steep hills to the height of 100 feet or more, unlike the low country along Levy creek, and beyond the hills of tuff to the north there is farming country.

On the north shore of the lake toward the west end a band of gray quartz porphyry cuts the tuff and might easily be mistaken for the acid phase of the nickel-eruptive but for its cutting rocks some distance north of the basal conglomerate. It may be a dike from the acid edge, though the lake prevents one from following it in that direction so as to make certain, and no other dike-like projections are known to extend so far from the edge as this.

The Trout lake conglomerate on the islands and peninsulas of the north side of Whitewater lake is usually schistose, and all the softer boulders and pebbles are greatly flattened, resembling the Michipicoten conglomerates of the Huronian. The strike of the schistosity varies from 45° or 50° to 70°, and the cleavage dips about 45° to the southeast. The boulders enclosed in the conglomerate are of considerable variety, including granite, quartzite, a brownish sandy looking rock, green schist and actinolite, the granite being the commonest rock and forming large boulders not much deformed. The matrix, which is sometimes almost free from pebbles, is gray or green schist merging into a rock like gneiss.



West Smelter, Copper Cliff.

Bays on the north shore give all transitions from the schist conglomerate to a much less altered rock which probably should be classed with the Onaping tuff, though often half the materials of which it is composed are ordinary sediments, including pebbles of the same rocks as in the coarse conglomerate. About a quarter of a mile north of the shore a ridge of characteristic tuff composed mainly of angular volcanic materials represents the completion of the transition.

Toward the northeast end of the lake there are hills of gray gneissoid rock, evidently belonging to the acid edge, and similar rocks are found a mile to the north on the railway west of Azilda station, though the intervening ground is clay; so that the contact changes its direction from N. 65° to nearly due north somewhere beneath the lake. The hill rising from the flat plain of clay west of the station consists of a very schistose rock which has hitherto been mapped as Huronian, but our detailed study makes it practically certain that it belongs to the nickel eruptive, since it has the micropegmatitic structure, and to the north is in continuity with less changed portions of the acid edge.

On the west side of the hill schist conglomerate occurs having a schistose strike of N. 15° and an apparent dip of 15° to the east; but at points to the north and northeast on neighboring hills the strike varies to N. 25° or 30° and begins to bend eastward once more. Along the road running north from the east end of Asilda a schistose variety of the acid eruptive continues for about a mile, after which the tuff crops out beyond a drift-covered surface.

Copper Cliff Offset

After running for a mile northeast from the Tam O'Shanter, the basic edge of the nickel eruptive turns nearly north for a quarter of a mile and then northeast toward the northern end of the line between lots 3 and 4, con. IV of Snider township It then turns sharply southeast toward the Lady Violet and other mines leading towards the Copper Cliff offset. The northward bend of the contact points toward the southeast bay of Whitewater lake where the acid edge has just been shown to change its direction, so that at this point the nickel range is only about 2½ miles wide, the least width found along the southern range, except near Whitson lake some miles to the east; but immediately beyond this narrowing the range widens once more to almost its maximum.

Along this northward bend there are few traces of ore or even of rusty norite. The rock is coarse-textured but grows finer grained toward the edge, where it is a good deal mixed with the country rock, coarse porphyritic granite, often gneissoid in structure. That the norite is the later rock is shown by its having carried off fragments of granite. The granitoid gneiss forms a group of steep hills in the re-entrant angle of the basic edge, but at the very edge the norite occasionally forms the top of a hill with the gneiss or granite dipping under it. The relations are well shown on a small lake just south of the Manitoulin and North Shore railway between lots 2 and 3, con. IV, of Snider. From this pond the basic edge runs southeast to Clara Bell lake, forming the margin of the upper end of the Copper Cliff offset.

The basic edge to the east of the offset runs from Elsie mine, which will be mentioned later, southwest near the edge of Pump lake to Lady Violet mine, about half a mile north of Clara Bell lake on the line between lots 1 and 2. At the Lady Violet mine the boundary swerves nearly west for about one-fifth of a mile, and then turns south and finally southeast, parallel to the basic edge referred to above. The offset in its upper portion, northwest of Clara Bell lake, is from 500 to 600 feet broad; and represents the outlet of a bay of norite almost as wide and deep as that of Creighton mine, though more regularly shaped.

The norite of central parts of the offset is like the main body of the rock, but along the edge toward Clara Bell lake where it comes into vertical contact with rather coarse granite, it becomes finer grained and occasionally picks up fragments of the adjoining rock, and may also contain pebble-like fragments or plates of a very fine-grained older norite. The southwestern margin of the offset shows few traces of ore but the northeastern side is commonly rusty and at the Lady Violet and Clara Bell mines enclosed small bodies of ore which were worked for a time in the early days of the Canadian Copper Company. The Lady Violet shows rather coarse norite with an irregular rusty edge against greenstone; and conditions are similar at the Clara Bell, where a gossan-covered hill consisting mainly of greenstone marks the boundary. On the dump at the latter mine, which is now dismantled, one finds beside norite, chloritic and hornblende schists and a number of minerals in addition to the usual pyrrhotite and chalcopyrite, such as quartz, calcite, dolomite, and actinolite in blades several inches long, indicating secondary water action. During mining operations a pocket of about five tons of magnetite was found completely enclosed in the sulphides.

After reaching Clara Bell lake the offset expands to a width of nearly half a mile with a projection to the northeast and another to the east. The rocks to the west and south are porphyritic granitoid gneiss, formerly considered to be Laurentian, while on the northeast various greenstones, diorite, hornblende porphyrite, hornblende schist etc., rise as hills, the norite occupying in the main lower ground between the greenstone and the gneiss. The norite is somewhat patchy, containing finer-grained parts, often angular, and sometimes also fragments of greentsone or green schist. Clara Bell lake has been dammed at its outlet and now covers much of the low ground, hiding the norite contact at some points.

On the eastern edge of the northern tongue an ore deposit of considerable magnitude was opened up years ago at No. 4 mine and the great open pits partly filled with water suggest a large but very irregular segregation of the sulphides.

At the eastern corner the projection of norite touches Lady Macdonald lake, and close to the shore is Lady Macdonald, or No. 5, mine, the first of the series of mines to be worked, now closed down like the others. An open pit near the lake is at the margin of the norite against mixed greenstones and not far from the granitoid gneiss, which is greatly mixed with it as a crush breccia. On the dump there are pegmatite, hornblende schist, hornblende porphyrite and a little re-crystallized arkose, as well as norite. A few scales of graphite were found in one mass of gneissoid rock. It is probable that a dike of pegmatite cuts the norite and ore at this mine, but the exposure is too poor to make this quite certain.

No. 2 Mine

Lady Macdonald lake, like Clara Bell, has been dammed to afford a water supply, and cuts off the broad expansion of norite containing the mines just mentioned from a narrow extension southeast to No. 2 mine. An island in the northern part of the lake consists mainly of granite but at its eastern end shows a gossan-covered patch of norite, and at the end of a bay on the east shore of the lake a band of norite from 100 to 180 feet wide runs for about one-third of a mile and is then lost to sight beneath a clay deposit. About 350 feet farther to the southeast there rises the small strip of norite in which the mine is sunk.

The norite band just outlined is of finer grain than the main range and is spotted with little rusty cavities from which ore has been weathered where it not quite covered with gossan. It begins between granitoid gneiss, to the southwest, and a greenstone hill including long strips and masses of well stratified graywacké to the northeast, but presently passes entirely into the gneiss. The southeast end near the mine is once more between greenstone and granite; and it appears that the contact between the two rocks was a line of weakness, probably also of faulting, permitting the molten norite and ore to flow in this direction. The granitoid gneiss is younger than the greenstone, enclosing bits of it, and both rocks are cut by minor fault lines and often squeezed into breccias. In the gneiss the breccia blocks are variously oriented and cemented by similar materials crushed fine.

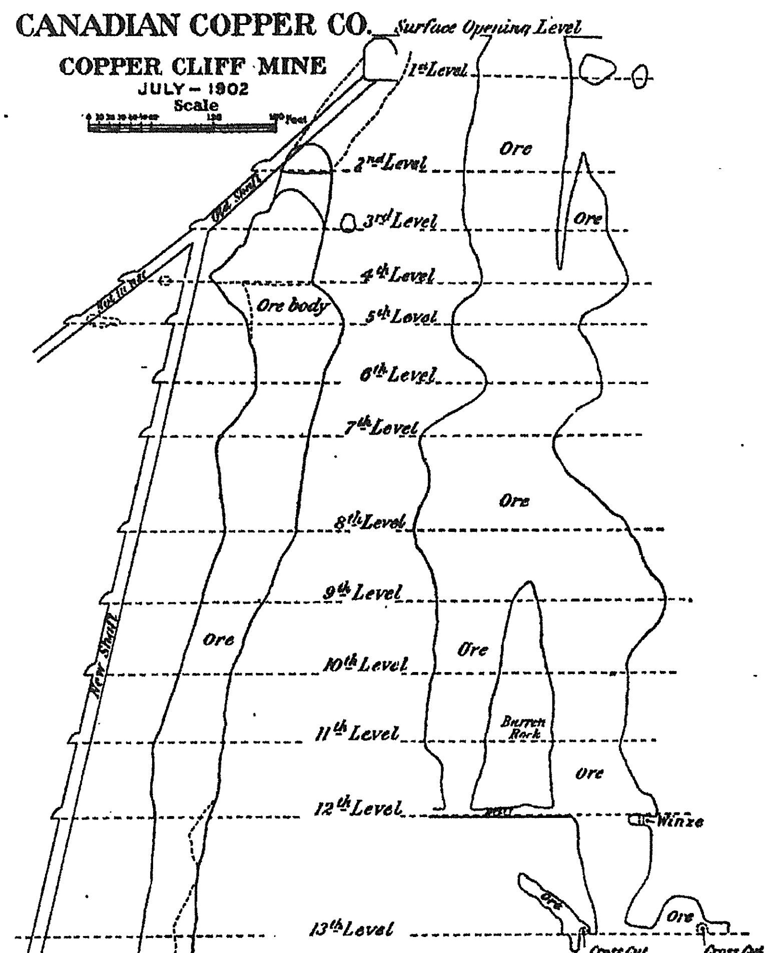
The dike-like band of norite grows finer grained at the edges, and is evidently later than the two rocks mentioned, but a dike 8 or 10 feet wide of non-porphyritic, rather fine-grained, granite, quite different from the gneiss, runs through it for some distance.

All along this norite offset there is more or less ore which has been opened up by small pits or shafts; but the only important ore body disclosed is No. 2, at the southeast end of the band near the point where it is apparently cut off by the older rocks, the relations being somewhat obscured by drift. The ore was present here in such volume that almost the whole width of the band consisted of sulphides, with an irregular margin of fine-grained norite against the granite walls, and with a large flange of norite projecting into the ore from the western wall.

The great open pit is about 230 feet long from northwest to southeast and half as wide, and it has a depth of 278 feet, while lower levels and diamond drill cores prove that it continues to a depth of at least 402 feet. The irregular column of ore stands not far from vertical, but inclines slightly to the west, and at the third level or pit floor it has diameters of 220 feet from north to south and 100 feet from east to west.

The Copper Cliff Mine

A valley filled with sand and clay extends for a third of a mile to the south of No. 2 with no indication of a continuation of the offset except a little outcrop of norite near a stream crossing the main street of the town. A short distance south of this



Vertical section through Shaft — *Section at right angles to Vertical section through Shaft*

and quite to the westward of the normal continuation of the offset rises the gossan hill of the famous Copper Cliff, next to the Creighton the most important mine of the

region and containing still richer ore. This was one of the earliest mines worked, having been located for its copper ore before its value as a nickel mine was known.

The rusty norite hill is surrounded on three sides by stratified clay, but toward the east lies against graywacké and flesh-colored arkose, the latter largely re-crystallized and formerly regarded as felsite or syenite. The arkose is cut by two granite dikes, one at the edge of the norite, and the latter rock is cut by two small dikes of diabase. The rusty hill is nearly 600 feet long and 200 wide.

The large rock dump at the mine contains a variety of materials, the most common being rather fine-grained norite with a little quartz, commonly called diorite, but there seem to be all gradations from this to a pale gray diorite merging into red granite. The norite has coarse varieties with some biotite and also hornblende crystals, and sometimes pegmatitic parts with large gray feldspar crystals, generally striated, almost to the exclusion of other minerals. There are also felsitic looking rocks, gray to red, arkoses as shown by thin sections. Finally there are numerous blocks of diabase, evidently from dikes, occasionally the whole width being shown in the blocks, the margin being finer-grained than the centre. The diabase is not porphyritic as at the Creighton mine. The norite mentioned may be found more or less charged with sulphides, and there are brecciated masses of rock cemented with sulphides. Among minerals, in addition to those belonging to the ore and rocks, there are calcite, quartz, and small amounts of galena.

A dike of diabase is said to have been followed down from the third level to the thirteenth, part of the dike matter containing ore, and having a margin of calcite on one side and of quartz with some ore on the other. The largest dike encountered is said to be very fine-grained and black, and to be twenty-five feet wide. Cores from diamond drill holes below the thirteenth level show, in addition to ore and the usual rocks, diabase dikes and a dike of medium-grained biotite granite.

As shown by the sections given, prepared from the plans of the levels in the mine with aid from Captain Lawson, who has charge of the underground workings, the ore body is roughly cylindrical, narrowing and widening several times and broken by a large horse of barren rock, beginning between the ninth and tenth levels. Many thanks are due to the mine authorities, and especially to Captain Lawson, for this instructive section of the deepest mine in Ontario, a mine that has reached a depth of 937 feet.

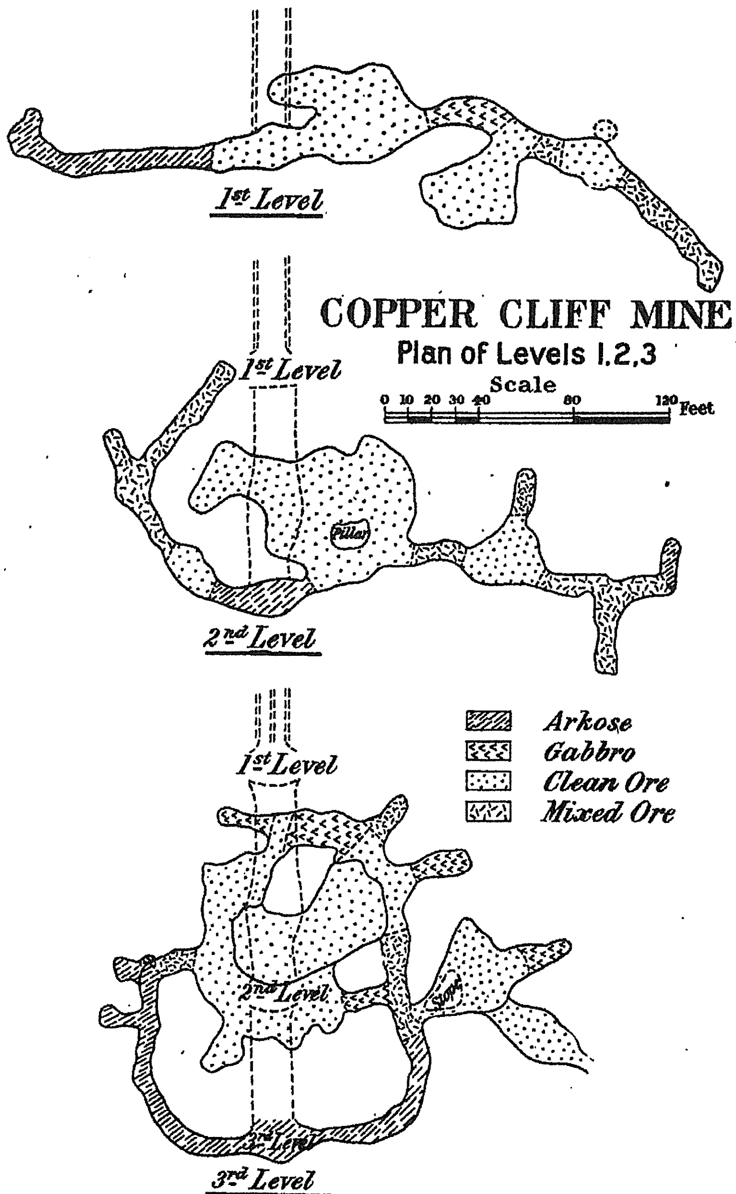
One curious feature of the later development of the mine is the finding of an odorless gas which may be lit with a candle in drill holes through ore at the thirteenth level.

The chimney-like ore body has a width of from 50 to 90 feet in the section through the shaft, which is inclined about 77½° toward the northeast, and from 75 to more than 200 feet in the section at right angles to it.

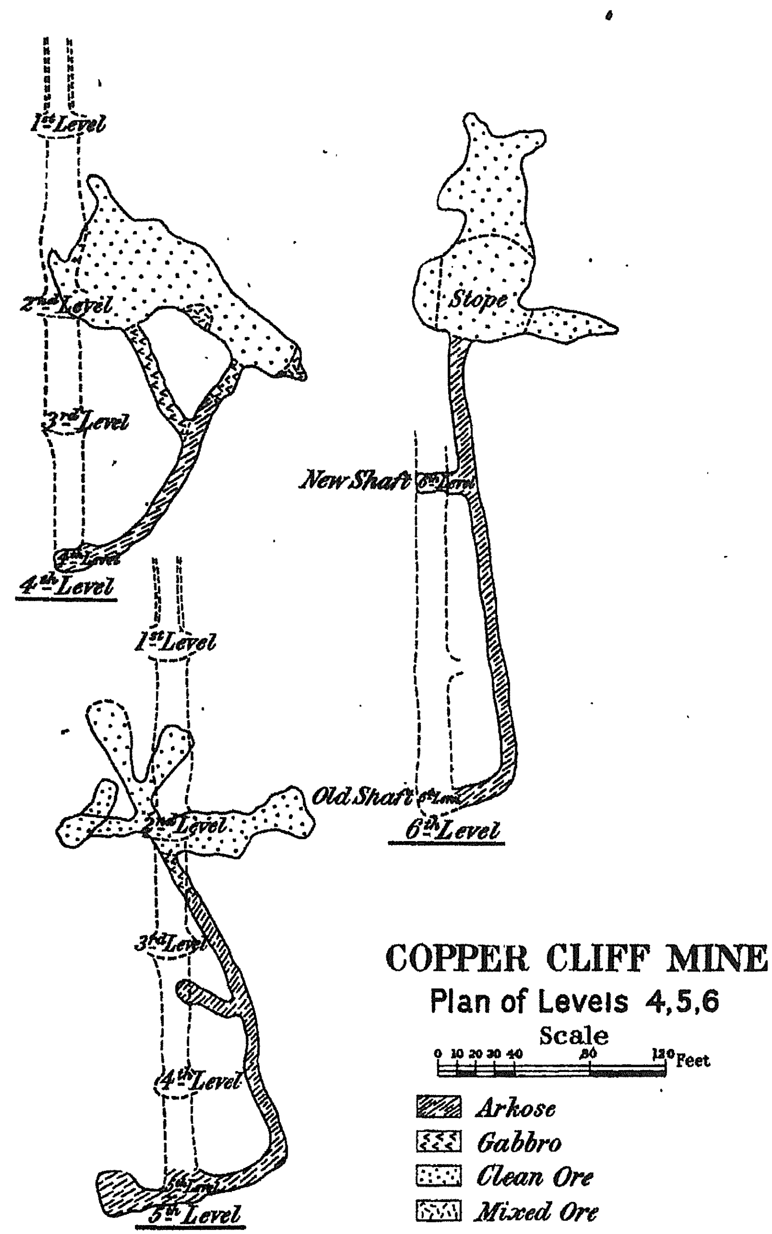
In the Copper Cliff, as in No. 2, the amount of ore seems greatly disproportionate to the size of the band of norite with which it is connected, and a certain quantity of the ore, being associated with quartz and calcite, must be of later deposition than the ore enclosed in the norite. The fact that two slips are rather marked features at the mine may indicate fractures and fissures in which water currents could circulate, and deposit there materials dissolved out of previous ore masses belonging to the original consolidation after the norite reached its present position.

It is stated that when the ore body in the Copper Cliff is narrow it is richer in copper, and when it widens it becomes richer in nickel.

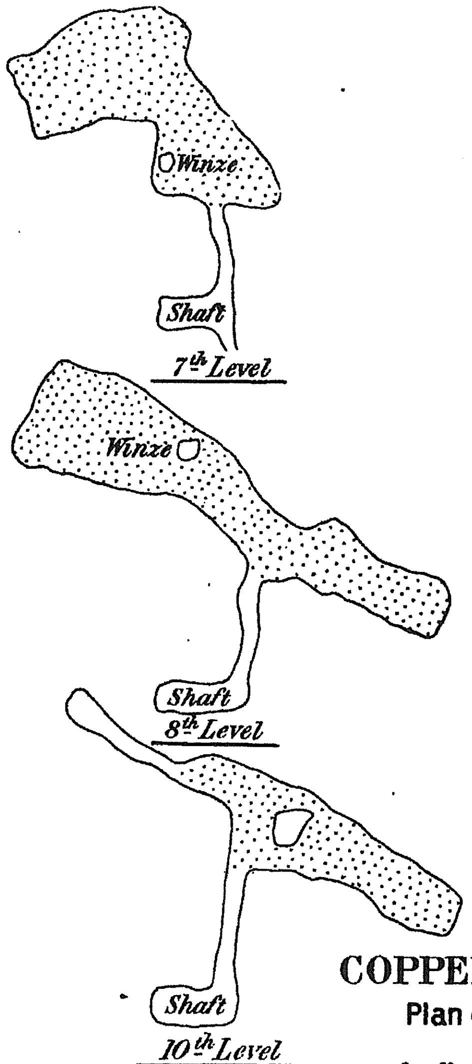
About 700 yards southwest of the Copper Cliff a small band of gossan-covered norite rises out of a swamp and runs southward towards the old Orford refinery. The norite associated with the ore has the customary pitted surface where spots of pyrrhotite have weathered out, and runs with interruptions between well-stratified graywacké



COPPER CLIFF MINE
Plan of Levels 1.2.3
Scale
0 10 20 30 40 80 120 Feet
1st Level
2nd Level
3rd Level
Pillar
Stope
Arkose
Gabbro
Clean Ore
Mixed Ore



COPPER CLIFF MINE
Plan of Levels 4,5,6
Scale
0 10 20 30 40 80 120 Feet
1st Level
2nd Level
3rd Level
4th Level
5th Level
6th Level
Stope
New Shaft
Old Shaft
Arkose
Gabbro
Clean Ore
Mixed Ore



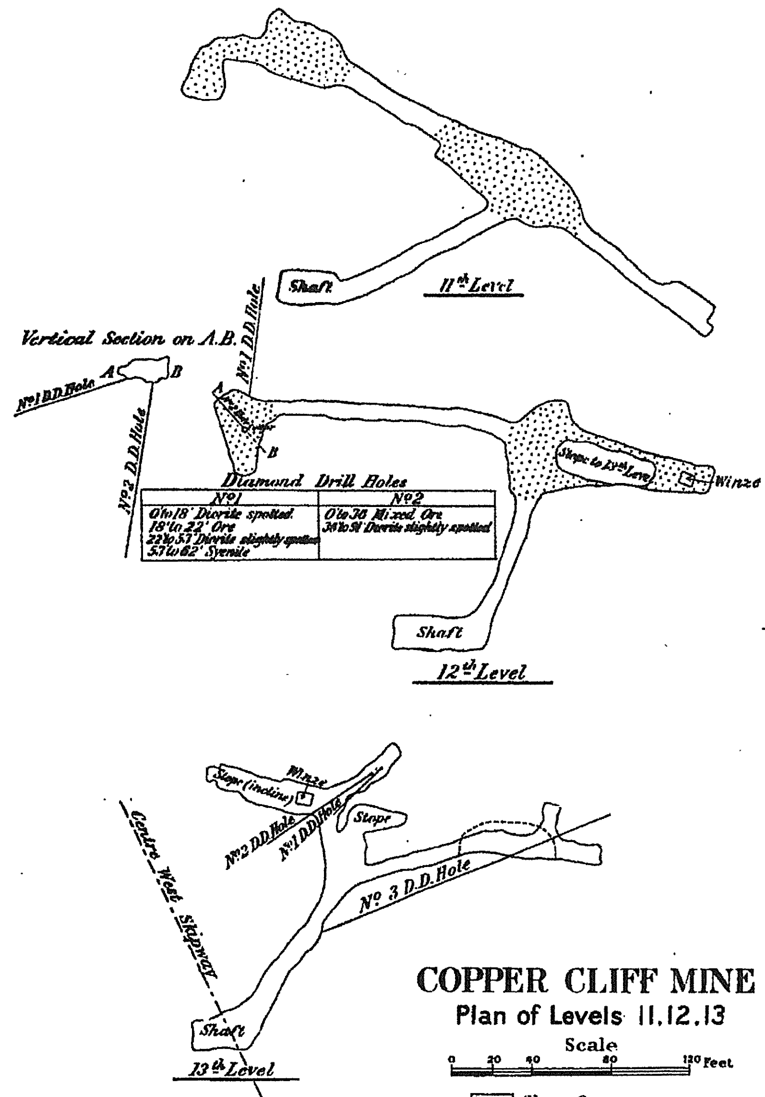
COPPER CLIFF MINE

Plan of Levels 7,8,10

Scale

0 20 40 80 120 Feet

Clean Ore



COPPER CLIFF MINE

Plan of Levels 11,12,13

Scale

0 20 40 80 120 Feet

Clean Ore

and a steep hill of pink felsitic looking arkose. Several pits have been opened upon the band, including No. 1, near the water tank of the refinery, from which some thousands of tons of rich ore were taken, but all are now filled with water so that not much more than the surface can be seen. The amount of norite as compared with ore seems to be reduced to a minimum, or even to vanish altogether in a confused intermingling of blocks of graywacké with thin seams of the eruptive.

At the most southerly large open pit hornblende porphyrite shows itself in considerable amounts, and the true norite or gabbro can scarcely be discovered at all It is as though almost only ore, out of the original mixture of ore and norite, had been forced into this narrow fissure. At the widest the band scarcely goes beyond 50 feet, and in the long extension toward the former Orford club house it narrows down to eight or ten feet. Several dikes of diabase cut the hill of arkose and approach the open pits, one or two of them actually crossing the norite band, but it is doubtful whether they have had any effect on the ore bodies.

The Evans Mine

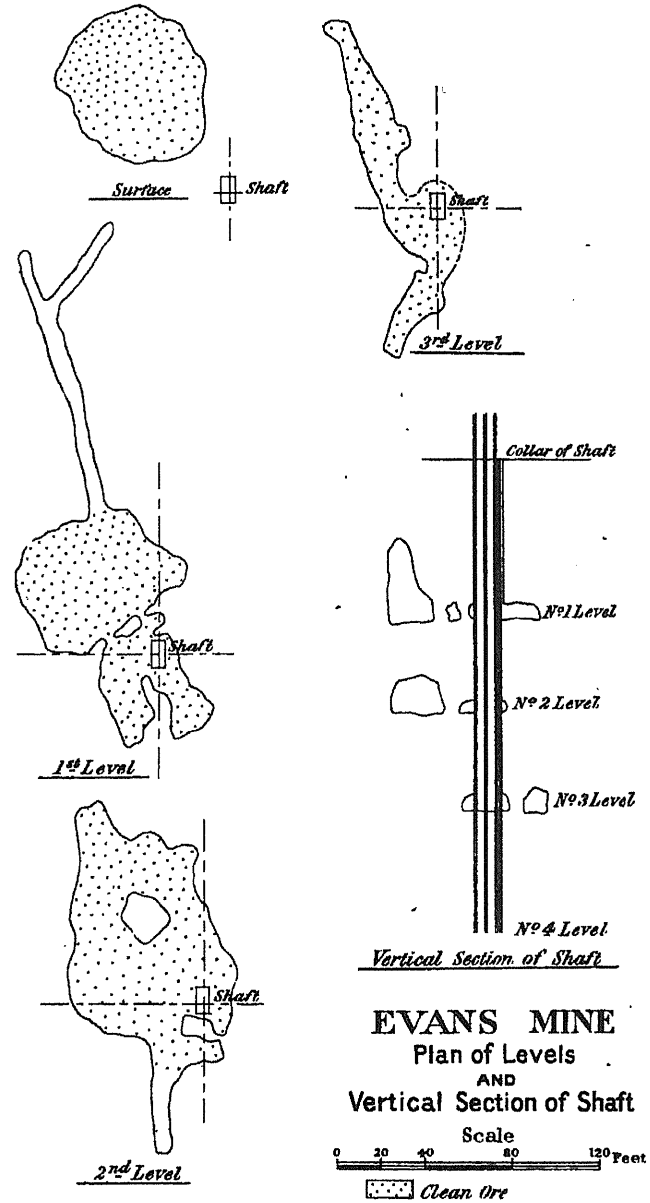
After an interval of about two-thirds of a mile of swamp and clay flats with no solid rock but a few low mounds of graywacké, the small gossan hill of the Evans mine rises gently above the clay, but is now mainly covered by the rock house and rock dumps, except at the two open pits filled with water. There is little to be learned at present from the surface outcrops, though the large rock dump shows a considerable variety of types, including gabbro, diabase (probably from dikes), graywacké and various products of weathering, such as actinolite rock. Much slickensiding was noticed on the blocks of rock.

The mine was worked by open pits to a depth of about 160 feet, and below this by levels to the depth in all of about 250 feet.

The question as to whether the Evans outcrop should be connected with the narrow band of ore-bearing gabbro two-thirds of a mile to the north near the Orford refinery, or with the ridge of gabbro rising only 400 yards to the southwest near Kelly lake is one of considerable interest and should be briefly discussed. The connection with the nearer gabbro area seems at first the more natural, but there are reasons for deciding in favor of the other theory. In the first place, all the important ore deposits in the Copper Cliff region are on what may be considered one curved belt of norite projecting from the main range and everywhere gossan-covered, indicating the presence of sulphides. On the other hand, the band of gabbro to the southeast of the Evans mine differs in character from the typical nickel-bearing norite. It resists weathering and rises as sharp ridges of hills, while the nickel-bearing norite generally has only low relief; it is never gossan-covered at its junction with other rocks, and only very small deposits of nickel ore have been found in it, and then only at a considerable distance from the margin. The gabbro belt near Kelly lake is narrow, averaging only about half a mile in width, but it connects about six miles to the northeast with a larger mass several square miles in area, just east of Sudbury. The narrow band and the main body rise through the sedimentary rocks in what seems a laccolithic way, tilting the slaty graywackés up on their flanks till they are nearly vertical or even slightly turned the other way; and this turned-up edge of graywacké runs right on between the gabbro ridge and the Evans mine as if quite undisturbed.

Still another point has a bearing on the question. The main range uniformly blends to the northwest into micropegmatite and granite, while the Sudbury gabbro mass with its prolongation to the southwest has no such peculiarity. The Kelly lake band of gabbro, then, is of quite different characters from the usual nickel-bearing norite, and having no ore bodies itself would be unlikely to send off from its flank such a large mass of ore as the Evans mine.

If the Evans ore body is connected with the band to the north, why should there be a gap of two-thirds of a mile between it and the next outcrop? This is not easy



EVANS MINE
Plan of Levels
AND
Vertical Section of Shaft
Scale

to answer, but one may suggest that connecting links are buried under the clay flats between; or the explanation current among prospectors may be accepted, that there is a subterranean connection between the outcrops "capped over" at certain points. If the latter is the case and the ore-bearing connection is not at too great a depth there should be magnetic disturbances between two outcrops, but this has not yet been demonstrated.

The evidence points toward a real connection of these chimneys of nickel ore among themselves by tortuous channels which have not always reached the surface, the chimneys representing weak points in the overlying rock where the more fluid part of the mixture of rock and ore, which would of course be the sulphides, could be forced upwards, sometimes as a column more than a thousand feet in height, as at the Copper Cliff. It is possible, however, that the connecting channel lay *above* the present level and that the heavier ore descended where opportunity offered. Since then the upper canal may have been removed, along with the thousands of feet of rock which have undoubtedly been planed off since Archean times.

The Copper Cliff offset, though only about three and a quarter miles long, and therefore shorter than two other offsets, at Worthington and in Foy township, is much the most important in the Sudbury region, for its ore deposits have already supplied more than 800,000 tons of rich ore.

The peculiar arrangement of the nickel range between this offset and that at Worthington, as if a block of the Archean support 11 miles long on the acid side and 16 miles long on the basic side had slipped down, producing faults at each end through which an outlet was afforded to the molten rock and sulphides, has already been mentioned; and the greater irregularity of the Copper Cliff offset is perhaps due to the variety of the rocks forming the substratum. This offset differs from the other two in the much greater volume of sulphides distributed along it and in its greater discontinuity, the southern outcrops, at Copper Cliff, the former Orford smelter, and Evans mine, being separated from the main offset and from one another by spaces of from a quarter to three-quarters of a mile.

There seems to be a connection between halts or obstructions in the devious channel followed by the molten material and the accumulation of sulphides, the main ore deposits occurring at the end of a continuous band of norite as in No. 2, or in isolated outcrops, as at the Copper-Cliff and Evans mines. Dr. Peters' comparison of these ore bodies to a string of sausages with a long bit of string between the sausages is very apt.

As the line of outcrop in the isolated parts does not correspond to the original southeasterly direction of the offset it is possible that faulting has taken place since the consolidation of the pyrrhotite-norite magma, producing the discontinuity and causing horizontal displacement toward the west, but in the large amount of minor faulting it has not yet been proved that there are main faults of this magnitude.

Elsie Mine

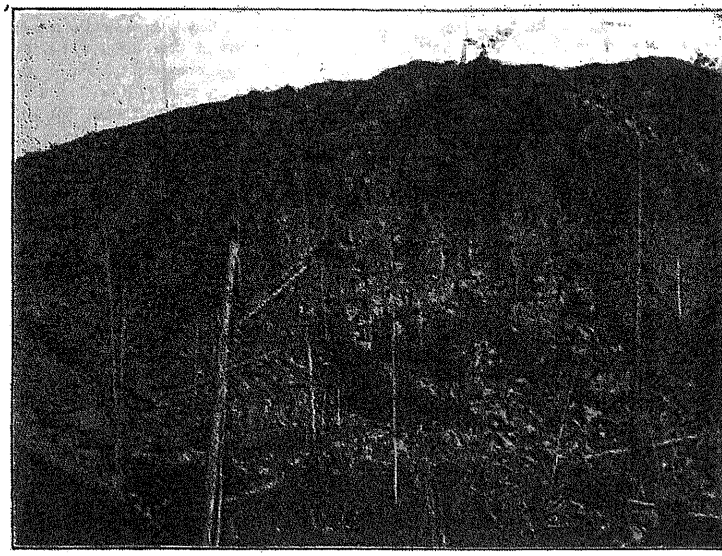
Returning to the basic edge of the main range the contact can be followed northeast from Lady Violet mine, passing to the southeast of Pump lake and then turning east towards Elsie mine. The norite is of the usual kind and most of the way is in contact with granite, partly coarsely gneissoid, having a strike of 65°, and looking like Laurentian, but partly medium-grained, flesh-colored, and probably later than the norite. With the granitic rocks are occasional hills of "older norite" and of greenstone near the boundary between Snider and McKim townships; and at the Elsie mine, in lot 12, con. V of the latter township, various greenstones cover a large area to the south of the contact.

Elsie mine is situated at a small embayment of the norite, which lies as a low plain extending for a mile or more to the north with little change of level. The

norite is weathering rapidly into rounded boulder-like masses partly buried in the coarse sandy materials resulting from the decay of enclosing rock, giving clear evidence of the origin of the plain.

At its edge the norite shows rusty, pitted surfaces as usual, and these increase till the elongated ore body is reached, where an open pit shows that the foot wall of various greenstones slopes at an angle of about 29° to the northwest. The clean ore has a thickness of 20 feet, but is in irregular pockets, while above it there is mixed ore and norite, in some places for about 40 feet. There has been some slipping and slickensiding, but the surface of the underlying rock is much more uniform than at other mines, such as the Creighton.

The ore, which is less rich than in the mines to the southwest, is almost wholly pyrrhotite and chalcopyrite, though a few seams of quartz and calcite with clay and iron pyrites occur. The pyrites contains no nickel.



Jointage of greenstone south of Elsie mine.

To the west and north of the mine the coarse-textured norite with the usual blebs of bluish quartz and black mica occasionally varies into patches of a much coarser grained variety with a suggestion of concretionary structure, consisting of vague bands which contain more hornblende toward the outer edge and more plagioclase toward the centre, with which there is usually a considerable amount of quartz intermixed. These areas vary from the size of one's hand to several square yards, and seem as a whole to be distinctly more acid than the average norite.

The Elsie mine dump shows a considerable variety of rock beside the norite, quartzite or felsitic arkose and greenstones being the commonest; and the hill which rises steeply to the south presents an even greater variety. At the foot near the ore there are some bands of arkose or quartzitic rock, evidently sedimentary, mixed with hornblende porphyrites, but higher up the hill the prevalent rock is "older norite," fine-grained and gray in color with a network of slightly raised green bands on weathered surfaces. Thin sections prove that this rock consists of plagioclase and hypersthene without quartz, so that it is a more basic rock than the nickel-bearing norite.

The older norite is mixed with or passes into, several other rocks, especially greenstones and hornblende porphyrites, but also an amygdaloidal rock showing very pronounced "pillow structure," indicating surface lava flows. The pillows may be from a few inches to four or five feet in diameter, and consists of a paler centre, sometimes older norite, with a dark margin having two or three inches of the outside thickly sprinkled with small white amygdules.

A wide band of this mixture of greenstones extends south toward Copper Cliff, covering several square miles.

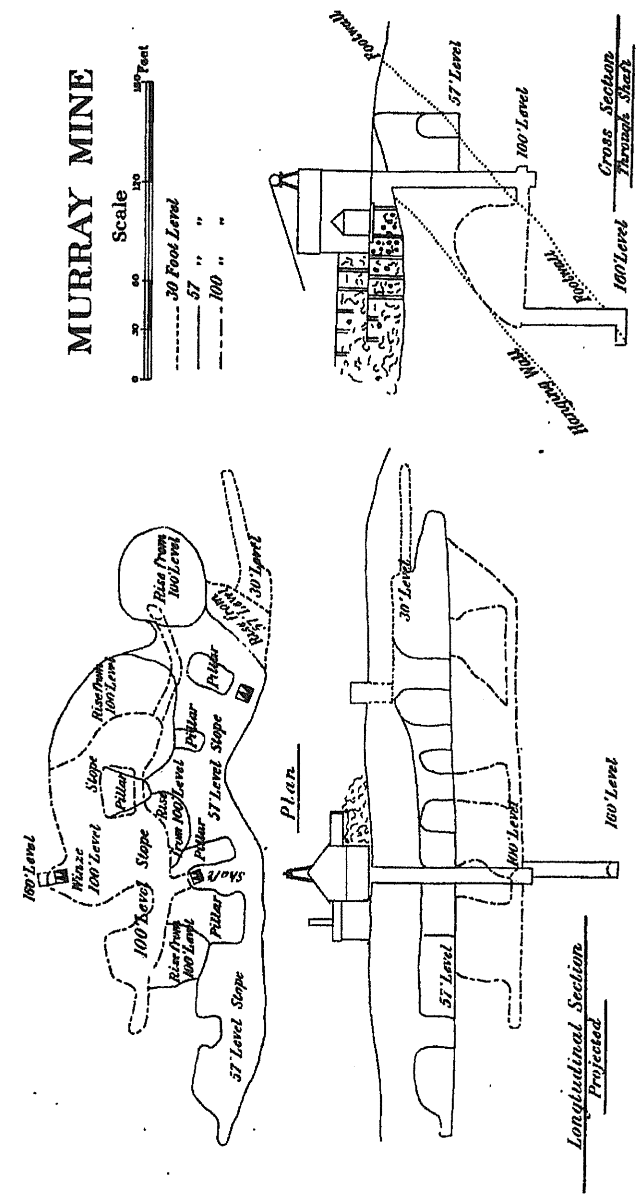
Murray Mine

The gossan edge of the norite at Elsie continues without a break toward the northeast to Murray mine on the north half of lot 11. This is one of the oldest and most carefully studied of the mines of the region, Baron von Foullon and Professor T. L. Walker having worked upon it, proving that the accompanying rock, up to that time called diorite, was really norite. For a number of years, however, the mine has not been operated, and conditions are not now favorable for its examination.

Much of what has been said of the Elsie mine applies to the Murray mine also; but the band of gossan is wider here and apparently the ore body considerably larger. Several large dikes of olivine diabase cross the norite, some of them cutting the ore body itself, and run in the direction 125° towards Ramsey lake near Sudbury, their course having been determined by Dr. Barlow. As the conditions of the mine are not easily seen at present it may be well to quote a description of it from one of the gentlemen who operated it 12 years ago.

In 1893 Captain Richards stated to the Inspector of Mines that "the ore body, which possesses an average thickness of 70 feet, strikes in the direction northeast and southwest and dips northwesterly 45° from the horizontal. This agglomerated mass of nickeliferous pyrrhotite and diorite is contained by diorite walls. The foot wall at certain points, as proved by mining operations, presents the appearance of a true fissured plane upon which, at some time or other, the ore body has moved, as evidenced by the coarse flucan or attrited matter which separates the ore from the wall. In some places through the occurrence there exist large inclusions, horses or intrusions of diorite containing fragments of granite." As these mines are now full of water, little can be said of the relationships of the ore body to the adjoining rocks beyond what is visible on the surface. The character of the norite mass has been elaborately described by Dr. T. L. Walker, so that it is only necessary to say that it is the ordinary coarse-grained rock with bluish quartz. The contact of the norite with the adjoining rock runs about northeast from the Elsie to the Murray mine, and continues in the same direction past the latter, more or less gossan marking the boundary all the way. The hornblende schist and porphyrite forming the foot wall at the Elsie is largely interrupted at the Murray mine by dikes from the southeast end of an area of red granite later in age than the norite, which it has penetrated in the most confused way, sometimes forming a giant breccia of norite blocks with narrow seams of granite between, but part of the apparent granite may prove to be squeezed and modified arkose or re-composed granite. The greenstone near the Murray mine is sometimes sheared into schist with bands of lighter and darker green, showing great dynamic action.

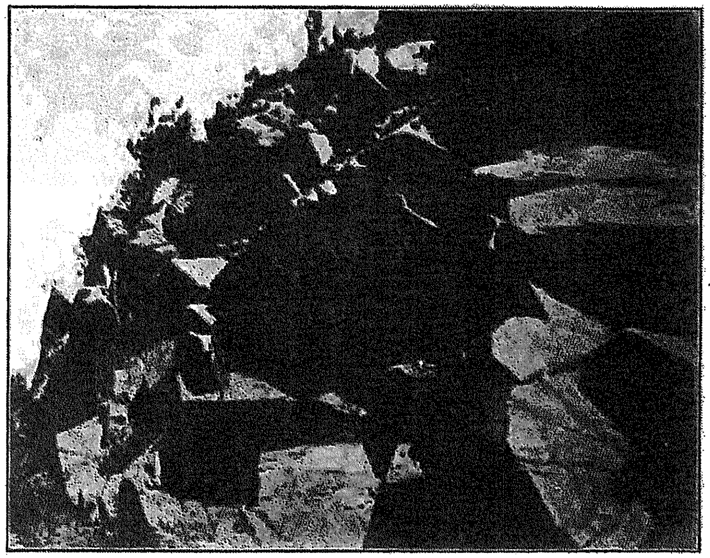
On the dump of the Murray mine much of the norite is found to be filled with sulphide granules of all sizes and in all proportions, as at most other nickel mines, the ore being in coarse grains when the rock is coarse and *vice versa*. In addition to the



usual country rocks on the dump there is a very coarse "malchite" consisting of green hornblende blades sometimes six inches long and white plagioclase with more or less quartz, evidently a segregation of the sort found at Elsie, but of a much coarser texture.

To the northeast of the mine the gossan-covered edge of the norite extends for half a mile with a few small outcrops of ore exposed by stripping or test pits from point to point. In one place a large dike of diabase has been partly stripped as if in searching for ore, just to the east of a mass of gossan. Superficially the two rocks are somewhat alike, though the diabase shows no quartz blebs, and is not pitted with gossan spots. At these outcrops the gossan leans against the older rock as at Sultana mine.

The range of later granite hills to the southeast of the Murray mine runs for some miles parallel to the edge of the norite, and in some places encloses patches of greenstone, etc., while it is cut by the diabase dikes mentioned above. One of the largest dikes has weathered out leaving a vertically walled passage 150 feet wide through a ridge of granite a little east of Murray mine, providing an easy grade for the old road from Murray mine to Sudbury.



Jointage of granite west of Murray mine.

Where the Canadian Pacific railway crosses the nickel range between Murray mine and Azilda (formerly Rayside), there is an excellent section displayed, which was described by Prof. Walker years ago,[23] but may be referred to here as one of the best known. The whole width at this point is about four miles, so that this is one of the broadest parts of the range, being surpassed only by the part north of Creighton. Near the mine the norite is of varying texture and largely mixed with ore as pyrrhotite-norite, and except for a somewhat coarse texture there is little variation for a mile and a half to the northwest along the railway or the wagon road to Azilda. At a few

[23] Quar. Jour. Geol. Soc., London, Vol. LIII (1897), pp. 47-54.

points the weathered surface looks somewhat reddish toward the northwest corner of McKim township, but fresh specimens have the usual dark color of norite. Where the road and railway pass from McKim into Snider township and descend towards the Rayside plain rather fine-grained granite crosses as a band about 400 feet wide but very irregular; and half a mile farther northwest there is a similar band. Here the eruptive becomes more acid in character and redder in color, while the rock rises as hills in a pronounced way, probably because of its change in composition, since it no longer weathers rapidly as in the low plain toward the basic edge.

Where road and railway pass into a bay of flat clay land the acid phase of the eruptive has distinctly come in, with flesh red weathered surfaces and very rugged forms with steep slopes or cliffs toward the valley. Beyond this the eruptive is very schistose, resembling gneiss or felsite schist and has been mapped by the Geological Survey as Huronian, though the finding of the basal conglomerate on a hill half a mile northwest of Azilda station, with typical granite boulders and the usual intense metamorphism proves that all the schistose rocks between the hill and the red cliff previously mentioned must be included in the acid phase of the eruptive. This view corresponds with that taken by Prof. Walker.[24]

Blezard Mine Region

From the small outcrops of ore in the southern half of lot 10, con. VI, of McKim township to the Cameron mine in lot 7, con. I, of Blezard, a distance of about two miles, the basic edge runs with minor curves toward the northeast, showing little gossan or other evidence of ore. The norite along this portion is in contact with later flesh-colored granite.

At the Cameron mine, where a small ore body has been developed, there is a slight bay of the basic edge, which here turns nearly east to the Little Stobie mine near the north end of lot 6. Along this part of the contact the relationships are largely concealed under drift deposits and by woods.

At the Little Stobie an open pit discloses ore resting against green schist and hornblende porphyrite; and the norite shows a little to the north and also to the southwest in a phase suggesting breccia or conglomerate, the usual rather coarse gray rock enclosing crowded fragments of the finer grained older norite.

In lot 8, con. II, of Blezard township, about a mile northwest of the Little Stobie, a small pocket of ore was found by dip needle work by Mr. Edison's party, and a test pit and diamond drill holes were sunk there to explore for ore, but without success. The drill core showed norite, weathered or fresh, to the depth of 1,030 feet, with, however, a band of schist at about 260 feet and a considerable thickness of fine-grained granite at 900 to 950 feet.

On the way to the camp two small outcrops of granite are found, so that here as northwest of Murray mine dikes of granite cut the norite.

From Little Stobie the contact runs northeast to the north corner of lots 5 and 6, con. I, and then east as a small embayment to Mount Nickel mine, which has been partially developed by two open cuts, the sinking of a shaft to a depth of 165 feet, and a considerable amount of drifting at the 75-foot level. This work and two diamond drill holes are said to prove that there is a good body of ore, dipping at about an angle of 30° toward the north, and the ore dump is of respectable size and quality. The open cuts show that the ore is partly to the south of the norite in fractured and broken greenstone, as if it had been squeezed into the fissures while molten, by pressure from the north, thus forming a sort of breccia of rock fragments cemented by pyrrhotite and chalcopyrite.

[24] Ibid, p 53

Blezard Mine

From the Mount Nickel mine the contact bends gently toward the northeast to the Blezard mine in lot 4 in the second concession of the township of the same name. Mr. Robert McBride, who was captain of the mine in 1892, states that it was opened in 1889 and 1890 by the Dominion Mineral Company, and shut down in 1892. At present the surface is so covered with buildings and heaps of waste rock that very little can be seen of the immediate surroundings of the ore deposit, and the large pit is of course full of water. The waste rock includes some norite and gabbro, but much more greenstone, such as hornblende porphyrite and fine-grained hornblende schist, as well as quartzite. The walls of the open pit consist mainly of green schist, including some masses of quartzite, but on the northeast side what is apparently a projection of gabbro from the large area to the north reaches the opening. The norite to the north is the usual coarse-grained kind with quartz and biotite, and, according to Dr. T. L. Walker, extends to the shore of Whitson lake where it gradually changes to gneissoid granite. The gabbro or norite band is flat and low, contrasting with the rough ridges of greenstone and quartzite to the southeast. As the surface is so much covered the description of the surroundings of the ore body as seen in the early days by Dr. Bell may be quoted:

"The ore consists of a body of mixed chalcopyrite and nickeliferous pyrrhotite mingled with more or less rock matter, giving the whole the appearance of a conglomerate. The general strike of the country rocks is here as elsewhere in the vicinity about northeast and southwest. The ore-bearing belt, which is associated with a dark quartz-diorite, is about 100 feet wide and dips northwest at an angle of 65°. It is overlaid by a massive bed of ash-colored graywacké, the weathered surfaces of which present raised reticulating lines. Immediately to the northwest of the shafts there is a dike from 30 to 50 feet wide, of dark brownish gray crystalline diabase, weathering at the surface into rounded boulder-like masses, which scale off concentrically."

The open pit is said to be 60 feet deep, and the lower workings of the mine reach a depth of 172 feet; but the plans of the mine appear to have been lost, so that the shape of the ore body cannot be definitely given. It may be mentioned that the rock dump is unusually free from ore, showing that the separation of the ore from the waste rock was carried out more carefully than at other mines in the region.

The Blezard is the last mine toward the northeast which has been worked on any large scale along the basic edge of the main nickel range, though several prospects and small workings are found beyond this toward the east.

The road from Blezard north past Whitson lake (locally called Blezard lake) gives a good section of the nickel-bearing eruptive, which is here only two miles and a half wide. A similar section is displayed along the shores of the lake, as described by Prof. Walker.[25]

The basic edge at Blezard mine is of the typical sort for the southern range, consisting of dark gray norite with bluish quartz and some plates of biotite. A wide swamp intervenes between the outcrops near Blezard mine and the hills to the north, where rock once more appears; and the character of the rock is still that of norite, though coarser in texture and paler in color than at the mine. After a short interruption of pale flesh-colored, fine-grained rock, probably a mass of metamorphosed quartzite, a coarse flesh-colored to gray variety of the eruptive is again encountered, either a syenite or diorite in appearance. A sharp hill of reddish gneissoid rock rises just beyond this, possibly a band of later granite, though it is sheared into a distinct gneiss. Next comes a dark flesh-colored variety of the eruptive, suggesting syenite, but proving under the microscope to consist mainly of pegmatite with much quartz. Coming down to lower ground near the northwest end of Whitson lake a darker gray rock, sometimes gneissoid, represents the acid edge of the eruptive and stands in contact with the sediments.

[25] Quar. Jour. Geol. Soc., Vol. LIII, (1897), pp. 47-56.

At the edge there is a narrow band of conglomerate containing pebbles and boulders of quartzite, granite, and perhaps other rocks, with some green chloritic schist, partly as matrix and partly without pebbles. There has been a good deal of crushing along the margin of the eruptive, and the relationships are not always clear, but the strike is about 60° with a dip of 35° to 55° to the southeast, as if the eruptive had overturned the edge of the sediments. Beyond the contact tuffs of the usual kind are found at various points along the road.

The Frood-Stobie Offset

The Stobie mine and its surroundings are probably best taken up in association with the Blezard and Mt. Nickel mines, its nearest neighbors to the north, though no surface connections are known between this important offset and the main nickel range, later granite and older greenstones intervening for a width of about a mile between the two.

The Frood-Stobie offset runs for a little less than two miles from southwest to northeast parallel to the main range, beginning as a narrow gossan band in lot 7, con. V, of McKim township, and ending at the Stobie mine in lot 5, con. I, of Blezard. The gossan is first seen about four miles northeast of Lady Macdonald mine at the upper end of the Copper Cliff offset, with which it probably has no connection.

Beginning at the southwest the rusty surface of gabbro is first encountered about 1,100 yards from the Frood as a band indistinctly separated from the adjoining rock, which is graywacké and schist, often containing large pseudomorphs after staurolite. The band rises as a ridge which is generally red-brown from the gossan, but is cut off by a narrow interruption of quartzite 600 yards southwest of the mine. The rusty gabbro quickly rises again and widens greatly, until near the mine it reaches its greatest width of about 200 yards. In this part it has quarzite and graywacké to the southeast, striking 40°, about the direction of the norite band itself. On the northwest the rocks adjoining it are more varied, but the rock in immediate contact is generally diorite. Beyond these rocks, which rise against each side of the gabbro, there are broad swamps. To the north of the mine the gabbro hill dips down quickly into swampy ground, and is presently cut off by quartzite and green schist. Beyond the swamp to the northwest at about 200 yards distance a chain of granite hills runs parallel. The granite is rather fine-grained, flesh-colored, and appears to be a part of the later granite mass observed near the Murray mine two miles to the west.

At the Frood mine or No. 3 belonging to the Canadian Copper Company, the gabbro rises about 90 feet above the low ground around, showing an eruptive contact with the graywacké and quartzite on its flanks, but the hill is so covered with gossan that boundaries are not easily fixed. The mine has been opened up by two large open pits and a shaft, and the ore is irregular in its occurrence and greatly mixed with rock matter, the large dump showing chiefly norite and graywacké, but also some blocks of actinolite and talc, no doubt secondary products. Angular and rounded masses of rock are enclosed in the ore as matrix, one pebble being of white quartzite, but these pebbles and boulders are probably the result of rolling between faulted surfaces.

This mine is on the southeast side of the widest part of the norite band, and a small open pit to the north shows typical pyrrhotite-norite, with every mixture of the two materials; while rusty surfaces extend all across the band to lot 7, where another company has done a small amount of development work on the northwest side of the ridge. The ore here seems greatly mixed with rock. Stakes placed at regular intervals over the ground show that a magnetic survey has been carried out, but the results do not seem to have justified further work.

This part of the offset, with a small band of graywacké to the southeast and of greenstone to the northwest, rises as a narrow ridge from swamps on each side and ends a little north of Frood mine, being cut off by green schist. Beyond it a very narrow band of norite or of gossan-covered surface runs for more than half a mile northeast, with a narrow strip of greenstone mixed with graywacké beside it, and a wider band of graywacké between it and the range of granite hills referred to before as beginning at Murray mine.

About half way between the Frood and Stobie mines the band of rusty norite becomes discontinuous, and beyond this there are only patches of gossan-stained surface with a little fine-grained norite entangled in graywacké conglomerate and greenstone; the ridge sinking into the swamp. There is much evidence of crushing and shearing along this line, which must indicate a plane of weakness and more or less faulting through which the norite could intermittently penetrate.

There is a gap of about 400 yards between the last undoubted outcrop of norite and the gossan hill at Stobie which rises steeply with a still higher point of greenstone just to the south.

The Stobie Mine

The Stobie mine was one of the earliest discovered, and has been worked more extensively than any other except the Creighton, most of the ore having been taken from great open pits, though there are also underground levels, reaching a depth of about 250 feet. The ore body dips at an angle of 65° toward the west. The mine has been shut down since 1901, and the pits contain much water, but the main cavernous opening with its stopes and irregular projections gives an impressive idea of the size of the deposit, which is said to be far from exhausted, though more than 400,000 tons have been taken from it.

The mine is at the foot of the gossan-covered hill on the east side, and the enclosing rocks are of various kinds, including but little norite. The hill top shows a number of small patches of this rock with more or less ore embedded in a mixture of green schist, hornblende porphyrite, graywacké and crush conglomerate, as if squeezed up through a colander from beneath; and the whole hill, which is 330 yards in length from east to west and half as wide, is more or less gossan-covered, making the relationships difficult to determine. To the north there is swamp, to the west graywacké, to the south green schist and hornblende porphyrite rising still higher than the gossan hill, and to the east there are the great open pit, the mine buildings and the rock dumps, with a mixture of rocks showing between, including those previously mentioned, and also a patch of graywacké conglomerate undoubtedly formed by water, since the well-rounded pebbles are of great variety.

The openings at the pits show mainly graywacké, hornblende porphyrite and grayish schists with only a minimum of rather fine-grained norite. The only other rock observed about the hill is a small patch of reddish granite on the south slope, isolated as if part of the crush conglomerate. The large rock dumps consist chiefly of graywacké, often somewhat granitic or dioritic looking, and quartzite, with a little gabbro and a few blocks of chloritic or actinolitic rock. One block of diorite schist had been sheared along a number of planes which are now gilded with films of sulphide. The norite on the dump is often filled with shot-like grains of ore as at so many other mines in the region.

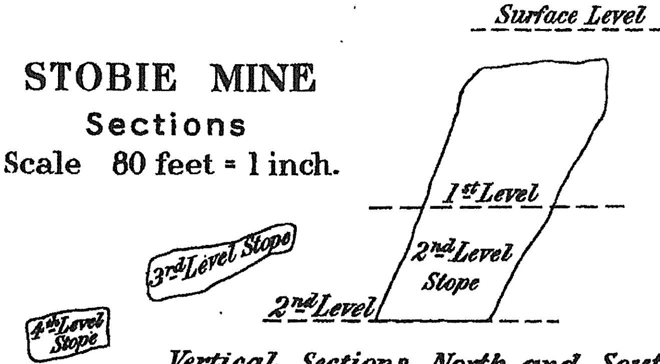
The offset has not been traced farther to the northeast, though a strip of swamp extending towards Blezard may conceal an extension in that direction, since there is considerable disturbance of the compass there. Where the swamp ends outcrops of greenstone, etc., bar the way to a direct connection with the main range. It may be that the widest part of the band, near Frood mine, was at first joined to the basic edge before the belt of granite was erupted between them.

It is evident that this offset differs from all the others in having no visible connection with a funnel-like bay of the norite edge. From the map it will be seen that the basic edge of the eruptive along this part of its course is unusually straight with

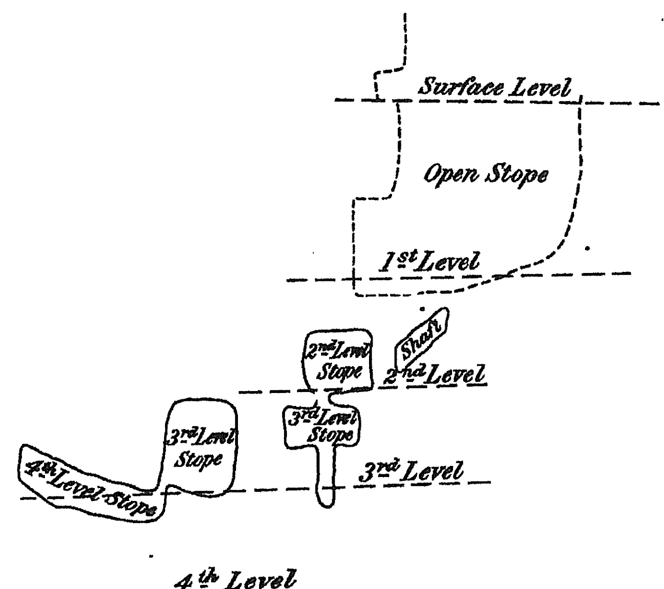
STOBIE MINE

Sections

Scale 80 feet = 1 inch.



Vertical Sections North and South



Vertical Section Northeast and Southwest curves to the northwest rather than towards the offset. The basic edge parallel to this offset contains little ore, and it seems not improbable that there was a subterranean outlet for the ore, which made its way up through a line of shattering corresponding to the strike of the band of graywacké, which has the usual northeast-southwest trend.

The rocks adjoining this offset are of extraordinary variety, including both sediments and eruptives of interest. The graywacké so often mentioned sometimes contains well-rounded pebbles and shows cross-bedding. It merges into fine-grained gneiss in some places, and in others is crowded with large white pseudomorphs after staurolite of a very showy character. These crystals are often oriented parallel to one another, but at an angle with the schistose structure, which runs about 55° to 65° and must be of later date than the staurolites. Other parts of the graywacké contain concretions or pebbles of quartzite from the size of a pea to that of an orange, the larger ones usually having an eye and eyebrow arrangement, as if a crescent-shaped shell had split off and separated itself half an inch from the oval mass in the middle.

Along with these curious rocks there are smaller bands of conglomerate crowded with pebbles of various kinds and a few small outcrops of gray or pure white quartzite. Bands and small bosses of hornblende porphyrite penetrate these sediments, and are generally oriented to corespond with the strike.

To the north of Stobie and separating it from the main nickel range there are rugged hills mapped as greenstones, but really containing a singular variety of rocks, such as the older norite merging into greenstone toward the north, and more altered rocks toward the south, often what appears to be hornblende schist crowded with white bean-like quartzite with sharp outlines. With these occur larger white spots with a darker centre and even concentrically arranged orbicular forms with lighter and darker belts having a diameter of an inch or two. Pillow structure of an indistinct kind is found in places but scarcely amygdaloidal as near Elsie.

Northeastern End of Main Range

Beyond Blezard the norite contact sinks beneath the swampy border of a creek flowing into Whitson lake, and when it reappears there are few indications of ore until the Sheppard or Davis mine is reached in the south half of lot 1, con. III, of Blezard township. It is said by Captain McBride that a shaft 180 feet deep was sunk on this property, and that very rich ore was obtained from it, some assays running as high as 19 per cent. of nickel. The surface showing is not promising as to amount of ore, but the sulphides include a drusy reticulated mineral which weathers rapidly, perhaps polydymite. In the green schist a little south of the basic edge on this property a pit has been sunk on quartz containing some copper pyrites and marcasite.

In lot 12 of Garson, just adjoining the Sheppard mine the edge of the norite against green altered eruptives is schistose and contains fragments of the adjacent rock sheared out into short narrow bands.

Within the township of Garson the basic edge runs nearly due east along the southern side of concession III, and the width of the eruptive gradually increases eastward from two and a third to three and a half miles at the Cryderman mine. On the line between lots 11 and 12 greenstone is found as low hills to the south, the north boundary being lost under swamps; but a half mile east the contact is found a third of a mile north of con. II, just beyond the line between 10 and 11, and some gossan and ore occur in a pit sunk by Malbeuf and Martin. To the south of the pit there is well-stratified graywacké rising as low hills through a surface of rolling clay on which settlers are taking up farms. East of this no evidence of ore was seen until the Kirkwood mine was reached in lot 8; the low norite hills of pale gray color being separated by a strip of swamp from greenstones, sometimes surface lava flows with amygdaloids and pillow structure. Neither rock forms hills of much height, the norite seeming as resistant as the greenstones, an unusual circumstance probably due to the squeezing of the norite and its re-arrangement to a somewhat schistose hornblendic rock which is not easily weathered.

At the Kirkwood mine a good deal of development work has been done including the sinking of two pits or shafts, now full of water, but fire has destroyed all the structures connected with the mine. The shafts are on hills about 100 yards apart, the western one seeming to be in greenstone 30 or 40 yards south of the norite, the other at the margin of very much sheared and crushed norite of a pale gray color, with somewhat banded greenstone to the south, the norite rising higher than the adjoining rock, which sinks into sandy drift-covered ground occupied by a farm. The rocks to the south are quite varied, graywacké and quartzite occurring as well as the greenstone, all frequently crushed to a breccia or conglomerate. At one point half a mile southeast of the mine a little patch of norite is found in the other rocks, having blebs and larger masses of ore disseminated through it, evidently a small discontinuous offset.

From the Kirkwood to the Cryderman mine the actual contact of the basic edge is hard to follow owing to drift and wooded country, but in general the norite is found not far to the north of the Huronian, the edge being more easily weatherd than the rocks on either side. The norite retains its sheared and altered character, and would hardly be recognized as the nickel-eruptive but for its continuity with the more characteristic rock to the southwest and its connection with ore bodies.

Half a mile east of the Kirkwood property the rock south of the norite is largely a crush conglomerate of quartzite and graywacké, some bands of water-formed conglomerate containing pebbles having a strike of 110°

At the Cryderman mine on the south halves of lots 4 and 5, con. III, of Garson there is a larger showing of gossan than at the Kirkwood, and several pits have been sunk, one large and the others small, while a considerable amount of stripping has been done. The surface has been gridironed with pegs for a magnetic survey, the results of which are not available; and diamond drill cores lying about show that a good deal of investigation has been devoted to the property. The pale gray, somewhat sheared norite has a very irregular margin against greenstone and green schist, and shows the usual spotted appearance where blebs of ore have weathered out. Part of the norite is very fine-grained for the main range. The most important openings are near the margin, but the most southern outcrop is in greenstone about 200 yards south of the basic edge, evidently on a small offset.

The basic edge can be followed for a mile east of the mine with little change except for the lack of gossan and of ore, the norite still presenting the greatly squeezed and rolled appearance. Sand and gravel plains now begin to encroach on the boundary of the nickel eruptive, so that there are some gaps in our mapping.

A very good cross section of the nickel range is afforded by the road north of Headquarters toward the Blezard valley, the southern part of which was formerly the grade of one branch of the Emery railway. Most of the road is over sand and gravel, but there are numerous outcrops of rock ranging from the peculiar pale gray sheared norite to coarse dioritic material and dark or pale flesh-red schistose rock belonging to the acid edge.

In the township of Falconbridge, lot 7, con. IV, the basic edge turns north and has been followed here for over a mile with gneiss containing greenstone inclusions as the country rock. Four hundred and eighty paces east of the corner post between lots 7 and 8, on the line between concessions IV and V the most easterly point of the basic edge is reached, here gossany and lying against gneiss. Just to the south some stripping has been done and a small shaft sunk in rock containing thinly disseminated sulphides, principally pyrrhotite. As there is a southeasterly bay of the norite at this point one would expect a considerable body of ore, as on similar bays along other parts of the basic edge; and possibly future exploration may disclose such an ore body.

Acid Edge in Blezard and Garson

After swinging from nearly north at Azilda to nearly east where leaving the township of Rayside, the acid edge runs in about the same direction through concession IV of Blezard to the northwest bay of Whitson lake. Entering Blezard township the sharp hills of the acid edge sink into swamp before the contact with the Trout lake conglomerate, but a little to the east the meeting of the two rocks is well shown on the hilly region southeast of the flat farm land of Blezard valley. The conglomerate here is wide and characteristic, the edge next the eruptive being schistose and containing large granite boulders; the next layer to the northwest is a conglomerate or breccia crowded with rounded or angular pebbles of several kinds of rock; after which come softer tuffs with flattened pebbles sinking toward the plain. The acid edge is no longer schistose, as near Azilda, but has the normal granitic look.

To the east the acid edge follows low ground usually, cutting two small lakes in lots 9 and 11, and then turning a little northeast to Whitson lake, where the eruptive is grayish and schistose, as was mentioned in describing the section of the eruptive from Blezard mine to Whitson lake. The conglomerate is here very narrow, only a few paces wide, and it as well as the tuff beyond it is very schistose. Similar relations are found on the northeast side of the lake, where the contact passes about a quarter of a mile from the outlet into Chelmsford creek. The eruptive is pale gray with a tinge of flesh color on weathered surfaces, but darker gray on fresh ones, and is distinctly schistose like the few feet of conglomerate next to it.

East of Whitson lake conditions are much the same as far as the eastern side of Blezard township, the edge crossing into Garson township about a third of a mile south of the VI concession in very swampy country, which continues half a mile beyond. The acid edge turns somewhat north, entering the VI concession in lot 8, and then east again across the middle cf the concession almost until it reaches the northeast corner of the township. The acid edge and conglomerate with part of the tuffs form a steep east and west range of hills with many swampy tracts to the north.

About half way across the township the eruptive rises as a cliff, reddish in color, felsitic in texture and penetrated by many small quartz veins. On lot 4 the acid edge is grayish and schistose with a wide band of schist conglomerate to the north, having a strike of 125°, and along the road from Blezard valley to Headquarters it rises as a steep hill from a gravel plain, formed of fine-grained reddish granite with a slight schistose structure running 110°. Here there is a gap of half a mile where no rock rises above the gravel.

Just within the southwest corner of Maclennan township there is a small outcrop of rock at the acid edge where the old railway grade ends in a glacial kettle mostly surrounded with sand and gravel. The acid edge here is schistose with a strike of 110° or 120°, and next to it is the ordinary schist conglomerate, followed to the north by a ridge of tuff. To the east of this a gravel plain and morainic ridges hide the solid rock for a long distance; but the acid edge must turn sharply north or northeast, since it is next found in lot 3, con. III, of Capreol on the northern range.

THE NORTHERN NICKEL RANGE

Introduction

The northern nickel ranges, as known to the prospector, were not continuous, but had large breaks where no gossan or ore deposits had been found, as in Morgan township and near Windy lake; so that it required careful geological exploration to follow up the band of nickel-bearing eruptive and fill in the gaps. This has succeeded so well that the northern and southern ranges have been proved to connect at the ends without a break, unless, very improbably, there should be an interruption beneath the sand and gravel plains of Capreol and Maclennan, where direct evidence is lacking for two or three miles.

The basic edge of the nickel eruptive has, of course, been followed with special care because of its economic importance as the bearer of ore deposits, but the acid edge has been studied in some detail also, since the width of the eruptive has been found to have an important bearing on the probable occurrence of ore bodies, a very narrow part of the range seldom showing any gossan and never ore bodies of workable size, while very wide parts are almost invariably accompanied by ore deposits of importance.

In the older maps the northern nickel range was represented as forking about the middle of Bowell township, one band running west to the middle of Foy and the other southwest toward Morgan township. Which of these norite bands formed the basic edge of the range was uncertain until our work proved that the southwestern one joins the range already known in Levack township.

The northern range as here described will be considered to include everything north of the Sultana mine in Trill at the west end, and of Falconbridge at the east end of the eruptive basin; and the work will be taken up at the western end, following the range eastwards. The northern range as thus defined has an irregular northward curve, its basic edge is 54 miles long; while the basic edge of the southern range is only 40 miles long, the doubtful part where the gravel plains cover the rock being omitted from both. The relative importance of the two ranges is however very different, since the northern range is on the average much narrower than the southern one.

The Nickel Range in Trill

Rounding the bend made by the basic edge of the nickel-bearing eruptive less than a mile west of Sultana mine the actual contact is lost under swampy tracts, though the acid edge is well defined to the northeast, and the Laurentian with some patches of greenstone occurs to the southwest and west. An old wagon road whose corduroy is almost rotted away follows the edge somewhat closely, having been made by prospectors who did some development work years ago on locations taken up to the north.

Trillabelle Mine

In the third concession on the line between lots 10 and 11 of Trill there is a fairly well beaten trail or portage running east and west connecting with a canoe route eastwards to Fairbank and Vermilion lakes; and here just to the west of the old wagon road granite of a Laurentian aspect rises as a rocky hill above the swamp so usual at the basic edge of the nickel-bearing eruptive. Next to this, going north, is a dark-green rock containing some boulders, evidently a Huronian conglomerate or breccia, and against it ore is to be seen. Half a mile farther north the wagon road ends at the mine called by our guide the Gillespie, but in the Bureau of Mines report the Trillabelle, where a considerable amount of work was done many years ago.

Here and 170 paces beyond are a few foundations of stone, remains of a hoisting plant and various log houses; and ore or gossan against the hill which rises to the west. The rock observed is mainly greenstone with boulders suggesting a crush conglomerate, though a gray fine-grained rock near the northern pits may be norite. The dip of the rock face against which the ore lies at the points previously mentioned is from 35° to 45° to the east.

Half a mile north morainic hills conceal the bed rock and the next outcrop observed is probably the basic eruptive edge, the rocks higher up the hill to the west being bouldery greenstones like those mentioned before.

For a distance of 550 paces east of the line between lots 10 and 11 and near the middle of the fourth concession the rocks observed are a somewhat re-crystallized arkose, evidently Huronian, and beyond this only bouldery drift is seen for 200 paces, probably covering the basic edge of the nickel-bearing eruptive, which here rises from under the drift.

To the north of the fourth concession the basic edge is hidden by wide swamps, though it is known to run to the east of Armstrong lake where Laurentian granite crops out; and the exact edge has not been visited in lot 8 in the I concession of Cascaden, though basic looking norite occurs to the east of a narrow lake which cuts off access to a location taken up years ago on the opposite side of the lake, said to contain ore. The northern arm of this lake marks the boundary between the norite and Laurentian rocks consisting of gneiss and greenstone. From this point to the northeast the basic edge is most easily reached by a trail from the southwest bay of Windy lake, which runs largely over drift deposits including a moraine, but gives access to outcrops of rock.

The basic edge is nearly straight from this point in a northeasterly direction to the bay just mentioned, and on Windy lake itself the northwest shore, where not drift-covered, is Laurentian of the usual kind in the region, consisting of reddish or grayish bands with darker gray layers of finer grained schist. The islands off shore and the large peninsula projecting from that shore are of norite. On the peninsula the boundary is largely hidden by morainic and esker ridges, but it is distinctly seen on the shore of the southwest bay. The rest of the shores of this beautiful lake are of norite or the intermediate rock between the basic and acid phases.

The best section of the nickel-bearing eruptive is provided by the railway cuttings to the west and east of the little station Onaping; and a number of rock specimens from these cuttings have been described by Prof. Walker.[26]

Beginning on the northwest near Windy Lake station, which is some distance west of the lake, Laurentian granite and gneiss with darker schistose inclusions are found until the shore of the lake is reached, when gray dioritic-looking norite occurs, the actual contact however being hidden by drift. The rock remains the same in appearance for 100 yards, but soon changes to a reddish syenitic phase of fine or coarse grain, which continues to Onaping station, and is followed toward the southeast by greenish-gray rock having a peculiar ophitic-looking structure. The color and general appearance of the eruptive at the ends of this section are much alike, but the intervening phase of flesh-red syenite-looking rock is very different.

The acid edge of the eruptive rises as very steep hills to a height of 300 feet above the station, and the railway is forced to follow the valley of Onaping river in a sharp curve in order to cross the range of hills. The southeast side of these hills consists of hardened sediments, at first gray, fine-grained graywacké conglomerate with pebbles and a few boulders of quartzite and granite, and sometimes also of gray chert, extending along the railway for about 1,000 feet; and followed by characteristic black vitrophyre tuff, often crowded with small fragments of gray material.

Acid Edge, Ross Lake to Windy Lake

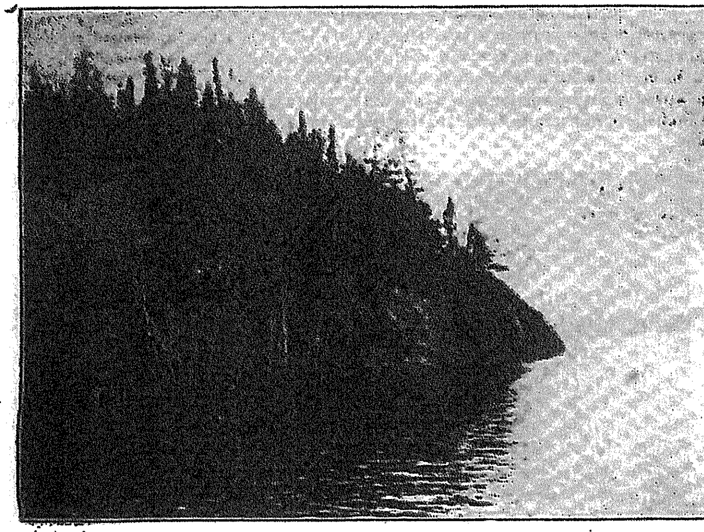
The nickel eruptive gradually widens from the northward bend to the northern part of the township of Trill, and then narrows slightly as it approaches Windy lake. The acid edge near Ross lake is fine-grained, gray and not schistose, but to the northeast it becomes dark green and schistose, as on Fairbank lake which has already been described. The conglomerate is not very prominent along this part of the contact, the tuffs coming close to the acid edge, if not actually touching it.

Along the acid edge in Cascaden the norite is not schistose and is paler gray in color than at the previous locality, sometimes slightly reddish. The conglomerate is much more prominent here, at the very edge looking like Laurentian, a fine-grained confused gneissoid rock with coarser patches in it, representing granite boulders, coming first, followed by less metamorphosed rock looking like Huronian conglomerate, with pebbles and boulders of granite, etc. Next comes a grayish, very fine-grained rock, like some graywackés, more conglomerate or breccia, and finally the tuff.

[26] Quar. Jour. Geol. Soc., Vol. LIII (1897), pp. 56-59.

Very similar relations are found at the acid edge half a mile south of Windy lake in lot 12, the eruptive, which is flesh-colored on weathered surfaces, seeming to blend into the Laurentian-looking conglomerate. The railway section, on the other hand, shows a grayer acid edge and little conglomerate.

In general one may say at this end of the basin the acid edge is more granitic in appearance when the conglomerate is wide and contains many granite boulders; and is dark green gray and very fine-grained where the conglomerate is thin or practically wanting. Is the darker color due to absorption of part of the black tuff in the latter case, by Dr. Daly's overhand stoping?



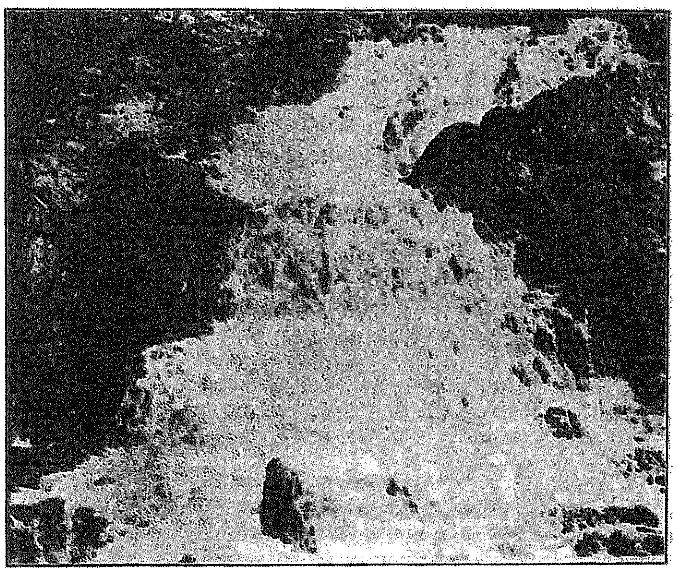
Acid Eruptive, Windy Lake.

The region of the acid edge just described is exceedingly hilly and rugged, more so than at most points on the acid edge of the southern range described in earlier chapters.

Levack Ore Deposits

To the northeast of Windy lake the basic edge may be traced, with some interruptions from gravel plains, to Onaping river; but no gossan or ore was observed between the Gillespie mine in Trill and the Onaping river in Levack township. The old mining road from Onaping to the Levack ore deposits is now in very bad condition from the heavy teaming of the lumbermen operating in the region, and also from flooding, due to their dams on the lakes intended to sweep down the logs in the somewhat shallow river and its tributary creeks. A diamond drill plant was taken along this road to the Strathcona mine during the summer of 1903 for the Lake Superior Power Company, but the difficulties met in transporting the heavy machinery were very great. The road leads along the river from the station for about 2¼ miles, largely over gravel plains, then crosses a bridge and follows the valley of a tributary toward the northeast, keeping along the foot of a range of Laurentian hills just at the margin of the norite. The actual margin is often occupied by small, narrow lakes, as though the norite had decayed more rapidly than the granite; and at several points where the norite still rises above the general level it is now weathering extraordinarily fast. The best instance is near the dam at the mouth of the creek draining Moose lake into the Onaping, where the spheroidal weathering is of a very characteristic kind. The rock, which is gray and coarse-grained, is irregularly fissured into blocks from 2 or 3 to 20 feet across. The weathering takes place along the fissures, leaving mound-shaped surfaces with channels between; and may go so far as to leave rounded blocks resembling drift boulders resting on the decayed surface, with material like fine gravel beneath the block, representing the products of decay. In many cases the actual margin of the norite is not to be seen, but Laurentian rock rises to the northwest out of a lake or swamp, and norite to the southeast.

About four miles from Onaping along the road just mentioned thick beds of gossan lying against the Laurentian attract attention at the Tough and Stobie property and test pits show that some ore underlies it, though no norite is to be seen. The Laurentian is of the kind usual in the region, granite running into gneiss and greatly mixed with fine-grained greenstone; and the ore, which consists of pyrrhotite, with a little chalcopyrite, sinks beneath the surface of the muskeg through which the creek winds.



Waterfall over gneiss west of Onaping.

The underlying Laurentian dips 33° to the southeast, and a little projection of rock near the top of the slope seems to have protected the ore beneath, which is now however largely turned to gossan. A hill of norite rises a quarter of a mile away beyond the muskeg, but none of the rock is to be seen where the stripping has been done.

Less than half a mile farther along the road there is another outcrop of gossan and ore like the first one, but with a lower hill of Laurentian on the northwest and a small lake on the other side. A little beyond this lake there is a gap in the Laurentian hills, suggesting an offset, and it is said that an ore body has been found some distance out in the granite, but we found no trail to it, and left it unvisited. Beyond

this apparent offset there is another marginal lake, and then the route passes through low hills to what was once called the Levack mine, in lots 1 and 2 in the fourth concession at the end of the wagon road, about nine miles from Onaping.

Here two properties, the Strathcona and the Stobie No. 3, or Big Levack mine, have been opened up by stripping and test pits, and have been surveyed magnetically as shown by the systematically arranged survey pegs.

Strathcona Mine

Mr. Ernst A. Sjostedt, who examined the Strathcona property some time ago, reports on it as follows:

"The mineral zone runs diagonally N. E. and S. W. across the north half of lot 3 and south half of lot 4 in the fourth concession of Levack township, and is bounded to the northwest by a range of syenitic granite, with which it forms a direct contact, and to the southeast by a wide range of norite, which usually forms one side of the mineralized zone throughout the Sudbury district. The largest body of ore is shown at the northeast end of lot 3, although the line of magnetic attraction is practically continuous across both lots, and ore is shown at various points on lot 4 as well. Near the northeast end of lot 3 the principal prospecting work has been done, a space of 3 or 4 acres having been cleared of timber and underbrush, and in places the formation stripped, exposing the capping and gossan, which generally reaches a depth of 2 to 8 feet. Part of the ore body is here shown up by a number of cuts and pits, also by two shafts, of which No. 1 shaft is 45 feet deep, passing 8 feet through barren cap rock, then through 25 feet of mixed ore, then through 12 feet of solid pyrrhotite, and a 10-foot hole having been drilled in the bottom of the shaft, showing clean ore the entire distance. No. 2 shaft (250 feet north of shaft No. 1) is 30 feet deep, 6 feet being in cap rock and 24 in solid pyrrhotite.

"Pit A (320 feet north of shaft No. 1), and pit D (40 feet north of pit A) show ore within 2 feet of the surface, and trench C, along a low hill-side about midway between pit A and shaft No. 2, shows a face of ore 50 feet long, in the centre of which a pit was sunk through 12 feet of solid ore.

"From the data furnished by the above mentioned pits and shafts, covering an area of about 600 feet in length and width, the amount of ore in sight on lot 3 is some 60,000 tons, but this includes an area of less than a tenth of the ground covered by equally promising surface indications, consequently there is every reason to expect a much larger body. The ore exists mainly in solid masses within a zone of 200 to 600 feet wide, and some 1,400 feet long.

Following are a number of analyses of samples taken from the above mentioned workings, which will show the character of the ore."

Sample from	Sampler.	Insol.	Fe.	Cu.	Ni.
Shaft No. 1, 8 feet from bottom	D. C. Schuler			.67	2.78
" piece from dump	E. A. Sjostedt			1.85	3.55
" 2, from dump	D. C. Schuler			.70	3.85
" 25 feet depth	"	5.03		2.11	3.54
" piece from dump	E. A. Sjostedt			.14	4.65
Pit A, surface	D. C. Schuler			.67	2.24
" B, surface	"			5.47	2.02
" B, bottom	"	6.10		1.54	3.37
" C, surface	"			.38	2.40
" C, trench	"	3.40		1.24	3.27
" C, 18 ft. pit	"			.28	2.72
" D, low ground	"	4.00	50.4	.80	3.21
Diamond drill hole, near A, 26 ft.	A. B. Wilmott			.65	3.80
" " 40 ft.	"			.58	2.60
Shafts, all over dumps	R. H. Aiken	5.01	54.8	2.23	3.15
Near norite wall	"			1.49	1.68
"	"			2.43	1.70
Average		4.71	52.3	1.81	2.97
Samples taken by Messrs. Cohen & Bradley, experts for J. R. DeLemar, N.Y.				1.99	2.67
Total average				1.70	2.82

The Big Levack mine just to the east of the Strathcona presents a very irregular margin of gossan and ore spread over Laurentian hill-slopes and sinking to the southeast under muskeg with a dip of about 20 degrees in some places, but steeper in others. Some norite is present mixed with the ore; most of it, however, and probably also of the ore, has been weathered away, but may perhaps be found beneath the swamp.

The second set of mines seems much more extensive than those nearer Onaping. Beyond the Big Levack mine the nickel-bearing eruptive bends off to the east in swampy ground with small lakes, and only one small patch of gossan was observed on its border.

Moose Lake Region

The acid edge of the nickel-bearing eruptive in Levack and the northeastern part of Dowling is best studied from Moose lake, which spreads out irregularly over a length of three miles along this margin. Moose lake may be reached by a road running northeast from Larchwood to Joe Seemo's farm on the banks of the Onaping river near its junction with the Vermilion; and then by a trail leading through the woods to a bay on the line between Levack and Dowling townships. From the river to a pond with no outlet near the bay only drift is to be seen on the portage, but the acid phase of the eruptive here shows itself, and practically the whole of Moose lake is enclosed in it. The outlet of the lake into the stream mentioned before as joining Onaping river two miles north of the station is over the eruptive, and the same rock is found at various points on the lake and on the next small lake to the northeast, generally called Trout lake, and another to the east of it.

The acid edge runs northeast and southwest as a range of hills often with sharp minor ridges, sloping to the southeast and precipitous to the northwest, resulting perhaps from faulting during the sinking of the basin, or possibly representing a main direction of joints. All the survey lines cross these ridges diagonally. The contact of the nickel-bearing eruptive, with the tuffs to the southeast is often drift-covered, and on this edge as well as on the basic edge there is frequently a valley or narrow lake in this position. The sedimentary rocks to the southeast also form sharp ridges parallel to the eruptive ridges, and occasionally a narrow hill consists of the acid edge of the eruptive on one side and on the other of tuff.

The best exposure of the contact between the acid edge and the sediments found in the region occurs on the shore of a pond a little east of the end of the portage from the south to Moose lake. This body of water, unlike most others, cuts across the strike, and near its outlet into Moose lake the edge of the nickel-bearing eruptive shows a reddish-gray medium-grained rock, followed to the southeast by coarse flesh-red granite or gneiss, possibly a pegmatite dike. Then comes rock much like the first mentioned, succeeded by conglomerate with a fine-grained gray crystalline base and granitic-looking pebbles, lasting for about 120 feet, doubtless the basal beds of the sedimentary series. Beyond this is coarse white quartzite for about 70 feet, and then conglomerate again for about 200 feet, after which there is a curious breccia of paler and darker chert with some pebbles and boulders of granite for 1,000 feet, evidently the same as had been found along the railway southeast of Onaping beneath the vitrophyre tuff.

Morgan Township

The basic edge of the eruptive crosses a small lake just east of the Levack mine and enters Morgan Township on the fourth concession line, then turns a little north of east to Island river, which follows the edge for more than a mile, and turns northeast once more to the fifth concession, finally passing into Bowell township from the northeast corner of Morgan township. The boundary may be reached partly from Trout lake and partly from a lumber road leading over sand and gravel plains from Chelmsford to a camp near the junction of Island and Sand Cherry rivers. Travel in the region is, however, very troublesome from fallen timber and the unusually rugged and precipitous hills along the contact. The best exposures seen are near the lumber camp, where a steep hill-side rises above Island river, having the nickel-bearing eruptive on its southern face pushing projections into the Laurentian rocks forming the summit. The former rock is not very gray, sometimes even rather reddish-looking, and of variable texture, coarse-grained and fine-grained parts running into one another, the finer grained material sometimes cementing blocks of Laurentian rock into a breccia. The Laurentian, which strikes east and west with a vertical dip, has the usual characters and consists of coarse gneiss with bands of gray-green finer grained material, the whole sheared in places into what looks like felsite. Near the edge it is greatly broken as if by the action of the eruptive mass to the south. No ore or gossan was found from the west edge of the township to lot 1 in the sixth concession, almost at the northeast corner, and prospectors have taken up no locations between the two points. Near a small lake where the four townships, Foy, Morgan, Lumsden and Bowell, meet there are two patches of gossan, on which very little work has been done.

The southern or acid edge of the eruptive in this township has the usual characters, and is in contact at various points with the basal conglomerate so often found below the tuff. The eruptive band is at its narrowest about the middle of Morgan township, having at one place a width of scarcely a mile, and there seems less variation in character between the basic edge and the central and southern parts of the band than it is customary to find in other parts of the nickel range. Perhaps this fact should be brought into connection with the absence of ore referred to above. The thickness of the molten eruptive may have been insufficient to provide any large quantity of sulphides by gravitational segregation.

In Bowell Township

In Bowell township the northern nickel range has long been known through the work of prospectors, and a row of locations has been taken up beginning at the southwest corner and running quite across the township, passing in the third concession into the next township, Wisner. About at the centre of the row of locations a long offset branches toward the west, extending out of Bowell into Foy, and ending almost exactly in the middle of the latter township; and the whole of this offset is included in mining locations also, so that there has been more interest shown in ore deposits of this township than in any other on the northern range.

The locations are best reached by colonization and lumber roads from Azilda (Rayside) to Trout lake (a larger body of water than the one of the same name in Morgan township). Crossing Trout lake by canoe a trail leads inland from its northern bay and branches toward the southwest, west and northeast. A part of this trail which was cut out for the use of pack-horses during the development of some of the properties is still in good condition, but towards the ends in each direction the path is rough and hard to follow, especially where the timber has been cut and fire has run.

Beginning at the southwest corner of the township the basic edge of the nickel-bearing eruptive is found a little north of the corner post of location W D 251, and in a general way the trail follows the edge, except where hills or swamps turn it aside, or where morainic ridges hide the contact. Gossan shows against the steep slope of the Laurentian toward the northeast corner of the location, and there is a swampy pond below, with hills of norite to the southeast. Near the west end of W D 241 an outcrop of gossan and a test pit along the trail indicate the boundary, and more gossan is seen toward the east side of the location, then drift hides the contact until W D 231 is reached where three similar small outcrops of gossan and ore occur against the Laurentian.

In W D 238 a small offset projects northward from the edge, running into a narrow valley in location W D 37, where there are strippings showing gossan. The valley is enclosed by steep and bare Laurentian hills. A small lake in location W D 242 and 239 appears to represent the boundary, and Roland lake a little to the northeast occupies the same position, having Laurentian on the north and norite on the south.

In a general way there is a valley running along the southeast edge of the Laurentian, which rises as a very rugged range of hills to a height of from 200 to 270 feet, with patches of ore along its foot. Southwest of the valley, which is often occupied by a narrow lake or muskeg, gray hills of norite rise to about the same height as the Laurentian.

In W D 35 the offset running to the Ross mine in Foy leaves the edge of the main range. In W D 36 near its northwest corner and probably extending into the previous location there is a promising outcrop of gossan and ore at the edge of the granite, but east of this to Trout lake no ore was observed.

Offset to Ross Mine

The longest offset on the whole circumference of the nickel-bearing eruptive extends for six miles nearly westwards from W D 35 to W R 5, reaching what is called the Ross mine, in the exact centre of the township of Foy. The path is at first good, but before the west boundary of Bowell township is reached fire and fallen timber and the debris left by the lumbermen injure it greatly, and beyond this care is needed in following it even in green timber, since it has scarcely been used for a number of years and the blazes are growing dim.

Just after turning off from the main range there is a considerable showing of ore on a hillside, and the adjoining rock consists largely of white plagioclase crystals so crowded together as to appear like anorthosite. Small seams of magnetite occur in this rock as well as sulphides. To the northwest in W D 150 a wide expanse of gossan is exposed by stripping and numerous test pits extending nearly to Nickel lake, where there is a log house occupied during the development work. Turning west the band narrows greatly and fine-grained norite penetrates between blocks of coarse-grained norite, of a gray gneissoid rock, of greenstone, and of a white rock with porphyritic feldspars, the whole rusty or gossan covered. The adjoining Laurentian is coarse red granite, an unusual variety in the region. On the shore of the next lake to the west a similar mixture of rocks is seen, and some gossan rises above the water.

From this point to the neighborhood of Ross mine little ore or gossan was seen, although the band of norite, narrowing and widening, seems to be continuous or nearly so the whole way; but somewhat similar outcrops of gray rock rising through drift-covered ground leave some doubt as to the relationships. Evidently the early prospectors considered the whole length to belong to the nickel range, or they would not have taken up locations along it. The greatest width of the offset, so far as observed, is in W D 234, where the rock seems to extend for about 500 feet, but usually it is much narrower, in one case apparently only 20 feet.

Our exploration of the locations just east of the Ross mine was greatly hindered by the work of a colony of beavers, which had recently built a dam backing up the water for half a mile or more in various directions into the flat wooded land along the creek. W R 5, the original Ross mine location, includes two outcrops of ore and gossan standing as usual against a hill-side of Laurentian, and dipping under the muskeg borders of a small lake; but the amount of ore to be seen is not large. It is reported to assay 2.75 per cent. of nickel.[27] Most of the Laurentian encountered along this offset is coarse-grained and flesh-colored, but some masses of gray-green rock, in general appearance not unlike the norite, are enclosed in it.

[27] G. S. C., 1890, Part R, pp. 43-4.

South Edge of Eruptive

The acid edge of the eruptive crosses from Morgan township into Lumsden in the fifth concession, and is fairly well exposed near the north shore of a small unnamed lake just north of the concession line in lot 9, as a gray rock weathering reddish. The neighboring sediments to the south look like quartzite with pebbles and merge into tuff, and these rocks continue to the northeast as a range of high hills, sinking, however, where Nelson river makes its way through. Along this valley gravel plains and morainic ridges conceal the rock. On the line between lots 6 and 7 to the south of a small lake crossing the concession line between Lumsden and Bowell the acid edge forms a hard grey-green rock, or some other eruptive appears to intervene between it and the sediments; but on the town line in lot 5 and also in lot 4 we find the usual relationships, the granitic-looking acid edge seeming to blend with a greatly metamorphosed coarse conglomerate. In places, if it were not for the coarser grain and different texture of the included pebbles and boulders, the matrix of the conglomerate could not be distinguished from the eruptive, and great care was necessary not to overrun the contact between the two rocks.

In location W D 252 at the southwest bay of Trout lake there is once more a fine-grained dark-green rock between the eruptive and the tuff, in places very much like a basic eruptive rock itself, but in others charged with a few pebbles of granite, and having the characters of "slate conglomerate." In this marginal rock there are veins containing quartz with zincblende, galena and a little copper pyrites, and at one point a shaft has been sunk to open up the ore. The quartz formed quite large crystals before the sulphides were deposited, and on breaking the ore the six-sided cross sections of the prisms are well marked. No very large amount of ore was to be seen and the deposit does not seem to be of great importance so far as the present development work goes.

There is a small opening near a blacksmith shop a little east of the east bay of Trout lake, also on similar dark-green eruptive-looking rock, but even less ore is to be seen here than in W D 252. These small ore-bearing veins are found in the adjoining sediments or in greenstones connected with them and not in the nickel-bearing eruptive itself, but the eruption of the latter may have some connection with the formation of the deposits.

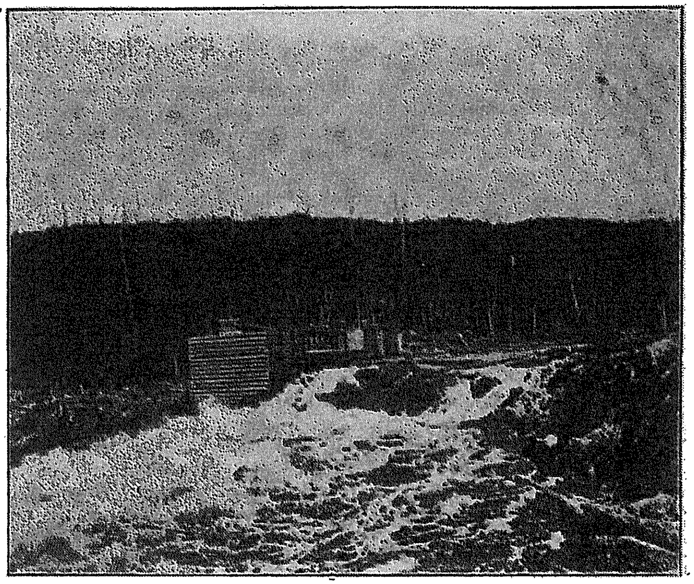
A very good section of the contact of the acid edge with the sediments is exposed on a small peninsula projecting from the south shore of Trout lake where the lumber road reaches the water. Two or three islets to the north show the nickel-bearing eruptive in its usual phase along the southeast edge, while the peninsula ends in a conglomerate having apparently two kinds of matrix, fine-grained green material containing epidote and quartz, and rather coarse reddish or grayish quartzite, both including many small and large pebbles of granular quartzite and of granite. Irregular projections of the acid edge granite penetrate the conglomerate for 100 yards or more. Next to the southeast is a narrow range of precipitous hills of hard splintery cherty-looking brecciated rock, then comes a breccia of a less cherty kind, with, however, a few granite boulders, probably the base of the tuff. The section described is about 1,200 feet in length. Still farther to the southwest is the usual tuff, less flinty and unaffected by the neighborhood of the eruptive.

Wisner Township

The basic edge of the eruptive runs almost due east from the northern side of lot 12 to lot 4 in the third concession of the township of Wisner, and then bends to the southeast toward Vermilion river and Norman township. The portion up to lot 4 has been surveyed as locations, but prospectors seem to have found no ore along the rest of it. This part of the nickel range is best reached by lumber road to Frenchman's lake and then by a canoe route to Joe's or Marion lake which crosses the nickel-bearing eruptive diagonally. The two Frenchman's lakes are in the sedimentary rocks, the south end being enclosed in the soft black slaty variety of the tuff, but morainic materials hide the bed rock as one crosses to Joe's lake.

The basic margin of the nickel-bearing eruptive has the usual characters north of Joe's lake, the boundary to the north being Laurentian and a swampy valley running at its foot with low hills of norite to the south. Not much gossan or ore is to be seen in the locations across this township, though considerable showings occur on W D 16 and W R 14 near the head of the lake.

The acid edge is very well shown on Joe's lake, which it crosses near the south shore, and the bare surface of the rock near a small lake to the southwest gives an uninterrupted section across the boundary. The edge of the eruptive is granitic-looking and seems to blend into a conglomerate with a fine-grained crystalline ground-mass which might be taken for granite containing small and large boulders of granite, often with vague edges. This conglomerate is penetrated by indistinctly bounded projections



Falls on Vermilion river at power plant.

from the eruptive, and seems to have been greatly re-crystallized in consequence of its presence. About 360 feet to the south the conglomerate has a ground-mass suggesting arkose or quartzite with a few pebbles of granite, and this dips beneath the small lake.

A parallel section on the shore of Joe's lake shows a similar conglomerate followed by breccia-like tuff at a distance of 400 feet south of the acid edge, but with a few feet of a fine-grained green-gray rock without pebbles between.

The eastern side of Wisner township is most easily reached from the Vermilion river near Dawson, and a canoe route leads across from the second Frenchman's lake to this point. The rock showing between the two lakes is mainly tuff, but half a mile west of Dawson a large dike of diabase rises beside the trail, perhaps the continuation

of a dike found by Mr. Culbert on Onwatin lake about two miles southeast. Near Dawson gravel plains and muskegs cover the rock along Vermilion river, but the norite forming the northern edge of the eruptive is found rising as hills a mile west of the upper end of Bronson lake, near a small lake at the corner of lots 3 and 4 in the fourth concession of Wisner township. At the boundary the norite leans against a Laurentian hill, but no ore or gossan was to be seen; and similar relationships are found to the northeast towards Vermilion river, but gravel terraces hide the rock nearer the river.

Near the head of Bass lake, the next expansion of Vermilion river south of Bronson lake, the acid edge shows itself with the usual metamorphosed conglomerate to the south, here having a width of 800 feet before the tuff is encountered.

Norman and Capreol

The boundaries of the nickel-bearing eruptive in these townships were mainly fixed by my assistant, Mr. Culbert, and the following account is given in his own words:

"The northern nickel range makes a sharp turn in the township of Norman, its outcrop there assuming a southward direction. In the northern concessions of Capreol township another change in direction is found, the strike being northwest and southeast to Massey creek as far as it was followed. The line of outcrop of the basic edge, owing to its comparatively rapid weathering, determines the position of a narrow valley from the Whistle property to Massey creek. This valley widens in many places, often containing lakes which conform to the strike of the eruptive. Examples are lakes Selwyn, Waddell, Ella and Clear.

"The basic phase along this part of its outcrop resembles the norite of the northern range, being a light mottled gray and is comparatively narrow. Darker phases occur in spots and resemble the rock at the Blezard mine, but the few small patches found near Moose lake are easily overlooked. Many peculiar contact varieties are found, such as the poikilitic kind near the Blue lake ore deposit, which to the eye appears quite coarsely granular, but is found under the microscope to consist of large aggregates of feldspar optically continuous with inclusions of bi-silicates. The transition to the micrographic phase takes place within a short distance, and the total width of outcrop of the eruptive is not great in the townships of Norman and Capreol, being less than two miles as a rule. The micropegmatite is of the usual flesh-colored rather coarse-grained variety found in the northern range and corresponds in mineralogical composition.

"On the east side the eruptive is in contact with Laurentian granite and gneiss. The granite is pinkish-red, with abundant quartz and few of the dark minerals in places where the acid magma has not incorporated inclusions and masses of earlier rocks. In many parts hornblende porphyrites and green schists occur, often running out in basic bands into the acid material and forming gneiss, or again occurring as immense blocks or large masses of considerable area which the action of the erupted material failed to shatter. A large mass of this kind occurs half a mile south of Moose lake near the small marsh on the road to Blue lake.

"The acid phase to the west comes in contact with the usual conglomerate, highly indurated with well-rounded pebbles and boulders of granite, greenstone, schist and quartzite. On passing westward this rock becomes softer and tufaceous, with no large boulders showing.

"A large diabase dike of great width, in some places a few hundred paces, was found in the valley of Massey creek on the boundary of Capreol and Maclennan townships in the third concession. It also outcrops on lot 5 in the fourth concession of Capreol on the shore of the small lake on the line between lots 5 and 6. This is probably the same dike that crosses lake Onwatin and which appears on lot 8 in the second concession of Wisner near the southwest post, the outcrops all being in a nearly straight line. The rock has a distinct green color due to a considerable content of olivine.

"Wherever the contact between the norite and the Laurentian appears on the surface indications of ore are found, either in thin patches of gossan or outcrops of ore bodies. Sulphide particles can be found on the contact wherever the rock is tested, and the red gossan product is present along its entire length in the townships near lake Wahnapitae. The more important outcrops of ore occur near Blue lake and south of it near the small Moose lake. On the shore of Blue lake the diamond drill has proved the existence of a body of ore of some size. The outcrop near Moose lake shows a band of ore following the contact and varying in width from two to six feet of fairly good sulphides. In the test pits this ore appears rather lean, being mixed with some of the mother magma, but the proposition looks promising, having in view the improvement of transportation facilities. Further north, strong local attractions are found on the north end of Ella lake near the west side of WR 2, but no test pits have been opened to prove the existence of an ore body. The east side of Clear lake near the shore shows a few test pits with ore and a considerable extent of gossan."

The Whistle Property

A canoe route leads from Blue lake to the Whistle property, passing through the northeast end of Capreol township by Clear lake and Trout lake to Waddell lake and Selwyn lake in Norman township. The Whistle property is on lots 6 in the fourth and fifth concessions; and has been opened up by stripping and test pitting, showing an extraordinary extent of gossan surface, about half a mile in length from southeast to northwest, and 250 yeards wide at the widest place. So far as extent of gossan is concerned, this seems to be the largest exposure of ore in the district. The hill on which the stripping has been done rises 230 feet above the valley of McConnell creek to the southwest.

The norite in connection with the ore on this property is very fine-grained and mixed with fragments of other rock, almost forming a conglomerate with a matrix of norite. It seems to be broken or crossed by some dikes of granite and patches of greenstone; and the adjoining rocks are granite, often pegmatitic. and greenstone; these two rocks enclosing the gossan hill on three sides, southeast, northeast and northwest. Here we find a large ore deposit caught in a sharp angle where the gabbro pushes into the neighboring rock, as happens so often elsewhere.

The ores of the Blue lake region are like those of other parts of the district in most respects, though the pyrrhotite is apparently more magnetic than elsewhere. Masses of the ore near Blue lake are fairly strong natural magnets, readily attracting the compass needle and holding iron filings, but they are, of course, far surpassed in this respect by magnetite. Some octahedra of pyrite are found in the pyrrhotite.

The string of small lakes mentioned above follows in a general way the basic edge of the nickel-bearing eruptive, as if that were most easily acted on by weather, and their western shores often consist of bluffs of reddish, syenitic-looking rock, the more acid and also more resistant phase of the eruptive.

Leaving the Whistle property going westward the contact is found forty paces north of the northwest corner post of lot 7 in the fourth concession of Norman. The ground succeeding is low and drift-covered for nearly a mile, with no outcrops of the basic edge till near the line between lots 9 and 10, where the contact shows with a test pit and gossan 210 paces south of the northwest corner post of lot 9 in the fourth concession. To the west this outcrop is followed to low ground again with gravel deposits, but the norite outcrops south of the northwest corner post of lot 10 in the fourth concession at 410 paces. On following the uncut line half a mile to the west between lots 11 and 12 north from the post at the south boundary of the fourth concession a small test pit in a body of ore was encountered at 1,940 paces. The Laurentian here contains good-sized bands of green hornblende schist like that which accompanies the Hutton magnetic ore deposits. The Laurentian was also found 1,010 paces north of where the boundary of Wisner and Norman crosses the Vermilion river in concession four.

The acid edge of the eruptive was traced southward through Norman and Capreol to the sand and gravel plains which hide the bed rock in Garson township; and the relationship of the eruptive to the overlying sediments was the same as has been described in other townships. A good exposure of the contact is seen on the road north from Dawson toward Moose mountain, where, as one advances, the tuff takes on the character of conglomerate, and then of boulder conglomerate with a felsitic

ground-mass before the edge of the eruptive is reached. In general, the ridges of tuff and conglomerate, as well as of the eruptive, run north and south at this eastern end of the range, evidently conforming here as everywhere else to the direction of the line of contact, showing a close relation between the dips and strikes of the overlying sediments and the line of outcrop of the basin-shaped eruptive sheet.

No ore deposits are known on the acid edge at this end of the nickel belt, but a so-called nickel mine was found not long ago at the east end of Onwatin lake in black slate. Two openings made here show only iron pyrites.

South of the Blue lake region the wide gravel plains referred to in the account of the northeast end of the southern nickel range intervene between the two ranges for about two miles, leaving the exact boundary at this point somewhat doubtful. On the map the boundaries have been connected in what seemed the most probable way.

The detailed account given in the foregoing pages, showing the continuity of the basic and acid edges of the nickel eruptive round the whole basin, and connecting up what were formerly spoken of as the main, or southern, range, and the northern range, make it clear that we have to do with a single sheet of eruptive rock, everywhere dipping inwards. This was originally buried under thick sedimentary rocks, but is now exposed all round the edge by their weathering and destruction, laying bare the eruptive sheet which had slowly cooled beneath them.

OTHER NORITE OR GABBRO MASSES

In addition to the great nickel-bearing laccolithic sheet which has just been described, there are numerous other outcrops of norite or gabbro, or of greenstone probably resulting from the alteration of gabbro, in the district, many of them having been mapped by Dr. Bell and colored in the same way as the nickel-eruptive. Most of these basic eruptive masses are elongated parallel to the strike of the adjoining rocks, which is in general parallel to the edge of the nickel-bearing eruptive, and in many cases small pockets of pyrrhotite and chalcopyrite occur in them, but always lower in nickel than the deposits of the main nickel range, and up to the present of no practical importance. The bands or bosses of gabbro in question are probably all later in age than the enclosing Huronian rocks; but there are also greenstones closely connected with much altered parts of the Huronian sediments, which seem to be of the same age.

What relation the isolated gabbro areas have to the nickel-bearing eurptive is uncertain, though they appear generally to be older than the nickel rock. Possibly they represent earlier eruptions from the same magma before differentiation had gone far, or possibly they are segregations from the magma of a medium acidity practically free from the sulphides. In many respects they differ greatly from the nickel eruptive, such as the lack of ore and of a differentiation into acid and basic phases on any large and regular scale. Until more time has been devoted to them their character in many points must remain doubtful.

Gabbros of the kind mentioned occur from Falconbridge township southwest to Nairn township, and locations for nickel have been taken up on many of them, but without important results up to the present. They are confined to the Huronian region south and southwest of the main nickel range, none being known from the Laurentian areas to the north and northwest or to the southeast.

To give an idea of these rocks the best known area, lying to the east and south of Sudbury will be described.

The Sudbury Gabbro Area

Just to the east of the town of Sudbury, beyond the creek, an irregular mass of hills cut by some ravines and embayments, rises to a height of over 200 feet, having an area of about four square miles, and sending a tongue five miles southeast along the northwest shore of Kelly lake. The rock is gabbro, usually much weathered, and wherever the adjoining Huronian sediments are found in contact with it along the edges they are tilted up to the vertical or even slightly overturned, so that the eruptive is clearly later than the Huronian. On the west and north of the main area and along the northwest side of the Kelly lake extension the adjoining rock is well stratified graywacké with slaty layers; on the south so far as known the sediments are graywacké conglomerate later in age than the former rocks. The east side of the eruptive mass has not been studied in any detail.

The laccolithic relationship of this mass is pretty certain, but its form is very irregular, and there may really have been a succession of laccolithic flows instead of a single sustained irruption of magma into the sediments. While the whole mass was probably domed over with sedimentary rocks in the beginning, there are now very few remnants of them left except some stretches which rise well up on the flanks of the hills but do not reach the top.

Far the greater part of the rock is a greenish gray gabbro in which the pyroxenes have mostly weathered to hornblende, though one specimen proves to be norite, of a quite different kind from the norite of the nickel eruptive. It has not the dark color, the blue blebs of quartz, nor the mica which characterize the nickel range norite; it is never "pockmarked" with rusty holes from which ore has weathered, nor has it gossan or deposits of ore around the edge; though a few small outcrops of ore occur away from the edge. It shows no tendency to have one side acid and the other basic, though there are large acid segregations in many places on top of the range of hills near the centre. If the band is laccolithic, as it appears to be, and similar to the main range, the acid portion should be at the top, with gradations to a basic portion with ore at the bottom. The latter part may be hidden below the surface, and the acid segregations on the tops of the hills may correspond to the acid edge of the nickel eruptive, though very different from it in character.

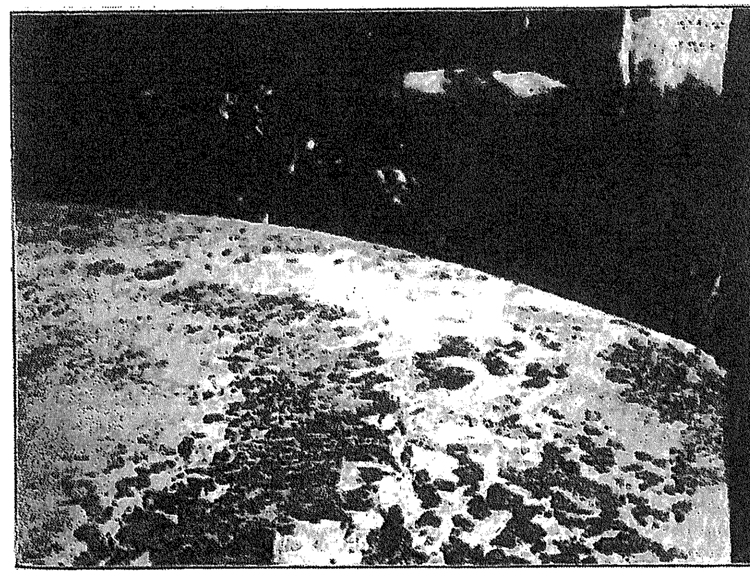
The acid segregations are very curious, sometimes having the look of gigantic concretions with a ring of green hornblende round the edge, followed by white plagioclase, which may become pegmatitic, and finally enclosing more or less quartz, the whole mass being from a few feet to 50 yards in diameter. The hornblende crystals are often several inches long, blade-like, and in cross section may have in the interior a negative crystal form filled with plagioclase or some other white mineral. Good examples of the segregations are found on various hill tops east of Sudbury and for half a mile or more along the top of the ridge near Kelly lake. In the latter region they follow a general direction along the centre of the range of hills, though the masses of white minerals are not connected. The largest known south of Copper Cliff is used as a source of quartz for converter linings, and already a great many tons of nearly pure quartz have been quarried from its centre, leaving the more felspathic portions as the walls of the pit, with an outer rim of hornblende, the line of mixture forming the rock sometimes called malchite.

It is possible that these areas of plagioclase and quartz represent masses of quartzite enclosed in the gabbro and completely re-crystallized, though there is no direct evidence of this. They seem to be analogous to the malchite masses with hornblende crystals, white plagioclase and some quartz along the edge of the main nickel range at Murray and Elsie mines; and the same cause must have produced them in each case. As the examples from Murray mine clearly have nothing to do with the acid edge of the eruptive, which is four miles away, we must conclude that the much larger row of white segregations in the Sudbury laccolith are probably not the equivalent of the acid phase of the nickel eruptive.

Beginning at the north end of the Sudbury laccolithic band where the rugged hill sinks northwards into a swamp followed by the creek in concession V of McKim, we find a rim of quartzite or graywacké with seams of slaty material running all along the flank of the hill and having a strike of 60° with nearly vertical dip. Passing to

the west and southwest the hill slope on the line between concessions IV and V shows quartzite or graywacké tilted round so as to have a strike of 100° with a dip of 80° to the north; but there has been great disturbance here, blocks of the sedimentary rock being carried off by the gabbro. Farther to the southwest the sediments lean against the gabbro in a more normal way, with a strike of 30° and steep dip beneath the eruptive; and just east of Sudbury the same relation is found, except that the dip is 70° or 80° to the east, i.e. under the laccolith, the eruptive growing finer grained against the quartzite.

A little to the south near the corner between lots 4 and 5, cons. III and IV, a wedge of the sedimentary rock runs a little north of east for nearly a quarter of a mile before it feathers out on top of the gabbro. Still to the south a valley runs into the hills in the same direction, perhaps weathered out of the sediments, though drift



Hill east of Sudbury; concretionary structure in gabbro.

covers the solid rock. To the south of the valley the gabbro shows no rim of quartzite, and near the Canadian Pacific railway it seems nearly cut off from the long band running towards Kelly lake, quartzite being exposed considerably to the east, though not seen in contact with the eruptive.

The relations on the east side of the gabbro area have not been studied; on the south we find graywacké conglomerate later in age than the quartzite for the most part, but cut by the gabbro. Some strips of quartzite occur, however, north of Ramsay lake and the railway against the gabbro or upon its southward slope, one such strip only ten feet wide running for some distance in a direction of N. 25°. The contact with the graywacké conglomerate and patches of quartzite along the south side toward Ramsay lake is somewhat confused, blocks of the sedimentary rocks being enclosed in the gabbro for 100 or even 200 feet from the edge; and a band of conglomerate runs for nearly a mile, with very irregular boundaries, between the main mass of gabbro and a narrow southern row of gabbro hills. As this has weathered faster than the eruptive, it has been made use of for the road between Sudbury and Wahnapitae.

The long band of gabbro running towards Kelly lake has relations to the quartzite much like those nearer Sudbury. The strike is about 60° or 70° and the sedimentary rocks rise along the northwestern flank of the hills as a fringe having with local variations the same strike, but being in many cases brecciated at the very edge. On the southeast of the ridge only the shore of Kelly lake has been studied, and here the gabbro runs beneath the water in most places, though quartzite or conglomerate occur at two points and are found against the edge farther northeast.

Ore occurs at two points at least in this band of gabbro, one east of Sudbury, the other half way between Sudbury and Copper Cliff. The Sudbury deposit occurs connected with one of the segregations of white plagioclase and quartz a little north of the water tank, where a small test pit shows rusty rock, copper pyrites and pyrrhotite with some quartz; but the amount of ore seems insignificant.

The other outcrop is on the north half of lot 6, con. II, McKim, near the middle of the gabbro band, where there is a considerable stretch of gossany surface containing a pocket of pyrrhotite with some copper pyrites, opened up by a test pit twenty feet long and five feet wide. Though larger than the other deposit, this too is of no economic importance so far as can be seen from the exposure. Another test pit is said to have been deep enough to require a ladder, but my guide was not able to show me it.

Since many strippings and small prospect pits have been opened on these outside gabbro bands with no valuable results up to the present, we must suppose either that the amount of magma in them was too small to provide a workable body of ore by segregation, or that the ore is at too great a depth to be visible on the surface.

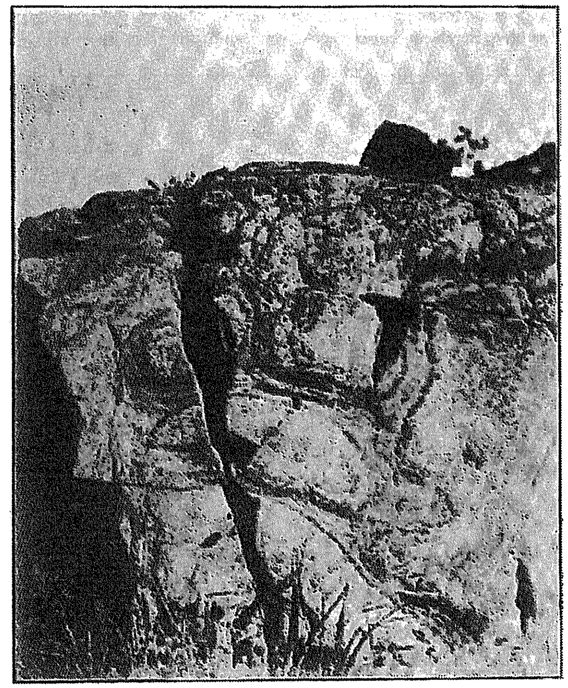
Smaller gabbro areas south of Ramsay lake and in the neighborhood of Nairn Centre have been taken up as nickel locations, and have been proved to contain some pyrrhotite, but the amount is too trifling and the grade of the ore too low to make them of value.

Older Norite and Greenstones

Along much of the southern nickel range and at a few points on the northern range an extraordinary mixture of green or gray rocks occurs, apparently having some relationship to the nickel-bearing eruptive. Though it has been referred to from point to point in the discussion of the basic edge of the main range, it should be briefly taken up as a whole. Much of this rock has been lava flows, as shown by the "pillow" and amygdaloidal structures frequently mentioned in previous parts of this report. The pillow structure is supposed to be due to dragging or rolling of still viscid lava; though it might be explained perhaps, in some cases at least, as formed of bombs. The pillows are of all sizes up to five or six feet in diameter, and show irregular rounded forms, apparently somewhat squeezed together, perhaps merely by their own weight. They are, however, separated by a narrow band of seemingly structureless green material, usually much finer-grained than the rock of the pillows themselves. The middle of the pillow is generally of dark or light gray fine-grained material, sometimes unchanged norite made of plagioclase and hypersthene, at others metamorphosed to a confused hornblendic rock. This merges into a speckled band containing many white spots suggesting amygdaloids, the spots being specially crowded against the edge, as if steam could expand near the outside of a still viscid mass of lava but was unable to do so in the middle, or as if the steam bubbles pushed in all directions toward the outside, but could not escape through a cold outer film.

The fine-grained green band which separates the pillows thickens to fill the spaces at some points, but at others there are white and green strips developed in the wider spaces with hornblende crystals, etc. Is this intermediate material ash?

The great mass of the older norite is, however, not pillow-like nor amygdaloidal, probably because these structures are confined to the surface of lava flows. No distinct lava sheets or flows have been distinguished, the varieties of rock mentioned seeming to be inextricably mixed through the large amount of faulting and brecciation which the region has undergone. In most cases the older norite is largely changed to hornblendic rocks, and almost all the surfaces even of the freshest norite are crossed by numerous bands of darker green, consisting chiefly of hornblende, where fissures permitted water to percolate so as to produce a variety of change going on at considerable depths, often confounded with weathering. These bands widen and become more numerous, until finally the rock has changed to greenstone or hornblende porphyrite.



Pillow structure in older norite, near Elsie.

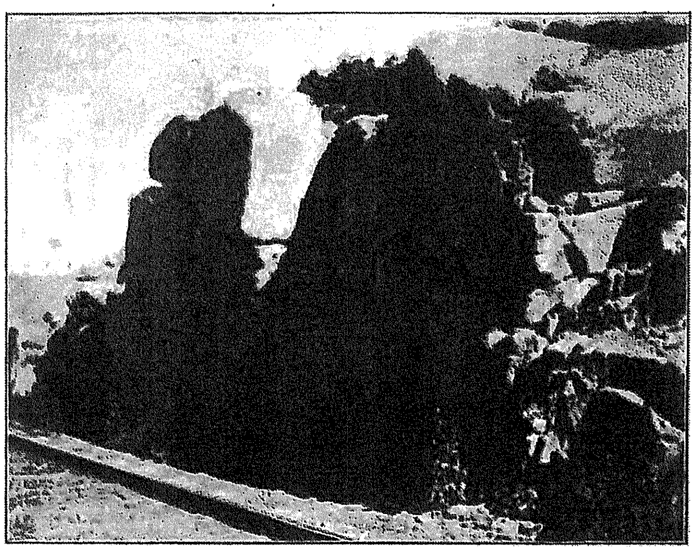
In many examples the general rock is older norite with large rhomboidal crystals of hornblende, often surrounded by a narrow white rim, scattered through it. On weathered surfaces these crystals and the hornblende seams stand out a quarter or half an inch above the rest.

The older norite is closely associated with singular green schists or greenstones filled with white pea or bean-like spots of quartz, which may be a variety of the lavas or a greatly metamorphosed sediment. All grades in size and complexity are found between the tiny, homogeneous "peas" and concretions two inches in diameter with dark hornblendic centres and white borders. Beside these doubtful rocks there are also some undoubted sediments, graywacké of a quartzitic kind, enclosed in the complex of the greenstones and older norite too intimately mixed with them to be separated in mapping.

This group of rocks is of a very resistant nature and commonly stands up along the low basic edge of the southern nickel range, as rugged hills, sometimes in a narrow belt but occasionally a mile in width.

DISTRIBUTION OF OLDER NORITE AND GREENSTONE

The older norite is easily distinguished from the norite of the basic edge of the nickel-bearing eruptive, being much finer-grained and more basic in character, but it is very difficult and often impossible to separate it from the greenstone into which it is transformed by the development of hornblende in place of the pyroxenes. Where any of the unchanged norite remains there is no difficulty in mapping it along with



Weathering of Norite, Manitoulin and North Shore Ry.

the products of its alteration; but where all trace of the norite and of the pillow and amygdaloidal structures have vanished, it becomes doubtful whether the rock should be classed with the older norite or not, since there are numerous bands of greenstone and hornblende porphyrite with considerable quartz in their constitution that probably have no relation to an original norite.

In this account of the distribution only greenstone found connected with norite or with pillow lava will be considered to belong to the series. They have been traced with some care along the nickel range, but have not always been mapped to the south, so that the width of the band is often uncertain; and they have not been looked for at all at a distance from the nickel range, so that other areas may exist in the district not distinguished from the common greenstones and green schists.

Beginning at the west end of the nickel range, there are fine-grained noritic rocks mixed with various greenstones as if the matrix of a crush conglomerate at the Sultana

mine, but it is doubtful if the hill should be classed with the older norite since the typical structures have not been observed; and the same may be said of greenstones occurring at the Chicago and Victoria mines as well as the Vermilion.

We come to undoubted older norite first in the vicinity of the Gertrude mine in the southeast corner of Creighton township, where this rock mixed with greenstone runs from west of the compressor plant to a point near the railway station, a distance of one-third of a mile, with a breadth of several hundred yards. Whether the greenstone which extends widely to the south belongs to it is uncertain, and the greenstones along the Manitoulin and North Shore railway to the east also are doubtful; but just to the east of the Gertrude proeprty, where the margin of the basic edge bends northward there is a half mile of greenstone mixed with older norite to the north of the railway.

At Creighton granitoid gneiss cuts out almost the whole of the greenstone series, and no older norite has been found between this and North Star, where a small strip lies just south of the nickel range. The rock is chiefly granitoid gneiss and granite with little greenstone, between North Star and the great Copper Cliff offset, and none of the older norite has been observed to the west of it.

Just east of No. 2 mine at Copper Cliff a range of greenstone hills begins and extends northward with some irregularities, but scarcely any interruption, to Elsie and Murray mines, a distance of more than two miles, with a breadth of half a mile on the average. Much of this area is typical older norite or shows pillow structure, so that there is no doubt of its position in general; but there are considerable patches of sediments, quartzite or graywacké, enclosed in it, and the younger granite comes between it and the nickel range where the offset joins the main range.

Near Murray mine a large mass of granite cuts off the greenstone and associated rocks, running between the Frood-Stobie offset and the main range, but immediately north of Stobie the older norite and greenstone in a typical form rise as rugged hills and extend to the Little Stobie, Mt. Nickel and Blezard mines with a length of a mile and breadth in places of more than half a mile.

Beyond this toward the northeast the country is largely covered with swamp or drift deposits along the margin of the nickel range, and not much detailed mapping has been done, but greenstones are known to occur at many points along the range, and the pillow structure has been found near Kirkwood mine in Garson township.

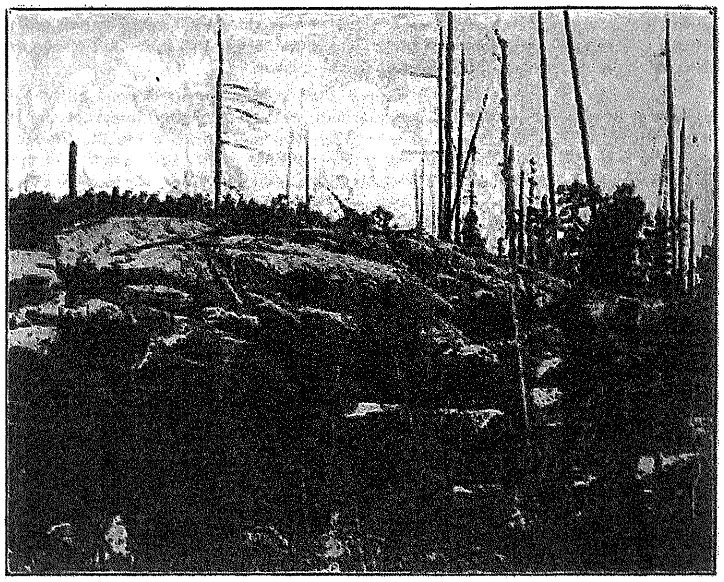
Along the northern nickel range the older norite and pillow lava have been observed only at one point, north of Joe's lake in Wisner township, but no special search has been made for them elsewhere. However, there is on the whole much less likelihood of its occurring there than near the southern range, since the granitoid gneiss of the Laurentian makes the usual country rock with comparatively little greenstone of any description.

There is plenty of greenstone to the east of the nickel range near Blue lake and points to the north, but the older norite has not yet been observed there, perhaps because it has not been particularly looked for. Pillow structure was seen at one point near Blue lake, however.

To sum matters up, the older (or micro-) norite is known to extend, with some interruptions from granite or granitoid gneiss, from Gertrude to Blezard mine, a distance of about 14 miles, with a greatest width of about half a mile. An outcrop has been found near Kirkwood mine, about three miles northeast of the Blezard mine, so that the total length is 17 miles. It is not known to occur anywhere in the district at a distance from the nickel range, but always at or near the margin of the nickel-bearing norite. It is highly probable that the lava flows, etc., of the older norite series represent an earlier outbreak of material from the same general magma as supplied the nickel eruptive, but at a very much earlier date, in fact before the sediments of the interior basin were laid down. If this supposition is correct there were surface outflows of lava of a basic type, followed by a long period of quiescence during which the 10,000 feet of sediments were deposited. A second period of activity resulted in spreading the great laccolithic sheet beneath the sediments and over the older norite, the magma as a whole being this time of medium basicity. Finally, an acid remnant of the magma may have been erupted forming the later granite which cuts both the older and the later norite, though this is uncertain.

Granites Near the Nickel Range

Several elongated areas of granite or syenite or gneissoid varieties of these rocks occur along the southern nickel range as if they had some connection with it, though the gneissoid rocks have generally been thought to be Laurentian. They differ considerably from the grayish medium-grained gneisses of the Laurentian to the east and north of the nickel eruptive, and are perhaps all later in age.



Later granite, Manitoulin and North Shore Ry.

In type these rocks are variable. running from flesh-colored to gray, from fine-grained to coarse, from porphyritic to non-porphyritic, and having all degrees of gneissoid structure. They are always later in age than certain greenstones of which they enclose fragments and than the graywackés, quartzites and slates of the Huronian. The variety referred to as porphyritic granitoid gneiss is generally older than the norite, which grows finer-grained against it; but there are doubtful contacts, and Dr. Barlow may be right in assigning it to nearly the same age as the nickel eruptive.[38] There are also reddish medium to fine-grained granites which are distinctly later than the nickel eruptive, since they frequently send apophysae into it and penetrate it, sometimes as long dikes. How these granites are related to the porphyritic granitoid gneiss is uncertain, but they appear to be a good deal younger, as a whole, perhaps

[38] Geol. Sur. Can., 1904, Part H, pp. 53-4.

later outflows from the same magma. It seems as if granitic eruptions were very long continued in the region, for not only have we the older granitoid rocks against which the norite cooled, but masses and dikes of granite up to the very end of the series of eruptions, for two small dikes have been found cutting the diabases which penetrate all the other rocks of the region. As these acid rocks have erupted at various times all along the scale without showing much difference in composition, we should perhaps look on them as separate in origin from the magma of the nickel eruptive, though from a neighboring source.

DISTRIBUTION OF GRANITES

A large band of granite and granitoid genies with some greenstones intermixed begins about three miles east of Victoria mine and runs east across Vermilion river to the northeast corner of Graham township, where it bends to the northeast and widens from a mile or a mile and a half to two miles or more as it approaches Creighton. It forms the country rock of the norite for two or three miles, but near Gertrude is separated from it by greenstone and older norite. The boundary between greenstone and granite is hard to fix in this region, the two being mixed. At Creighton it once more touches the basic edge and continues in this relationship to Copper Cliff. The hill south of Creighton shows an extraordinary confusion of coarse granitoid gneiss with inclusions of finer gneiss, arkose and porphyrite, the whole greatly faulted and crushed into conglomerate. Some of the gneiss has light and dark bands like the Laurentian.

Between Creighton and North Star different phases of granite and granitoid gneiss with some greenstone are well exposed in the rock cuts of the Manitoulin and North Shore railway, some parts with large flesh-colored porphyritic crystals in a darker ground being very handsome and worthy of mention as ornamental stones.

Near Elsie junction the coarse porphyritic rock is replaced by a small area of rather fine-grained bright red granite which forms two or three hills in the greenstone series, but the fine-grained granite has not been found in contact with the coarser rock so as to compare their age.

To the west of Copper Cliff coarse gneiss rises as steep hills and encloses in part the offset of norite as far as No. 2 mine, the norite being finer-grained at the margin. Small dikes of finer-grained granite penetrate the norite, however, as though later in age, so that two eruptions of granite are represented here.

The band of granite described is about 12 miles long and runs roughly parallel to the nickel range and to the strike of the Huronian. It is not, however, a single eruptive band or sheet, but includes rocks of quite different ages, one cutting the other in some cases, and in almost all parts there are older greenstones included, sometimes to such an extent that sharp mapping of the boundary between the granite and greenstone is impossible, the latter rock increasing more and more until it becomes more important than the granite.

To the southeast of Murray mine a range of pale flesh-colored granite hills rises along the Canadian Pacific railway and runs northeast near the nickel range to a point near Little Stobie mine, greenstone, graywacké and various schists lying along its southeast border. This granite touches the norite at Murray mine, and is distinctly younger than it, since it sends projections into it. The boundary of the granite with the greenstones is often a very brecciated one, blocks of the dark rock being enclosed in a matrix of granite which ramifies between the masses. Somewhat similar granite occurs as irregular bands near the middle of the norite at various points to the west and northwest, as well as towards Whitson lake, and it is probable that all have had the same origin. Diamond drill cores show rock of the same kind fom 900 feet depth below the surface of the norite about the middle of lot 8, con. II, in Blezard township.

Bosses of paler gray granite, perhaps of different age, appear in the graywackés and quartzites near the northwest corner of McKim township; and small areas are found in other parts of the region to the south and east of the nickel range, but they have not been studied in detail.

Huronian Greenstones

In the sketch of the character and distribution of the eruptives of the Sudbury district just given only the more important types have been referred to, the nickel eruptive, the Sudbury laccolith, the older norite and asosciated greenstone, and the granitic rocks. There are, however, many bands or bosses of a peculiar hornblende porphyrite with coarse crowded crystals occurring in various places in the sedimentary rocks, probably older than any of the eruptives that have been taken up. Examples of these are found running as a succesion of small lenticular patches for about two miles parallel to the Frood-Stobie offset, and many other outcrops of the same nature have ben noted in McKim, the only township studied in detail apart from the nickel range. It is likely also that the bands and irregular areas of greenstone, partly porphyritic and partly without phenocrysts, between the Blue lake face of the nickel eruptive and lake Wahnapitae belong to the same category. They are older than both the norite and the granite, the latter having carried off great strips and masses of them, and are of the same character as the greenstones enclosed in the Laurentian to the west and north of the nickel range.

Diabase Dikes

At the other extreme from the very ancient basic eruptives just mentioned, which are so far altered that their constituent minerals and in most cases even their original

Weathering of diabase, west of Sudbury.

structures have been lost, we have comparatively modern and usually very fresh basic rocks in the diabase dikes which intersect all the rocks of the district. The rock varies from fine-grained or compact to coarse-grained in the middle of large dikes, and in many cases it is highly porphyritic, flat plates of plagioclase sometimes two inches in longest diameter being embedded in a fine-grained ground. The color is gray, weathering brown, and the rock is specially apt to form spherical shells and boulder-like masses on exposed surfaces. Thin sections show that the rock is an admirably fresh olivine diabase.

The dikes are of every dimension from paper thinness to 100 yards in width, and they may have a length of several miles. In almost every part of the region which has ben carefully studied south of the main nickel range, these dikes have been found, and they appear to be particularly numerous in the neighborhood of the mines, perhaps, however, merely because those parts have been the most minutely studied. There are few rock dumps at the mines where the diabase is not to be found, and often the dikes cut ore, country rock and norite in various directions. These dikes are specially numerous and interesting at Creighton and Murray mines, where they cut the ore bodies and have been chilled against the sulphides because of their better conductivity, so that a glassy edge has resulted, while the contact against the rock is very fine-grained but not glassy. At Creighton mine the great open pit shows dikes running 20° 15° and 35° west of north respectively, and two dikes meet on the north side of the ore body, while another dike, on the southeast wall of the pit bends round so as to become nearly horizontal. A curious feature of these dikes is the well-rounded boulder-like projections from them enclosed in the ore. These pseudo-boulders are coarser grained in the middle and compact or glassy in contact with the ore.

The great dikes near Murray mine having a strike of 125° or 130° have been mapped by Dr. Barlow, who has followed them from the mine to Ramsay lake beyond Sudbury, a distance of six miles.

Near Worthington mine also dikes are numerous, and a short distance to the northeast near Totten mine an irregular hill of diabase crosses the narrow band of norite. Large dikes are known also at Copper Cliff; in the laccolithic band of norite near Evans mine; north of Chelmsford in the sandstones of the upper sedimentary series; in the tuff near Joe's lake and the Vermilion river, at the northeast of the nickel basin; and near the Blue lake ore deposits; as well as at numerous other points which need not be detailed. No dikes have been reported, however, from the Laurentian to the west and north of the northern nickel range, but this may simply be because that formation has attracted less attention than the others. The majority of the known dikes are in or near the southern nickel range, which seems to point to some connection between them and the ore masses. They have nowhere affected the ore bodies, however, beyond filling fissures in them; and they clearly belong to a much later set of phenomena than those connected with the coming into place of the nickel-bearing sheet and its accompanying ores. It may be, however, that the great number of fissures filled by the diabase dikes resulted in part at least from shrinkage due to the cooling of the nickel eruptive and the rocks which were heated at its contact.

It is noteworthy that the directions of the dikes show no relationship to the northeast and southwest strike of all the other rocks in the region, which usually have a more or less perfect cleavage or schistosity parallel to the nickel ranges; showing that the compressive force due to the settling of the foundations after the nickel-bearing magma had risen and spread out where we now find it, was then at an end.

Eruptives Compared as to Bulk

If we omit the "basal complex" of eruptives, mainly gneiss but with some unfoliated granite also, as well as considerable patches of greenstone, the nickel-bearing eruptive sheet far outweighs all the other igneous rocks of the region with its estimated bulk of 600 cubic miles. In average composition it comes near to the mean of eruptive rocks the world over, the percentages working out as follows:

	Per cent.
$Si O_2$	62.172
$Al_2 O_3$	14.661
$Fe_2 O_3$	1.112
$Fe O$	6.753
$Mg O$	2.489
$Ca O$	4.868
$Na_2 O$	3.417
$K_2 O$	2.299
$H_2 O$	1.213
$Ti O_2$	0.712
$P_2 O_5$	0.177
$Mn O$	0.10
$Ni O$	Trace
S	Trace

The eruptives most immediately associated with it are the "older norite" and related greenstones, and the finer-grained granites which lie parallel to it or form dikes in the eruptive sheet; and it is possible that these rocks are derivatives from the original magma, the older norite having been separated and erupted before the main sheet, and the granites after it. The porphyritic granitoid gneiss of the region has probably no direct connection with the hearth of the nickel eruptive.

In volume the older norite and the later granite are insignificant when compared with the great laccolithic sheet, each containing only a few cubic miles so far as known.

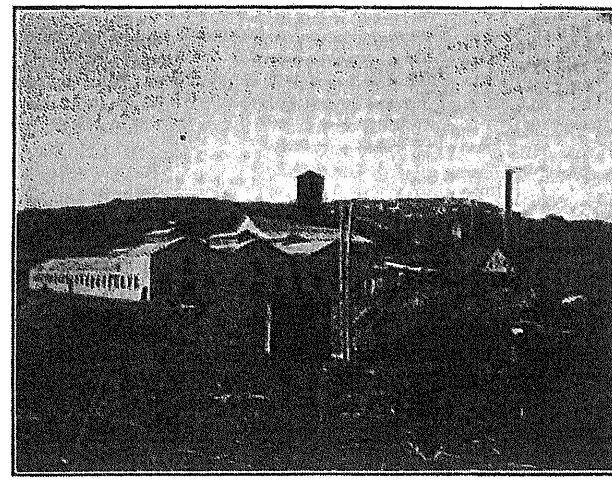
However, there is in the region another mass of materials of eruptive origin, the thick sheet of pyroclastic sediments called the Onaping tuff, including a number of cubic miles of volcanic debris, which must have come from some source not far off, possibly at the time of the surface flows of the older norite. That the tuff is older than the norite-pegmatite sheet underlying it has been shown in a previous chapter. An analysis by Prof. Walker gives this rock a composition somewhat more basic than the average of the nickel eruptive, but not so basic as the norite at its outer edge. There are, however, fragments of quartzite in the tuff which would increase the silica, and on the whole the rock seems quite different from either the nickel-bearing eruptive or the older norite, more basic than the former and much less basic than the latter.

THE HURONIAN SEDIMENTS

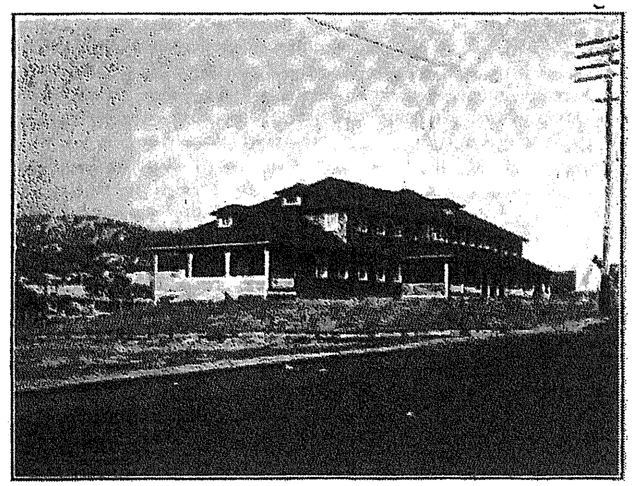
The sedimentary rocks of the Sudbury district underlying the nickel-bearing sheet are undoubtedly older than those overlying it, and have generally been considered to belong to the Upper Huronian as hitherto defined in Canada equivalent to the Lower Huronian according to the latest classification. Their relationships have never been worked out in detail, since they contain no economic minerals to give them special importance, and are exceedingly complex in their structure. As Dr. Barlow well says, "In the first place all the rocks of the district have been greatly disturbed, so that the originally horizontal strata are now tilted at very high angles, in some cases having assumed a vertical attitude, and occasionally have even been overturned as a result of the mechanical stresses to which they have been subjected. In some cases and over extended areas the rocks have been so metamorphosed that the planes of original sedimentation are more or less completely masked or even destroyed altogether." In addition Dr. Barlow calls attention to the schistose structure and cleavage crossing the bedding planes and the intrusion of eruptive masses through them disturbing the original order of deposition.[39] To the difficulties shown in the above quotation may be added the fact that faulting has taken place extensively all over the region, resulting in crush conglomerates and breccias which still further confuse the relationships.

The history of these sedimentary rocks is far from easy to unravel, but certain facts stand out clearly. They are distinctly water formed sediments, and in my opinion mainly ordinary clastics, sands and clays, and not to any large extent pyroclastics. They must have been once approximately horizontal, but they were greatly disturbed during the elevation of the Laurentian mountains, whose truncated bases touch them at various points, being thrown into close folds between the Laurentian areas; and perhaps before that time they had been domed up over laccolithic eruptions of norite older than the main eruptive sheet, and perhaps also by bosses or batholiths of porphyritic granitoid gneiss of a different age from the Laurentian. Then came the vast disturbances before and during the formation of the nickel-bearing laccolithic sheet, beginning at a remote time with surface lava flows and the raining down of a great thickness of tuff; followed by the spread of 600 cubic miles of magma between the older rocks under consideration and the later sediments. This climax of

[39] G. S. C. Vol. XIV, Part H, p. 62.



Plant for treating Cobalt ore, Copper Cliff.



Hospital at Copper Cliff.

the eruptive operations was accompanied by immense faulting and settling of the older rocks through the removal of molten material from beneath and the spreading out of the laccolithic sheet above them. With the settling of the sheet into a synclinal form came the lateral pressure which developed slaty cleavage and schistose structure parallel to the curved axis of depression under the syncline. Finally there was settling and shrinkage due to the cooling of the great eruptive sheet, causing many faults and fissures into which diabase could ascend.

When this complex history is kept in mind the difficulties of the stratigraphy are not surprising.

As probably the oldest of the sediments the gray or greenish or flesh-colored rocks variously called graywacké, quartzite and sometimes arkose may be taken up first. In some places these rocks show little or no hint of stratification and have been so far reconstructed as to look like fine-grained gneiss or granite or syenite, for which they have at times been taken; but the lowest part consisting of interbedded coarse and fine materials often shows well developed stratification on weathered surfaces. As suggested by Dr. Barlow, these darker rocks are bent into a syncline enclosing flesh-colored arkose.

Graywacke

As the oldest rocks of the region it is intended to describe first a series of well stratified rocks ranging from quartzite to slate, usually including a good deal of decayed feldspar and fine-grained dirty-looking materials as well as angular or rounded fragments of quartz and a chloritic or sericitic substance. In many cases the rock is very distinctly banded, coarser quartzose bands standing out while finer slaty bands with less quartz have weathered down as parallel furrows. These rocks have usually not been so greatly re-crystallized as the overlying arkoses, though there are phases looking like gneiss or mica schist; and this fact with their characteristic appearance of stratified sediments gives one the impression that they are younger than the felsitic-looking arkoses. There are, however, transitions between the two rocks and they probably represent a continuous succession, the graywacké being the older of the two.

The graywackés as here defined have well-marked bedding and sometimes cross-bedding and other structures characteristic of wave action; and rather rarely, rounded pebbles of various kinds of rock are found interbedded with the finer materials. They cover much more space than the arkose and present much more variety.

In the southwestern part of the district rocks of this kind show as hills and ridges near Worthington and Victoria mine, accompanied by thick bands of slate and also of quartzite as extreme phases, and one band of quartzite is pure enough to be worked as material for the lining of converters at Victoria mine,[30] containing 90 per cent. of silica.

Some of the more slaty bands are impregnated with sulphides and have rusty surfaces which have attracted prospectors, but they contain only traces of nickel or copper. The strike is generally about east and west, parallel to the basic edge of the nickel eruptive, and near Worthington a dip of 708 to the south has been recorded. Green schist and greenstone are often interbedded with the slaty graywacké.

Near the church at Victoria mine a common phase of the graywacké is well illustrated, showing an ice-planed surface of pale gray color slightly banded with darker gray, and in parts covered with markings half an inch long, oval depressions with a narrow ridge in the middle, probably pseudomorphs after staurolite. Small stretches of fairly well stratified graywacké occur near Gertrude mine. Graywacké is widely distributed near Copper Cliff and Sudbury also, with much the same features as near Victoria mine. At Copper Cliff it is largely buried under the clay flats, but numerous small hills rise above the drift, and narrow bands skirt the flanks of harder rocks,

[30] Hixon, Eng. Min. Jour., Dec. 29, 1904, p. 1022.

such as the arkose west of the village and the laccolithic range of hills near Kelly lake. The strike has here changed to N. 40° to 75° E., parallel to the general structures of the rocks of the region, and the dip varies from 65° to verticality. In the village of Copper Cliff the graywacké contains some patches of conglomerate which may be of beach formation. The hills to the northeast of the village and in the neighborhood of Clara Bell junction are largely graywacké, some parts near the latter point containing sulphides enough to weather very rusty. To the southeast of the range of arkose hills which occupies the centre of the syncline the graywacké with very pronounced bedding occupies the lower ground and apparently extends from this east almost to Ramsay lake, being cut off in that direction by a band of gabbro. Very good exposures are found between miles 2 and 3 of the Manitoulin and North Shore railway, and east of the C. P. R. station at Sudbury, the peculiar spotted variety formerly called "rice rock" occurring along the C. P. R.

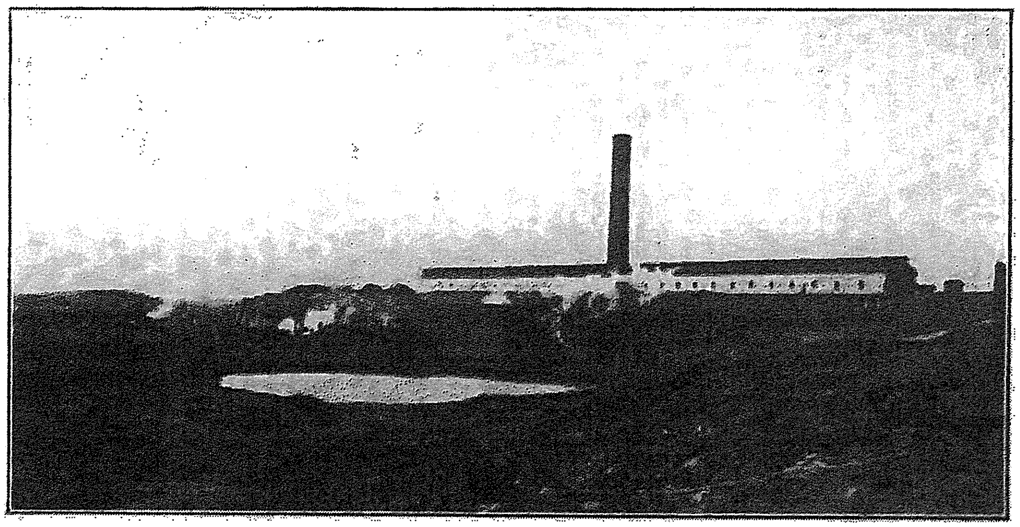
Perhaps the most typical exposure of these rocks is to the north of Sudbury on a steep hill which dominates the town. Here the stratification is very distinct, and various interesting structures occur, cross bedding on a small scale and wavy projections of a quartzitic variety into slaty bands. The road north towards Stobie gives fine exposures of the same rock, which ends, however, before Stobie is reached, being cut off by greenstone. In this part the strike ranges from 30° to 80° and the dip is not far from vertical. The graywacké extends to the east also along the valley of Sudbury creek between the gabbro of the laccolith east of the town and the hills to the north, but it is cut by dikes or bosses of hornblende porphyrite and by a boss of granite just within Neelon township. To the north of McKim stratification is not evident in many places and as there is little of the slaty material, the hills in this direction should perhaps be called quartzite or arkose, though without the pale flesh color usual in these rocks elsewhere in the district. Where the strike is visible it trends about east and west. West of this toward Stobie a mass of gray quartz porphyry is almost indistinguishable from the quartzite enclosing it.

The most singular phases of the graywacké run for about 5 miles northeast and southwest from near Copper Cliff almost to Stobie mine, parallel to the edge of the nickel range but some distance to the southeast. Here the graywacké has been more thoroughly re-crystallized than in most places and has the appearance often of sericitic or chloritic schist or even of fine-grained gneiss. Along most parts of the band of altered graywacké, which is not more than a quarter of a mile wide at greatest, there are numbers of pseudomorphs after staurolite, which may even reach 5 or 6 inches in length. The elongated six-sided cross-sections and occasional twins of the St. Andrew's cross type make the original nature of the mineral clear, though the crystals are now completely changed to quartz in minute grains or a pale green scaly mineral like talc or sericite. As the pseudomorphs are commonly paler than the rock, or even white, the appearance is very striking. In some parts the crystals are crowded in bands with spaces containing few crystals between them, the strike of the bands differing from that of the schistosity; in one case the crystals run 110 while the cleavage is 60°, and in another the two directions are 90° and 45°. It is likely that the stratification is indicated by the bands of crystals, the original beds having differed in composition.

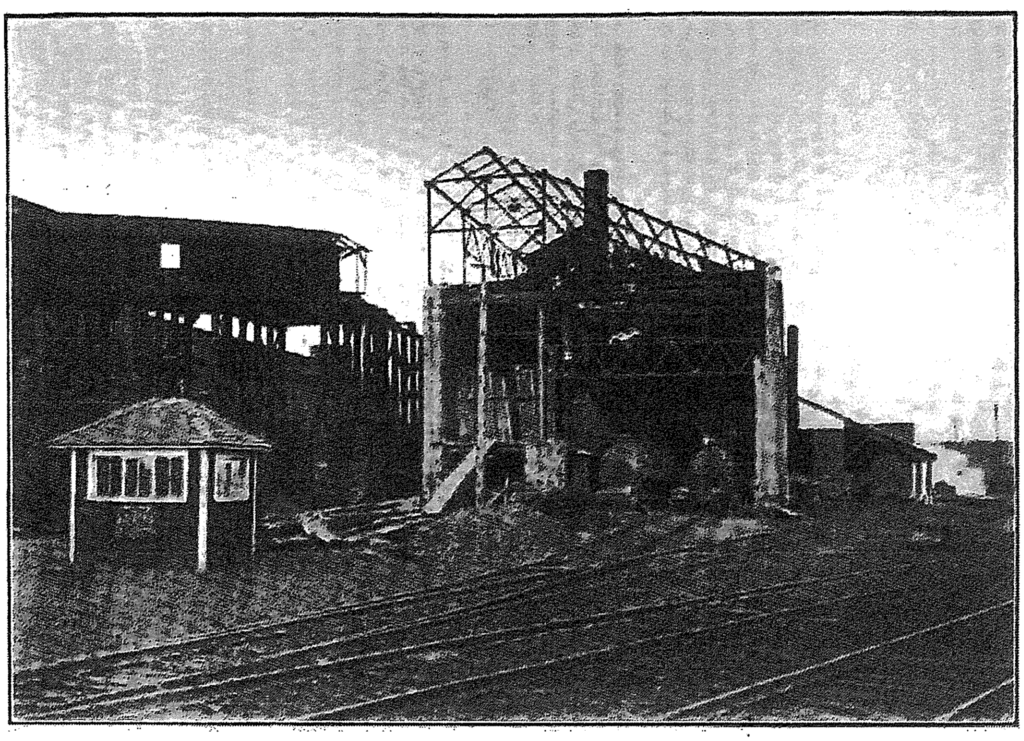
Close beside this very schistose variety there is a curious rock showing less change, but containing the "eyes and eyebrows" of fine-grained quartz which have been noted before; and there are parts with smaller whitish spots of quartz not unlike those described previously in certain hornblende schists.

The presence of later granite near by and the fact that the Frood-Stobie norite offset runs through or beside this band of graywacké probably furnishes an explanation of their altered condition.

From point to point a very narrow and broken strip of typical water-formed conglomerate runs near the altered graywacké from Frood to the hills beyond Stobie toward the



Canadian Copper Company's new smelter, looking west.



Canadian Copper Company's new smelter in process of construction, showing Bessemer converters.

northeast. This was probably once a continuous stratum but is now pinched and faulted into short separate strips, two of which occur in the village of Stobie and just east of the mine. As the conglomerate contains large pebbles of granite, quartzite, greenstone, green schist, etc., it is evident that it indicates a break in the succession, but whether this is a basal conglomerate at the bottom of the Huronian or is of minor importance in the series of sediments has not been determined. The thickness of the conglomerate as exposed near Stobie is never over twenty feet, so that in magnitude it cannot be compared with the great beds of basal conglomerate found in the typical Huronian region or at Michipicoten.

Arkose

Between two irregular bands of the graywacké described above, sometimes sharply separated from the lower rock, sometimes passing gradually into it, is a range of rugged pale gray or flesh-colored hills consisting of arkose, beginning near Copper Cliff and ending near Stobie mine. The hills are not continuous but in a general way run through the centre of the graywacké as if enclosed in a syncline of the latter rock, though there is so much faulting and irregularity in the relations of the two rocks as to make the matter somewhat doubtful. The arkose is so much harder, owing to re-crystallization, that it resists the weather better than the graywacké, the latter often forming the low ground beside the range of arkose hills.

Just west of Copper Cliff one such hill stands up from the clay plain with a fringe of graywacké just to the east along its flank. No distinct stratification was observed in the arkose though the graywacké close by is well stratified. The next outcrop is a small sharp hill just east of the Copper Cliff rock house, sometimes spoken of as syenite; though the rock is so fine-grained as to suggest felsite. To the north this rock becomes mingled with blocks of stratified graywacké as if it were an eruptive, so that the usual term is not to be wondered at. Dr. Barlow maps it as "regenerated granite" (re-crystallized quartzite). Mixed with green schists, graywacké and a little conglomerate, and more or less covered with stratified clay, the quartzite band extends to the eastward, growing wider to the west of Sudbury, where the two railways cross it giving excellent sections. On the Manitoulin and North Shore railway two miles west of the town the arkose has the look of fine-grained gneiss and is often sheared and crushed into a conglomerate. Farther north along the Canadian Pacific railway the re-crystallization has gone even farther in places, and boulder-like patches in the rock are filled with hornblende crystals.[31] This range of hills, which is in places half a mile wide, continues northeast beyond the C. P. R., but dies out before reaching the Frood mine. though patches of the same rock are seen between Stobie and Blezard mines. Many smaller strips and patches of similar arkose are found in the band of mixed greenstone and graywacké lying to the northwest of this range of hills, and the contact of the two rocks is often brecciated, as if it had been a zone of weakness where faulting was specially active.

Arkose occurs on a still larger scale but of the same general character east of the Sudbury district along the south shore of lake Wahnapitae and at other points.

Beside the more prevalent pale gray or flesh-colored rocks which contain a large amount of feldspar, and so have been called arkose in the description above, there are true white quartzites in the region consisting almost wholly of quartz grains more or less cemented with silica; but these occur only in small outcrops and do not require special description. The best localities are a small hill south of the railway between Frood and Stobie, and the north shore of Ramsay lake east of the boat houses. These quartzites are closely like the widespread white quartzite of the typical Huronian region near Echo lake, etc. The hill of schistose quartzite west of Headquarters in Garson township belongs to the same class.

31 Barlow, Ibid., p. 66.

Slate

Thin layers of slaty material occur at many points interstratified with the graywacké, but in some places there are thick beds of slate, quite free from coarser layers, so that they may be referred to as an independent formation. Beginning at the southwest, slate is found about half a mile west of Worthington station, the cleavage running 84° and the dip being 80° to the south. The rock is pale gray and somewhat lustrous and has a very perfect cleavage. A mile east of Worthington also gray slate is found in railway cuttings with the slaty cleavage cutting the stratification at a sharp angle; and slaty bands of considerable width, sometimes rusty from the weathering of pyrites, occur north of Victoria mine village. Slate occurs between Whitefish station and the band of granite south of the nickel range, and evidently has a considerable development in an east and west direction, since it is found at the falls of Vermilion river about two miles east of Whitefish where the Sault branch of the Canadian Pacific crosses the river. Here the stratification is well marked with a strike of 80°, while the slaty cleavage runs 50° with a dip of 85° to the southeast.

Slate and phyllite which probably correspond to those of the Victoria mines region are found to the west near Massey and Webbwood outside the boundaries of the district. The slaty rocks just described are always much more crystalline through the development of sericite or chlorite than the black slate of the Onwatin formation belonging to the sedimentary series above the nickel-bearing eruptive.

Middle Huronian (?) Graywacke Conglomerate

All of the sedimentary rocks so far described belong probably to the Lower Huronian, adopting the terms agreed upon by the international committee on the classification of the Pre-Cambrian, but there is graywacké conglomerate in the region of a quite different character from the graywacké interbedded with slaty layers hitherto mentioned. The best exposure of the graywacké conglomerate is on the north shore of Ramsay lake between the lake and the Sudbury laccolithic band of old norite. The matrix of the conglomerate is dark gray and massive-looking, containing many small fragments of quartz and a variable proportion of boulders and pebbles, the latter being usually rather sparsely scattered. The larger boulders are commonly of granite, but there are some also of quartzite, and many small ones of white quartz. Near a small lake between Ramsay lake and the hill to the north there are large fragments of the stratified graywacké enclosed in this rock, which hardly shows any trace of stratification; but there has been so much faulting and crushing in the region that the blocks of supposed older rock may have reached their place by those means and not by process of sedimentation. At a small point on the north shore of Ramsay lake there are suggestions of a basal conglomerate overturned, so that the older rock is now uppermost, and the crowded granite boulders of the younger one are beneath it, but here again there is some doubt as to the relation of the two rocks. We may assume however that the inclusion of numerous quartzite pebbles, often of pale flesh color, implies a later age than the Lower Huronian, which so far as we know is the only source of these pebbles.

In our own work only this small area, two or three miles in length by half a mile in breadth, is known to belong to the graywacké conglomerate, but very similar rocks occur on a large scale near Kokogaming lake east of Wahnapitae and in other parts of the Huronian.

UPPER HURONIAN OR ANIMIKIE SEDIMENTS

The series of sedimentary rocks, referred to earlier in this work as the Trout lake conglomerate, the Onaping tuff, the Onwatin slate, and the Chelmsford sandstone, resting on the basin-shaped sheet of the nickel-bearing eruptive, are probably of Animikie age or according to the latest classification, Upper Huronian. There is little doubt that before the eruption of the laccolithic sheet these sediments were nearly horizontal and rested on the folded and truncated edges of the Huronian and Laurentian rocks below, though few undoubted pebbles of any other Huronian rock than quartzite have yet been recognized in them. The common granite boulders and pebbles of the basal conglomerate may well have come from the Laurentian, though they may include other granites also.

Trout Lake Conglomerate

The rock immediately overlying the acid or upper surface of the eruptive sheet is always a conglomerate, often very coarse, containing pebbles and boulders of granite, quartzite, etc., clearly an ordinary basal conglomerate. This passes up into quartzite or cherty rock, often brecciated, and sometimes into a dark gray rock, which may be called graywacké, all containing some pebbles like those of the conglomerate. The width of the basal conglomerate varies from a few feet to more than 2,000 feet, and at 30° dip, the average thickness of the conglomerate and associated aqueo-clastic sediments has been worked out at about 450 feet.

The base of the conglomerate is always powerfully metamorphosed, often to such a degree that the boundary of the acid eruptive is hard to trace. The matrix of the conglomerate is changed into felsitic-looking material very like the finer-grained parts of the micropegmatitic granite, and the pebbles or boulders enclosed in it have very vague edges, though one can usually distinguish them as coarser textured spots, and thus decide that the rock is really conglomerate. In many places along the southeastern margin the rock has been squeezed or sheared into schist conglomerate with the pebbles greatly flattened and a matrix often like mica or chlorite schist. The finer-grained sediments above the conglomerate proper have been much less changed, but still show signs of silicification, rendering them often very resistant.

In the detailed account of the nickel-bearing eruptive the acid edge has been described as always in contact with the Trout lake conglomerate, which it has penetrated more or less from beneath and greatly metamorphosed. In that connection the distribution of the conglomerate has been referred to, so that it is not necessary to recapitulate the points at which it is found. It will be sufficient to say that next to the acid edge round the whole inner rim of the nickel eruptive the conglomerate is known to exist as a band varying from a few feet to more than half a mile (south of Gordon lake) with an average of about 1,000 to 1,500 feet. Good exposures are met between Vermilion river and Gordon lake, south of Windy lake, on the north shore of Whitewater lake, south of Trout and Joe's lakes and near Garson lake. The band is unusually narrow north of Whitson lake. It is noteworthy how often the line of contact between the acid edge and the conglomerate crosses lakes, the very accentuated topography favoring the formation of lake basins.

Onaping Tuff

Resting on the water-formed sediments of the Trout lake formation, and with transitions between them, is the Onaping tuff, a thick sheet of pyroclastic sediments mingled with varying amounts of pebbles or boulders of granite, quartzite and chert. The volcanic ash and lapilli are angular and now consist largely of serpentine and chalcedony. No clear evidence of stratification has been found in this series of rocks, which range from hard, almost flinty materials standing up as sharp hills, to soft slaty forms verging towards the true slate of the next formation. It may be that the flinty variety, which lies immediately upon the Trout lake rocks, has been solidified with silica brought by circulating water from the acid eruptive; while the upper part not being thus consolidated has yielded to pressure and taken on the slaty cleavage.

The thickness of the tuff is hard to determine sharply because of its blending upwards into the Onwatin slate, but assuming the boundary to be the low hills facing the valley occupied by the slate proper, we find an average thickness of 3,800 feet.

Much of what has been said of the distribution of the conglomerate will apply also to the overlying tuff. It forms an oval band from a mile to a mile and a half wide round the whole basin, but is separated from the acid edge by the conglomerate into which it appears to merge, more and more ordinary sedimentary material coming in toward the base until the majority of the constituents are water-formed clastics, and the transition to the Trout lake formation is complete. The edge of the pyroclastic sediments toward the nickel eruptive, like the underlying conglomerate, is generally hardened by the action of the fluids from the acid edge and so stands up as sharp hills, but the softer inward edge sinks away into the low ground and is largely covered with drift. Perhaps the best exposure for the study of the tuff is along the railway east of Onaping, though here the softer phase is mostly hidden. Good sections are afforded on the road from Trout lake to Azilda, especially on the north side of the basin, and along the southern side of the basin in Capreol and Hanmer townships.

At several points the tuff has been found to contain small deposits of sulphides, especially zincblende and galena, but never on such a scale as to be of economic importance. Such deposits are known at points to the north of Fairbank lake and along the same side of the basin toward the east, but the largest visited by us was a little east of the south end of Trout lake in Bowell township, where a location (W D 252, sometimes called Prue's mine) has been taken up, and a small shaft sunk showing quartz with zincblende, galena and a little copper pyrites. A dark gray basic eruptive rock occurs beside the shaft and its eruption probably influenced the formation of the small ore body. Pyrites is very commonly found scattered in small particles through the tuff, as near the high falls of the Onaping river, sometimes in such amounts that the surface weathers rusty; and there are places near the northeast corner of Creighton township where considerable veins of quartz with pyrites have been taken up as gold mines, but hitherto with no success.

Onwatin Slate

The black, carbonaceous slate is soft and has generally weathered so far as to be covered with Pleistocene beds; but it occasionally forms low hills, as near the east end of Vermilion lake. It has a very perfect cleavage, and the stratification, as indicated by darker bands, is cut by it at high angles. Its thickness may be fixed at 3,700 feet on the average, that being the space separating the tuff from the sandstone.

The softer phase of the Onaping tuff merges on its inner side into the black slate, which forms a third band running round the basin, usually, however, occupying the low ground and very often hidden by old lake deposits. It is best studied in the river valleys, especially along the Vermilion river from Vermilion lake east and south. Just below the exit of the river from the lake a range of low ridges of slate occurs on both sides, one of the few points where this rock rises as independent hills. At Stobie falls the river, which has hitherto run parallel to the strike, turns southward across it, causing two small falls. Apparently the slate at these points has been more or less shattered and the fissures have been filled with quartz and sulphides giving it greater resisting power than elsewhere. A small shaft has been sunk on one of these deposits of sulphides just where the river turns sharply southward, but so far as known no ore of value was found.

The most interesting feature of the black slate is the large amount of carbon contained by it, amounting to from 6.8 to 10 per cent. according to analyses made in Dr. Ellis' laboratory in the School of Science. In lot 10, con. I, of Balfour township, a little north of the bend of the Vermilion a vein of anthraxolite or anthracitic carbon was found in the slate in 1896, giving rise to the hope of finding coal in the region. An examination showed that an irregular vein ran about north and south up a hill of slate having a length as far as exposed of 70 feet and a width of 12 feet where widest. The walls are very uneven, and large horses of slate occur in the anthraxolite, which would not average more than six feet in thickness. Diamond drilling has shown that the deposit goes to a depth of at least 100 feet, so that some thousands of tons of the anthracitic material may exist in the vein. Originally the anthraxolite entered the fissure as bitumen which gradually lost its volatile constituents and became changed to the present hard coaly material having nearly 95 per cent. of fixed carbon, an analysis of the purest specimens giving the following results:

	Per cent.
Carbon	94.92
Hydrogen	0.52
Nitrogen	1.04
Sulphur	0.31
Ash	1.52
Oxygen	1.69
	100.00

It will be seen that this contains more fixed carbon than the best anthracite;[32] and in hardness and slowness of burning also it goes somewhat beyond hard coal. In losing its volatile constituents the bitumen contracted greatly, forming small lustrous fragments, often cubical, and seldom more than half an inch in diameter; and later quartz and a little pyrites were deposited in the spaces, so that the average material contains from 25 to 45 per cent. of quartz, diminishing greatly its value as fuel.

The adjoining slate has a strike of 60° and a dip of the cleavage varying from 55° toward the south to the vertical, the cleavage being oblique to the stratification, which dips to the northwest.

North of the east end of Vermilion lake part of the slate is very carbonaceous, soiling the hands, and here also an attempt was made to find coal. The rock dump shows a great amount of slickensided fragments having a perfect polish as of graphite, evidently resulting from brecciation and faulting. Somewhat north of the anthraxolite vein mentioned above on lot 2, con. II, of Balfour township, Mr. William McVittie has sunk a diamond drill hole for 1,000 feet without any other result than to prove that the slate goes to at least that depth.

Not far from the anthraxolite deposit zincblende with some other sulphides have been obtained from the slate or from the slaty edge of the tuffs, but the amounts are too small to justify mining. At the east end of Onwatin lake, from which the name of the slates has been derived, a pit has ben sunk upon a mass of pyrites with the idea that it was nickel-bearing, but with no results of importance. Evidently the shattering due to earth movements since the nickel eruptive reached its place has caused many fissures, some of which have been filled with molten rock, forming the diabase dikes, others with pitchy materials forming anthraxolite, probably derived from the enclosing rocks charged with hydrocarbons, and still others filled with zincblende, pyrite and other sulphides with a little quartz as a result of circulating water. Appreciable quantities of nickel or copper apparently do not occur in the sulphides deposited in the slates.

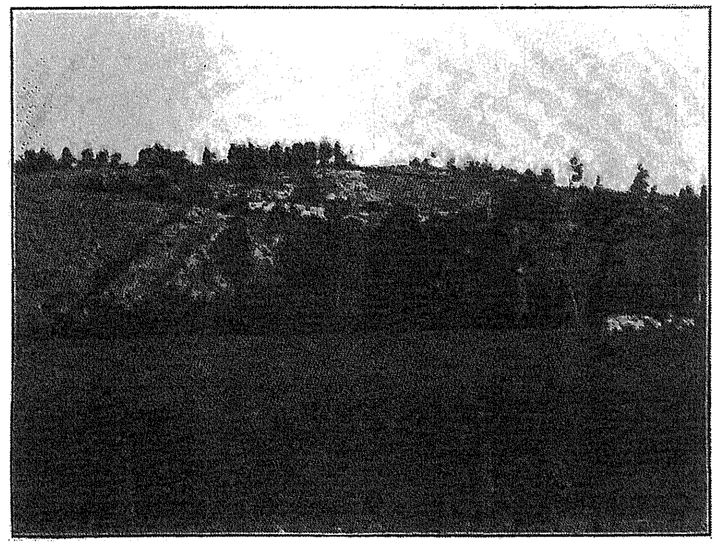
Chelmsford Sandstone

The uppermost rock of the series is distinctly marked off from the slate below, though a few bands of slate part the thick beds of sandstone and bring out prominently the bedding of the formation. The sandstone, where it rises above the plain, forms a succession of gentle anticlines, usually four in number, running parallel to the axis of the main syncline, i.e., about 50° to 80° east of north. The synclines between the anticlinal hills are always buried under stratified lacustrine deposits or under swamps,

[32] Bur. Mines, 1896, Anthraxolite or Anthracitic Carbon, by A. P. Coleman and W. Hodgson Ellis, pp. 159-166.

so that a complete fold is never seen. In almost all cases the top of the anticline has been destroyed, and often narrow, sharp, outlying ridges run parallel to the central hill, ruins of former upper beds of the anticline. In size the anticlines vary considerably, the longest mapped having a length of 2½ miles and a width of about a quarter of a mile, while the next to the northwest is only a mile long and 760 feet wide. The slopes of the folds vary from 20° or 25° to 45° or 50°, and the present height of the hills is seldom more than 150 feet above the plain formed by the old lake deposits. However, in crossing these anticlines one usually finds a more or less steep hill following the bedding and then a sharp break with a nearly vertical cliff of 5 to 15 feet, where the stratum has been destroyed. Then comes another ascent of gentler slope along the next stratum with perhaps a smaller cliff; and at last a gently rounded surface on top of the arch; the opposite side being of the same nature but reversed.

The sandstone occupies the centre of the synclinal trough, running from the west end of Vermilion lake to the east side of the township of Hanmer, a distance of 18



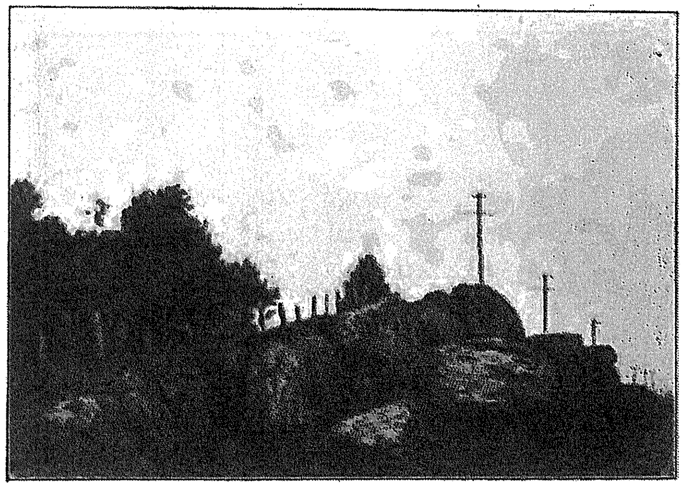
Anticline of sandstone, west of Chelmsford.

miles, with a width of about three miles. It is probable that it really extends about 8 miles farther toward the northeast, but that part of the basin is covered with old lake deposits. In general the sandstone does not form a continuous area, stretches of flat farm-land or of swamp separating the anticlines, or their ruins from one another. No attempt has been made to map the numerous small outcrops of sandstone where little ridges representing remnants of elongated domes rise a few feet above the soil with a steep face toward the centre of the ridge and a gentler slope outwards.

The road from Larchwood to the west end of Vermilion lake touches several of these outcrops and in one place runs for some distance along the nearly flat surface of an anticline; and in canoeing up the Vermilion from the lake toward Larchwood several small outcrops represent the bases of anticlines which have mostly been destroyed.

The neighborhood of Larchwood presents one of the best places to study the sandstone, sections being presented by wagon roads, the railway and the river, which here flows first parallel to the strike along a syncline to the railway bridge, where it turns southeast across the strike of a broken anticline, forming two falls, and then southwest again along the strike.

The sandstone is medium-grained with particles of quartz and of mica visible, as well as some feldspar, so that it might be called arkose. It is not very strongly cemented, is dark gray on fresh surfaces and paler gray on weathered ones, and frequently contains large oval concretions richer in lime and iron than the rest of the rock, so that they might be called impure ferruginous limestone. The large concretions weather out and leave shallow holes which give a very characteristic look to some of the flanks of the anticlines. The beds are from two to seven or eight feet thick, and often a thin seam of slate, less carbonaceous than the slate below, occupies the break



Southern edge of anticline, west of Chelmsford.

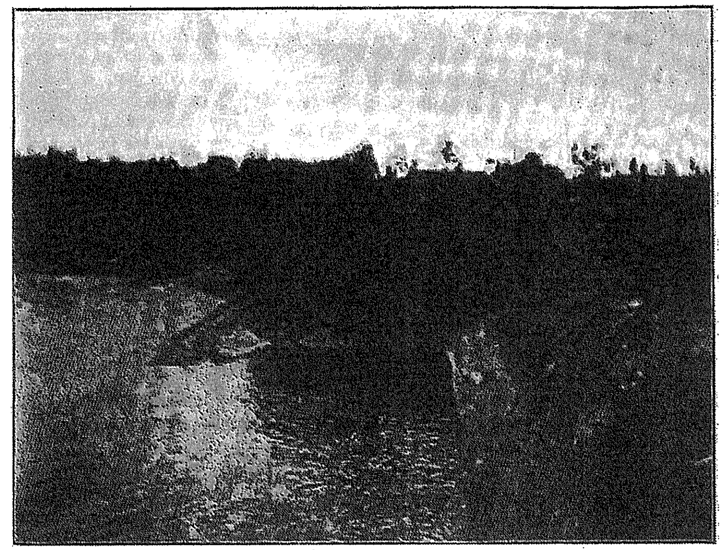
between two strata. Occasionally this slaty part of the rocks has been greatly crumpled and thickened at some points, probably while the harder sandstone underwent folding.

Between Larchwood and Chelmsford the railway runs mainly on a clay plain and seldom cuts the sandstone, the route having been chosen so as to avoid the anticlines, but both to north and south ridges a mile or two long and from 50 to 150 feet high rise above the plain with slopes ranging from 20° to 45°. The wagon road between the two places, running south of the railway, crosses several of these ridges but lies to the south of the Chelmsford ridge, one of the most extensive ones which has been rather carefully studied, and may be taken as typical.

It begins just west of Chelmsford with the appearance of a dome, small buttresses of sandstone rising a few feet above the clay with slopes of 15° to 18° toward the north, northeast, east and southeast. A little beyond Chelmsford creek and south of the railway the dome rises completely above the clay and has been quarried for building stone. The cleared surface shows shell after shell of gently rounding beds sloping toward the plain, but to the southeast a gap has been cut out of the anticline so that

a small bay penetrates the outer edge from the plain. The end of the anticline is slightly double, a very gentle depression separating a higher part to the northwest from a lower swell to the southeast. Beyond this point the anticline rises with a broken top to the height of from 75 to 125 feet or a little more, and keeps this height and a width of about 600 yards for about a mile, when it sinks somewhat irregularly with a dome-like form into the plain. The direction of the anticlinal axis is 65°, the length is 2½ miles and the width, if the outer remnants of strata which have been destroyed are counted in also, of about one-half mile. If the crest of the anticline were completed from the outer remnants with the average dip of 18° or 20° at the edges, the height would be about 350 feet above the plain.

Another anticline to the north of the railway is on a much smaller scale, but with steeper slopes, having a length of about a mile, a breadth of 700 feet, and a height



West side anticline of sandstone on Vermilion river. Larchwood.

of 80 feet, with a dip of 36° to the southeast and of 26° northwest. If it were completed its height would be about 125 feet above the plain.

An anticline at the Larchwood railway bridge has steeper slopes still, one side dipping 43° northwest into the river, the other 44° southeast under drift. It is 730 feet wide where the section was made, and if restored would have a height of about 200 feet above Vermilion river. As fully half of the folds from trough to crest is buried under the clay, we may suppose them to measure 400 or 500 feet in total height.

In order to give a complete idea of the structure of the sandstone area a section has been made across the whole width, but it was found necessary to make a jog of half a mile in one place and of a quarter of a mile in another so as to avoid large swamps. It is believed, however, that the section as worked out gives the general relationships correctly. In all, four anticlines are found, the two which have been described a little west of Chelmsford and two somewhat wider ones toward the northwest, the last one, however, seeming much less regular than those to the southeast. Much more of the surface is covered with drift towards the southeast than toward the northwest, and the rugged sandstone ridges on the latter side are uncleared and not so easily studied as those rising out of the fields.

After the last fold on the northwest the sandstone dips gently toward the southeast with small cliffs facing in the opposite direction, and is underlain by the Onwatin slate. On the southeastern side of the folded central region there is a similar attitude of the beds, but the slate is not found, so that evidently the lower part of the series is buried. The contact of the sandstone with the slate is even better shown on the road from Larchwood westward, the slate at that point dipping 20° to the southwest under the sandstone. The dip of the sandstone near the hotel at Larchwood, about one eighth of a mile from the contact with the slate, is 42° to the southwest, and the thickness has been worked out as 350 feet.

To the northeast of Chelmsford sandstone ridges covered with woods continue some distance north of the railway to the east side of Lumsden township, where they are well exposed on the road from Azilda to Trout lake, rising first above the clay a little north of the line between Rayside and Lumsden townships, as a small ridge striking northeast and dipping 10° to the northwest. There is a cliff of 15 feet facing southeast, and this outcrop may be part of the first anticlinal ridge, the rest not rising above the clay. After three-fourths of a mile of swamp another anticline is reached toward the northwest, having a strike of 75° and a dip of 26° toward the southeast with a corresponding dip in the opposite direction.

The sandstone continues a mile or two farther to the northeast, and the anticlinal hills extend for about the same distance along the strike, beyond which plains of clay and sand cover the rock, so that the northeastern end of the sandstone area cannot be exactly determined.

SOURCES AND FORMER EXTENT OF THE SEDIMENTS

The sources of the materials of the sedimentary series are not easily explained in all cases, though the granitic pebbles and boulders of the basal Trout lake conglomerate no doubt originated in the underlying granites, especially the Laurentian; and the sand of the quartzitic layers may have been supplied by Huronian quartzite. The cherty ingredients of the upper layers may have been deposited from solution like those of the Animikie of the west.

The water-formed sedimentary materials mixed with the Onaping tuff also are easily accounted for, as they are mainly granite, quartzite and chert; but the volcanic centers from which the explosive eruptions of ash and lapilli took place remain undiscoverable. The thickness of the tuff, estimated at 3,800 feet, and the area, of about 200 square miles covered by it, if continuous beneath the slate and sandstone, indicate a total amount of perhaps 130 cubic miles of material still preserved, and this would be increased greatly if we imagine the tuff extended so as to cover the whole area of the laccolithic sheet, which was no doubt the case in the beginning. An analysis of a sample from north of Whitson lake by Prof. Walker indicates a composition not unlike the average of the basic and acid portions of the nickel eruptive, and it is conceivable that the tuff may represent an earlier eruption from the same magma, actually reaching the surface in volcanoes. Until some trace of the bases of old volcanoes is discovered this must, however, remain doubtful. Whatever the origin of the volcanic materials may have been they seem to have dropped into the sea and to have been mingled with waterworn fragments of non-volcanic rock.

The Onwatin slate may be looked on as ordinary mud mingled with organic matter, probably coming from marine plants or animals; and the Chelmsford sandstone is largely arkose, which may have resulted from the decay of adjoining Archean land.

The former extent of the sediments must have been much greater than the present, but there is very little evidence of similar rocks from the surrounding districts. The

only outside example of the tuff, so far as known, is a small patch near Bear lake, and the other rocks of the series have not been found with certainty anywhere in the region. Apparently the soft sediments have been destroyed everywhere beyond the protective wall of the acid edge of the eruptive and of the metamorphosed base adjacent to it.

Probably the most nearly similar formation elsewhere is the Animikie at Port Arthur, where black slate, chert and arkose-like rocks sometimes called quartzite occur, but the basal conglomerate there is thin, and there is nothing that suggests explosive volcanic eruptions such as formed the great sheet of vitrophyre tuff.

PLEISTOCENE OF THE SUDBURY DISTRICT

Glacial Action

The geological record of the Sudbury region, as shown in the solid rocks, ends in very ancient times, certainly not later than the Cambrian, and from that age to the Pleistocene no deposits are known, probably because the land remained above sea level. A vast amount of erosion must have taken place as shown by the cutting down of the more than 10,000 feet of sediments which once spread more widely than the present area of the nickel-bearing eruptive.

The thick sheet of residual materials which must have resulted from this prolonged period of weathering and erosion has been completely swept away or worked over by various agencies in the Pleistocene. Like all of northern Ontario, the Sudbury district shows the effects of glacial scouring in the bare and usually rounded rocky hill tops, covered with striae where the rock has not suffered from post-glacial weathering. The usual direction of the ice motion is from N. 30° to N. 45°, but in a few places more than one set of striae are to be seen; as near Copper Cliff, where later and less incised striae run N. 15°, and at Chelmsford where the usual scoring having a direction of N. 45° is crossed by later ones running from N. 60° to N. 65° It is probable that these divergent striae are due to local ice currents caused by the shape of the hills and do not indicate the work of later ice sheets coming from a different direction.

There are parts of the region where cliffs facing northeast have not suffered much rounding, as if the ice pressure had been unequal, but in general the direction of the ice movement was not far from parallel to that of the strike of the ridges, so that great abrasion can hardly be looked for. The low but sharp edged cliffs of the interior sandstone ridges, for instance, run from N. 50° to N. 80° as a rule, so that the ice advance if not parallel was only slightly diagonal to them.

Certain of the rocks, such as the basic edge of the nickel-bearing norite, crumble too quickly under the action of the weather to preserve ice markings or even *roches moutonnées* forms; but it is rather surprising to find how often the ore bodies along offsets from the norite rise as gossan-covered hills which have resisted ice erosion, as at Copper Cliff, Evans mine, Stobie mine, etc. It may be noted also that perfectly fresh surfaces of pyrrhotite, polished and grooved, were disclosed at Creighton mine when the covering of till was stripped off. It is evident that boulder clay almost hermetically seals the surfaces on which it rests.

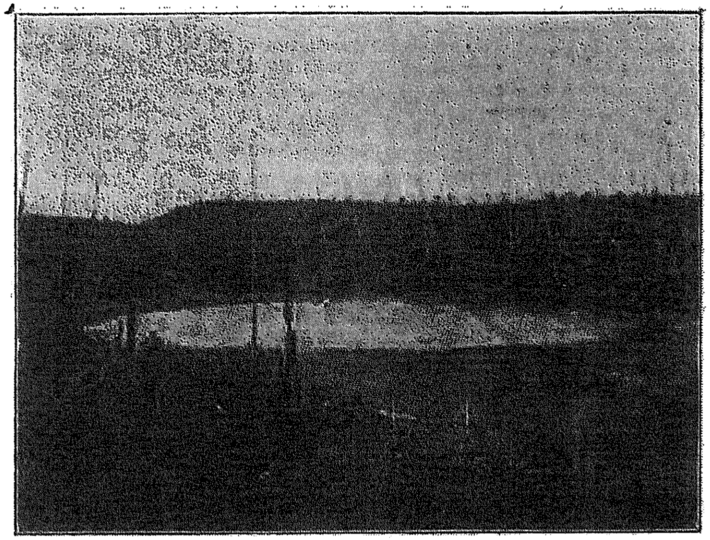
Boulder clay and sandy varieties of till occur in many localities in the region, especially on the lee side of hills or ridges, but they cannot be traced as a continuous sheet as in southern Ontario, no doubt because this part of the area covered by the Labradorean ice was near enough to the centre of accumulation to be much more heavily loaded than farther south, so that the erosive and transporting work of the ice sheet was more effective than towards the edge where it was thinned by melting.

During the retreat of the last ice sheet morainic ridges were left in many places and erratics and perched boulders are common in various parts. No moraines have been traced in detail, the nature of our rock in this wooded and difficult country making that almost impossible; but morainic accumulations were found to be specially common near the northern nickel range.

Morainic ridges and kettle ponds occur to the southwest of Windy lake, and a long esker, beginning on the peninsula which projects into the lake on its southwest corner, runs northeast along the basic edge of the nickel-bearing eruptive for about six miles toward the valley of Onaping river.

Bouldery moraines and glacially dammed ponds are found just east of Sand Cherry creek in the north part of Morgan township, and sharp ridges of boulders run for about three miles east from the northwest corner of Lumsden township, evidently a moraine. A similar moraine is crossed by the portage between Frenchman's lake and Joe's lake in the southern part of Wisner township; and coarse morainic materials are found for considerable distances to the west of Hutton township some miles to the north of the nickel range.

Kame deposits are frequent, as at the gravel pit just west of the town of Sudbury, where irregularly stratified sand, gravel and boulders rest on a beautifully carved and scoured surface of quartzite.



Kettle Lake in drift, near McDonald's camp, Falconbridge township.

The combined action of ice and water is excellently shown in the wide plains of sand and gravel with some morainic and kame-like hills and ridges at the east end of the southern nickel range, from Headquarters toward Blue lake and Wahnapitae, where there are several kettles of various dimensions, some empty but others occupied by a pond or lake. As this region consists largely of lake deposits, however, it will be referred to more at length under that heading.

Lake Deposits

When the last ice sheet (Wisconsin?) retired from northern Ontario the drainage of the region was towards the Mississippi, and in the earlier stages the area of the great upper lakes was largely covered by lake Warren. In the later stages lake Algonquin was the representative of the upper lakes, emptying mainly by way of Niagara, but for a time through the Trent valley, into lake Iroquois, whose outlet was through the Mohawk valley into the Hudson.

The beaches of lake Warren are probably the highest in the region, reaching 1,100 or 1,200 feet above sea level along the northern nickel range, and even 1,400 feet within 40 miles to the north, as at Meteor lake.

Cartier, somewhat to the northwest of the nickel region, is built on a gravel terrace 1,367 or 1,398 feet above the sea, representing the highest lake deposits in the district along the line of the railway, except a gravel flat near Geneva lake, 4 or 5 miles beyond, which reaches about 1,400 feet. No beaches as high as these have been found in the nickel region proper, but along the northern range somewhat lower terraces occur at many points, often three in succession. The following table gives the elevation of most of the terraces known in the Sudbury district:

	Feet.
Meteor lake—sand and gravel terrace	1,420
Geneva lake—gravel terrace	1,400
Cartier—gravel plain, (1,367 from Montreal), 1,398 (from L. Sup.)	
Lake expansion of Spanish river—gravel plains	1,335
Muskegogema lake—gravel plains	1,316
Near Onaping, Windy lake—gravel plain	1,216
" Moose creek—gravel plain	1,110
" Onaping siding—sand plain	1,057
" Phelan's siding—sand and gravel plain	927
Trout lake in Morgan township—gravel plain	1 123
Island creek—gravel plain	1,163
" lower terrace	1,057
Trout lake in Bowell township, and region to south:	
" between Trout lake and next lake	1,216
" south of 2nd lake—gravel flat	1,160
" "	1,110
North of Vermilion river—sand plain	950
Terrace along river—sand plain	926
Rayside or Azilda—clay plain	881
Hutton township, Osborne's camp—gravel terrace	1,090
Upper Vermilion river, Gordon's placer claim—gravel terrace	1,047
" " west of Bronson lake—gravel terrace	1,060
" " " " "	970
" " Dawson—main gravel terrace	958
" " One mile east of Dawson—bouldery terrace	950
North of Onwatin lake on Dawson Road—terrace	1,000
South of Onwatin lake—sandy plain	900
Near the southern nickel range:	
North of Fairbank lake—gravel terrace	1,050
North of Worthington—clay plain	775
Near Sudbury and Copper Cliff, north of smelter—sand terrace	934
Cemetery north of Sudbury—gravel terrace	877
Clay flat	850
Headquarters, east side of Garson township—sand plain	1,080

Many other terraces and flat plains of clay, sand or gravel were observed, but owing to weather conditions or length of absence from a bench-mark my aneroid readings seemed too uncertain to be relied upon. In the above table heights determined by aneroid are given in the nearest round number; other elevations, mainly determined by hand level from railway bench-marks, are given more exactly. As the hills along the northern nickel range rise, as a rule 200 or 300 feet higher than along the southern range, there were more opportunities to record the higher beaches there. Still farther to the north near the watershed between the great lakes and the rivers flowing into Hudson bay there is a broad tract of stratified sand and gravel with numerous kettle lakes at about the level of Meteor lake (1,400 feet).

In a general way one may say that the highest terraces, say those above 1,200 feet, belong to lake Warren, and the lower ones down to about 900 to lake Algonquin. Still lower gravel terraces may belong to some intermediate stage between it and lake Nipissing. Until the connections have been worked out it must, however, remain uncertain just where a given terrace should be placed in the series of old lakes from Warren downwards. As lake Nipissing is only 648 feet above sea level, and the level of old lake Nipissing was not very much higher, it is evident that none of the water-levels of the Sudbury region belong to it, all being considerably too high.

In the highest stages of lake Warren the basin enclosed by the nickel ranges was completely submerged with only the higher hills along the northern edge standing above water as a low rocky shore or as small islands. At this time indeed most of the basin may still have been occupied by ice; but as the ice front retreated the region to the northeast was rising, so that the enlarging waters of the lake stood relatively lower and lower here towards its northern end, forming the succession of terraces mentioned.

By the time when lake Warren was drained to the lower level of Algonquin the water had so far fallen that the interior of the basin became a bay completely enclosed except at a few channels opening southwards across the southern nickel range, as along the valley of Vermilion river.

While the broad gravel plains were being constructed at the higher levels sand was being deposited in the shallow water and silt and clay in deeper parts, forming the flat plain of clay and sand standing at levels between 750 and 900 feet, affording several townships of good land now largely taken up by farmers. In general the valleys of the rivers and creeks are cut more or less deeply into these deposits showing finely stratified clay often covered with a few feet of yellow sand. Along the watercourses sand prevails for a few hundred yards or half a mile, but inland from the streams clay is found. These deep-water deposits are often quite thick and fill up all depressions in the older rocks to a common level out of which the steep walled hills rise suddenly with very little talus to blend their slopes into the plain. The contrast in coming from the excessively rugged and precipitous hills formed by the acid edge of the nickel-bearing eruptive and the hardened conglomerate and tuff to the plains of clay near Azilda or Chelmsford is very striking.

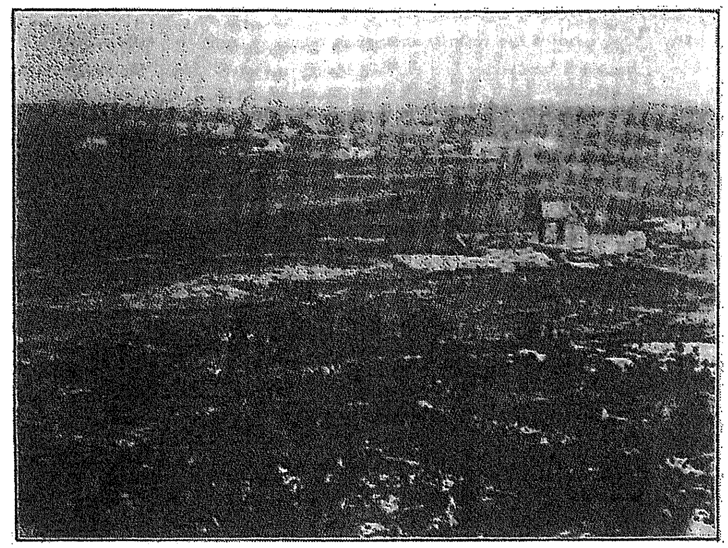
The depth of the stratified clay has seldom been determined, but in one case, north of the railway at Azilda, a well was driven to a depth of 105 feet without touching rock.

It is probable that the retreating ice occupied the region east of Headquarters for some time toward the end of the series of Warren water levels, and the stagnant ice of its edge frequently got buried under shore deposits of sand and gravel, to thaw at a later time and leave the irregular basins which are called "kettles." These have walls of sand or gravel as steep as the materials will lie with a fairly flat marshy floor drained through some pervious layer or a lake, often with no apparent outlet. One of these basins on the road to lake Wahnapitae is three-quarters of a mile in length by a quarter of a mile in breadth, and 165 feet deep. Part of the bottom is occupied by a pond said to be 60 feet deep.

The source of the materials for the large gravel plains along the northern nickel range and farther north toward the height of land is to be found probably in glacial gravels of a kame-like character which the waves of the great lake at the front of the ice distributed as they were brought down by the sub-glacial rivers, which have left behind esker ridges in various places.

Distribution of Lake Deposits

The lacustrine clay which includes most of the farm land of the Sudbury region has almost the flatness if not the extent of the prairies, and covers not alone large tracts in the interior basin but also to the south of the nickel range. In the interior basin clay land suitable for farming begins along the shores of Vermilion lake in the north half of Fairbank township, fine groves of maples and other deciduous trees occupying a mile or two along the northwest side of the lake on low land of a silty nature. To the east the flat clay plain with some ridges of slate rising through it extends to the southward bend of the Vermilion river and as a narrow band along the river valley to the falls (17 feet) in the southeast corner of Creighton township, and



Farm land, Azilda; from cliff of Acid Eruptive.

then to the north shore of Whitewater lake, where it projects some distance into the acid edge of the nickel-bearing eruptive beyond Rayside or Azilda. The two southward extensions of the clay occupy parts of two low passes in the southern rim of the basin, the exit of Vermilion river, which carries the whole drainage of the basin, being of course the lower of the two, having a level of about 800 feet above sea level.

The southern clay band then turns northeast through parts of the townships of Rayside, Blezard, Hanmer and Capreol, in the latter township becoming silty and sandy, but still affording good land now being rapidly taken up by settlers. At the southeast end of Capreol the loamy plains give place to glacio-lacustrine plains of gravel with kames and moraines and kettle holes, as mentioned earlier, unfit for farming; and to the northeast rise the hills of the acid edge.

To the northwest of the clay belt just referred to good land extends into the southern half of Dowling, here becoming more sandy in character until it merges into the sand and gravel plains along the northwestern margin of the basin. Except for anticlinal ridges of the central sandstone there is good clay soil from Larchwood to Chelmsford and on northeastwards to Hanmer township. Along the Vermilion river and to the north of it the lowland consists mainly of useless sand and gravel plains with stony gravel terraces in the openings of the hills along the acid edge of the northern nickel range. The villages of Chelmsford, Larchwood, Azilda and Blezard Valley are growing up as prosperous centres for the farming region.

South of the nickel range the areas of good clay land are more scattered and of less extent, owing to the more resistant character of the Archean rocks as compared with the sediments of the interior basin. A considerable number of farms extend from Sudbury north to Stobie and northeast into Garson and Neelon townships; but farther northeast the land becomes sandy and passes into gravel plains near Headquarters.

There are small areas of good soil southwest of Sudbury along the Sault branch of the Canadian Pacific near Copper Cliff, Naughton, Whitefish, Worthington and other points, each occupied by a few farmers; and there are still wooded tracts of rolling clay land to the north of the railway in various places suitable for settlement.

More or less good land extends along the lower ground adjoining the Sault line to Lake Huron, Sault Ste. Marie and Goulais bay on Lake Superior; but this goes beyond the district now under consideration. In these western regions as toward the east, one finds the low-lying clay rising toward the north and becoming mixed with sand, ending with sand and gravel terraces along the rocky hills which rise a few miles from the shore of the lake.

Gravel Plains and Terraces

Gravel plains, or flats of sand and gravel, extend between the Archean hills far to the northwest of the Sudbury district, and have been put to use by the Canadian Pacific railway, which always locates its sidings and stations on such plains if possible. Within the limits of our map such plains exist near Geneva lake, at Cartier, at Windy lake siding and at Phelan's, the last point being within the basin here described. The gravel plains around Phelan's and Onaping extend northwards along the Onaping valley to the mouth of Moose creek. Similar sand and gravel terraces stretch bay-like into all the river valleys which come south through the northern nickel range, as along Island and Sand Cherry creeks in Morgan township, Nelson river and the region south of Trout lake. They are found too along Rapid river and south of the Frenchman's lakes in northern Hanmer extending to Vermilion river north of Onwatin lake.

Away to the north for 40 miles sand and gravel with eskers, kames and kettle ponds and lakes extend along the Vermilion, the head waters of the Wahnapitae and around Meteor lake, itself an immense kettle walled with gravel.

This irregular chain of gravel plains running up from 1,050 feet above sea in the south to 1,400 in the north at the watershed is of interest as containing placer gold, sometimes 50 or 100 very fine colors being got in a pan, though usually the number is much less.[33]

Southeast of the east end of the nickel basin is the large sand and gravel area referred to before near Headquarters, including parts of the townships of Capreol, Maclennan, Garson and Falconbridge, and covering for a space the basic edge of the southern nickel range. Here, as on the Vermilion south of the west end of the range and also along the line of the Canadian Pacific west of Sudbury, there is a sinking in the hardened tuffs and the acid edge of the nickel-bearing rock, which in the later times of the glacial lakes formed a channel between the bay enclosed in the basin and the broad lake to the south and west.

The sandy and gravelly terraces and plains were formerly covered with a good growth of pine, but in most parts this has been cut, and too often fire has run since, reducing the plains to barren wastes or a low scrub of second growth jack-pine.

33 Bur. Mines, 1897, pp. 256-9; and 1901, pp. 151-9.

PETROGRAPHICAL SECTION

Petrography of the Nickel Eruptive

Since it was discovered by Professor T. L. Walker in 1897 that the basic rocks associated with the Sudbury nickel ores pass by insensible gradations into acid rocks having the composition of granite, it has been difficult to give a petrographical name to the whole mass of eruptive rock, now known to form a synclinal sheet a mile and a quarter thick on the average. It would be manifestly incorrect to name it either norite or granite, so that hitherto in this report non-committal terms such as the "nickel eruptive" or the "nickel-bearing eruptive" have been employed. Before Prof. Walker's discovery the basic side of the sheet was mapped separately as greenstone, and such names as diorite and diabase were applied to it, naturally enough, since the ordinary weathered phase shows no pyroxene, and to a certain extent there is a suggestion of ophitic structure in the rock. In 1892 Baron von Foullon showed that the fresh rock at Murray mine is norite; and it is certain that one of the samples from a supposed dike at the Blezard mine, sent by Dr. Bell to Prof. G. H. Williams for identification, and named quartz-hypersthene gabbro, was really from the basic edge of the eruptive, so that the true nature of the rock had already been shown in 1890.[34] In 1893 the present writer noted the presence of gabbro containing diallage and enstatite associated with ore in the northern nickel range.[35]

The acid phase of the sheet has been variously named syenite, gneiss, granite and micropegmatite, and there is some justification for all of these names, since the rock contains considerable quartz, but almost always pegmatically intergrown with feldspar, so as to be invisible to the naked eye, and there is frequently a distinct gneissoid or schistose structure. In former reports on the region the acid side of the eruptive has been mapped in many cases as Laurentian gneiss, but occasionally as a Huronian schist, and never as granite or syenite, except by Prof. Walker in the sketch map accompanying the paper mentioned before. That the rock was a micropegmatite in structure was noted by the present writer in connection with the northern range, but it was not observed that the basic and acid phases belonged to the same sheet of eruptive rock.

Excellent accounts of the nickel eruptive have been given by Prof. Walker in his Inaugural Dissertation and by Dr. Barlow in various Geological Survey reports, especially his latest, published in 1904;[35] and detailed accounts of the rock as shown in various sections across the eruptive have been given in former reports of the Bureau of Mines.[36] Since the last report was written the eruptive has been examined, in some new localities, and it will be useful to give the results as a whole in this final report on the region.

That good sections across the whole width of the eruptive are found along the C. P. R. between Murray mine and Azilda, and near Onaping, has been well shown by Prof. Walker; and several other fairly good sections occur at some of the lakes, such as Fairbank lake, Whitson lake, Blue lake and Joe's lake. Some of the wagon roads of the region also give good exposures, as from Blezard to the north end of Whitson lake, and between the Emery Headquarters and Capreol township. Most of these sections, which are from three to four miles long, have been briefly mentioned in the detailed account of the nickel ranges. One very interesting section across the narrowest portion of the range in the northeast part of Morgan township is very inaccessible, but specimens have been obtained from each edge.

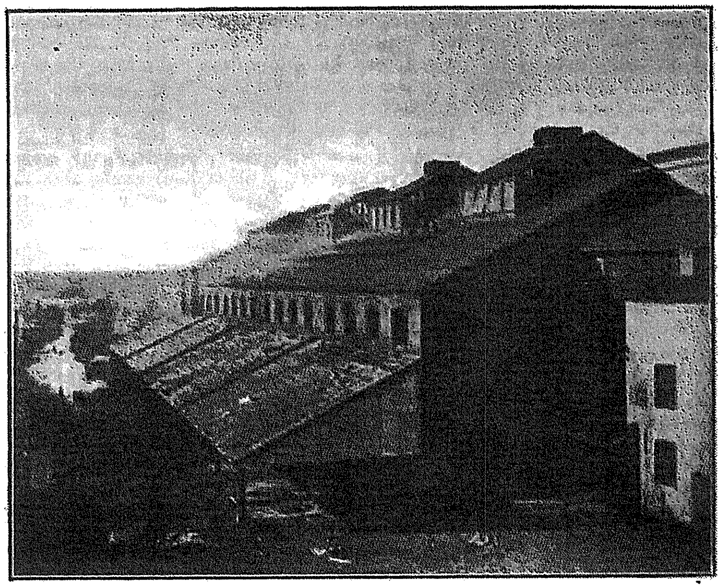
Two of these sections may be chosen as typical, the ore from Murray mine to Azilda and the section at Onaping.

34 G. S. Can., 1890, Part F, p. 77.
35 Can. Rec. of Science, Apr., 1893, p. 344.
35 G. S. C., Vol. XIV, Part H.
36 Bur. Mines, 1903, pp. 293-6; and 1904, pp. 208-213.

THE MURRAY MINE SECTION

The norite near the Murray and Elsie mines is dark gray, coarse-grained, and contains blebs of blue quartz and flakes of mica, which are easily seen without a lens. There is a tendency to the ophitic structure in some specimens but not in others, and there is a great difference as to freshness. The rock weathers readily into rounded forms half embedded in coarse sand resulting from its own decay.

Fresh thin sections consist mainly of plagioclase and hypersthene with a little augite, quartz and biotite, the plagioclase having the extinction angles of labradorite. The feldspar makes up two-thirds of the rock in my best section and the hypersthene a quarter, the latter mineral being pleochroic. There are also a slightly pleochroic augite in small quantities, a little biotite, and a very little hornblende. Sometimes the hypersthene has good crystal forms against the feldspar and sometimes the reverse. Quartz forms wedges between the rather platy feldspars, which are fresh but have a pale brownish color.



Canadian Copper Company's new smelter from northeast.

A specimen from the mine itself, containing several per cent. of ore differs from the one described in having less plagioclase than hypersthene and very little quartz, and there are also variations in the amount of biotite, so that the proportions of the minerals normally forming the rock are somewhat uncertain.

Most of the norite from Murray and Elsie mines is however no longer fresh enough to retain the pyroxene, which has been transformed into rather compact-looking hornblende in some cases, and in others to uralite or serpentine. The plagioclase remains fresh, however, and the biotite seems unchanged.

For a mile and a half to the northwest along the railway there is little change in the norite, except for an increase in the amount of quartz which has more or less of a graphic intergrowth with the feldspar, but beyond this the weathered surface of the rock becomes reddish and suggests a dark syenite. Thin sections disclose quartz and plagioclase with biotite, secondary hornblende and apatite, the first two minerals largely intergrown as micropegmatite which radiates from a crystal of andesine. There may be a little orthoclase, but in the main the feldspars are of the soda-lime varieties, so that the rock should be named micropegmatitic quartz diorite.

Nearer the acid edge of the eruptive the rock does not change much in appearance except to grow more schistose, and thin sections differ only in containing more micropegmatite and also more unstriated feldspar, so that it should be classed as pegmatitic granodiorite or granite. Where the schistosity is pronounced there is often too much crushing to show the micropegmatite distinctly.

The series collected on the road from Blezard north to the end of Whitson lake is very similar to that just described, except that there is less schistose structure toward the acid edge. The norite at a point a little north of the mine was found by Prof. Walker to be the freshest in the region, and thin sections are very handsome. Plagioclase (labradorite), hypersthene, diallage and biotite make up the most of the section, but some hornblende, probably secondary, quartz partly as pegmatite, and apatite are found also.

Prof. Walker has published analyses of specimens taken somewhat to the east of the road along the shore of Whitson lake and his results will be given later along with rock analyses from other parts of the range. His work shows an increase in silica, potash and soda from south to north and a decrease in lime and magnesia, corresponding to the change in mineral composition of the rock.[37] Both of the sections just described include considerable masses of granite and of re-arranged arkose, which have been left out of account in the description.

THE ONAPING SECTION

The best section across the northern nickel range is one which Prof. Walker first described, following the railway from Windy lake to Onaping from basic to acid edge, reversing the order found at Murray and Blezard mines. Railway cuttings provide a very complete series of specimens which differ considerably in appearance from those described from the southern range.

At the basic edge the rock is rather coarse-grained and of a much lighter gray color than the corresponding rock at Murray mine. There follow syenitic-looking rocks made up of flesh-colored and green minerals, and finally near the acid edge greenish gray rocks rather finer-grained and with lath-shaped feldspars. No part of the series is schistose, indicating less squeezing and shearing than on the southern range.

Going eastwards along the railway from Windy lake siding Laurentian is seen for a quarter of a mile, when drift and an esker ridge cover the rock for a distance. At the northwest end of Windy lake gray, dioritic-looking norite crops out, rather coarse and speckled in appearance, consisting, as seen under the microscope, mainly of plagioclase, hypersthene and augite, with a little quartz, biotite, and hornblende, many prisms of apatite and some magnetite. The plagioclase, which is clear and colorless and makes up about half of the rock, has extinction angles corresponding to andesine or labradorite, and is generally hypidiomorphic; while the hypersthene is idiomorphic. This mineral presents some anomalies, since some crystals showing the usual pleochroism, red brown, pale brownish green and pale yellowish, have parallel extinction, while others extinguish at various angles up to 28 degrees. Diallage, brown and fibrous-looking, non-pleochroic, and with an extinction angle of about 45 degrees occurs in small quantities also; the small amount of hornblende present forms margins about the minerals just mentioned; and the brown biotite is present only in trifling quantities.

A specimen from a cutting a hundred yards east is coarser grained and not quite so fresh, but does not differ greatly in composition. An analysis of this rock given

37 Quar. Jour. Geol. Soc., Vol. LIII, p. 56.

later, shows 56.89 per cent. of silica, considerably more than Professor Walker found in norite from Blezard mine on the southern range.

Fifty yards farther east coarse red syenitic-looking rock begins and lasts to Onaping station, showing in various cuttings. Thin sections prove, however, that the rock contains a large amount of quartz mostly pegmatitically intergrown with feldspar, but partly as fairly large clear spaces, so that it is too acid for syenite, and an analysis given later confirms this by showing 68.48 per cent. of silica. The feldspars are very badly weathered, but the well formed crystals making the starting point for micropegmatite seem to be all plagioclase, though the analysis proves that potash and soda are present in about equal amounts, (K_2O 3.36, Na_2O 3.72), so that the feldspar in the pegmatite must be chiefly orthoclase. The dark minerals include secondary looking hornblende and the mineral resembling epidote named by Professor Walker woehlerite. The last specimen collected to the west of Onaping station has extraordinarily slender prisms of feldspar, which strike the eye immediately on fresh surfaces.

To the east of the station the appearance of the rock changes and it becomes greenish gray and finer-grained; though the microscope shows little difference except the presence of more hornblende. An analysis proves that this rock is less acid than the red variety west of Onaping, since it contains only 61.93 per cent. of silica.

At the margin of the eruptive against the basal conglomerate beneath the tuffs, it becomes finer-grained, though still green and dioritic-looking; and thin sections show short, stout crystals and little micropegmatite, the quartz, which is present in considerable amount, being mostly granular.

The sections just described may be looked on as typical, since they include fresh norite and cover the full width of the eruptive, four miles on the southern range, and about two and a half in a straight line on the northern. Each begins with quartz-biotite-norite on the basic edge, passes through intermediate stages in which micropegmatite occurs in increasing amount, and ends in a rock consisting mainly of micropegmatite enclosing crystals of andesine with hornblende and biotite, having a chemical composition corresponding to grano-diorite. There is one very important difference between the southern and the northern sections, which are arranged in opposite directions to one another, each having its basic edge outwards from the central line of the eruptive sheet. The southern range has a mile and a half or possibly two two miles of the more basic rock, norite; while the northern range has only a quarter of a mile which can properly be reckoned to norite. The acid portion of the sections is about equal, but the basic portions are very unequal. This probably has some bearing on the fact that large amounts of nickel ore occur on the part of the southern range selected for study, while no ore is found at the basic edge of the northern range where the section was made and where the norite is small in amount.

It is of interest to compare with the sections just given the rocks found at the basic and acid edges of the narrowest part of the northern range, near the northeast corner of Morgan township. The specimens show little difference to the eye, though the one from the acid edge has a faint tinge of flesh-color which is lacking in the other. Thin sections show considerable differences, however. One from the basic edge contains mainly feldspar with micropegmatite radiating from it, hornblende and chlorite, the feldspar being largely plagioclase not far from andesine in optical characters, but with some untwinned crystals, probably of orthoclase, and one peculiar crystal, unstriated but containing irregular patches of plagioclase having low extinction angles from twin planes. Micropegmatite running into areas of unmixed quartz makes about a fourth of the section. The augite, partly very fresh, is nearly colorless and not appreciably pleochroic. The rock has not the usual character of the basic edge, being without hypersthene (or pleochroic pyroxene) or biotite among dark minerals, and containing a good deal more than the usual proportion of micropegmatite and orthoclase. One may hold that the true basic edge is absent at this narrow portion of the eruptive, and that the rock just described belongs to the intermediate facies between the basic and acid edges.

A thin section from the opposite or southeast side of the band consists mainly of very fine, often plumy, micropegmatite, sometimes arranged round broad crystals of andesine, sometimes about a narrow strip or about no apparent nucleus. This makes up at least two-thirds of the rock, while plagioclase and a crystal or two of orthoclase with hornblende and a small amount of epidote make up the rest.

At this very narrow point the typical acid edge phase of the eruptive is well represented, and the lack of width is due to the absence of the basic or noritic phase. Along with this goes the total lack of ore or rusty surfaces so far as known along this part of the outer edge of the laccolithic sheet.

While the typical rocks of the nickel eruptive are dark gray or pale gray norite at the basic edge, somewhat flesh-colored pegmatitic rocks at intermediate points, and flesh-colored or greenish gray micropegmatite rock having the composition of granodiorite at the acid edge, there are, nevertheless, considerable variations in the appearance and composition of the basic edge at different parts on the circumference of the sheet, and some interesting varieties in the acid edge also; and a few characteristic localities will be taken up in illustration, especially from the southern range, where the greatest variations are found.

In the first place, it may be shown that the norite in connection with ore bodies is not always quite the same in character as that of the Murray mine, and for this purpose examples from other parts of the southern range will be studied.

Other Norites of the Southern Range

Except that the hypersthene and diallage are usually completely weathered to fibrous hornblende or uralite the basic edge southwest of Murray mine as far as Lady Violet mine differs little from the typical example, and the same is true toward Blezard mine. An interesting diamond drill hole sunk by Mr. J. V. Miller for the Edison party in lot 8, con. II, of Blezard township, more than a mile northwest of Little Stobie mine should be referred to. The drill reached a depth of 1,030 feet, and an examination of portions of the core at every 50 feet, provided by the kindness of Mr. Miller, shows that the rock is norite to the full depth except for micaceous schist with pyrite and vein quartz at 264 feet and fine-grained flesh-colored granite at 900 to 950 feet, probably from a dike. Thin sections show that the rock varies greatly in freshness, being generally so far re-arranged as to contain only hornblende, etc., in place of the pyroxenes; but curiously the lowest parts of the core are much less fresh than the rest, though the best preserved section is from 550 feet. In it the feldspars (andesine to labradorite) are very fresh and somewhat brownish and there is a little quartz, partly interstitial and partly intergrown with feldspar as micropegmatite; while the dark minerals include much hypersthene and also a pleochroic monoclinic pyroxene very like the hypersthene, a little diallage, hornblende and biotite.

It is evident of course that the term weathering as employed for deep seated changes in eruptive rocks, like the norite at 1,000 feet, is not to be taken in a literal sense, as due to water with carbon dioxide or oxygen. Probably the different states of the rock as to freshness are due to differences in the amount of shearing or crushing allowing water to circulate more freely in some parts than others.

THE CREIGHTON NORITES

The norite of the Creighton mine differs considerably from that at Murray mine, containing usually appreciable amounts of quartz, often micropegmatitic, and orthoclase or microcline, in addition to the usual plagioclase and dark minerals. The hypersthene is fairly fresh in most sections, even those containing ore, and has a strong pleochroism. Biotite is plentiful, and the hornblende usually present seems to be secondary. The most interesting sections are those containing considerable amounts of pyrrhotite and chalcopyrite, which may lie in contact with any of the rock-forming minerals, but are mostly found in or beside the darker ones, especially the biotite. The ore is often completely enclosed in biotite and may be accompanied by magnetite, distinguished by its iron black color and bluish lustre, the two minerals appearing to have been formed at the same stage of cooling. The sulphides, however, often show a tendency to penetrate the fissures of adjoining minerals, being evidently more easily dissolved and re-deposited than the magnetite.

It is rather surprising to find minerals like orthoclase, microcline and micropegmatite in connection with the ores at the largest nickel mine, and the fact suggests that the more acid phases of the ncrite are sometimes associated with ore bodies.

Sections of ore often show small quantities of rock-forming minerals enclosed in pyrrhotite, plagioclase, quartz and secondary hornblende being found in that position.

To determine the composition of the rock (free from ore) at the Creighton open pit Mr. M .T. Culbert has made an analysis of a fresh specimen, with the following results:

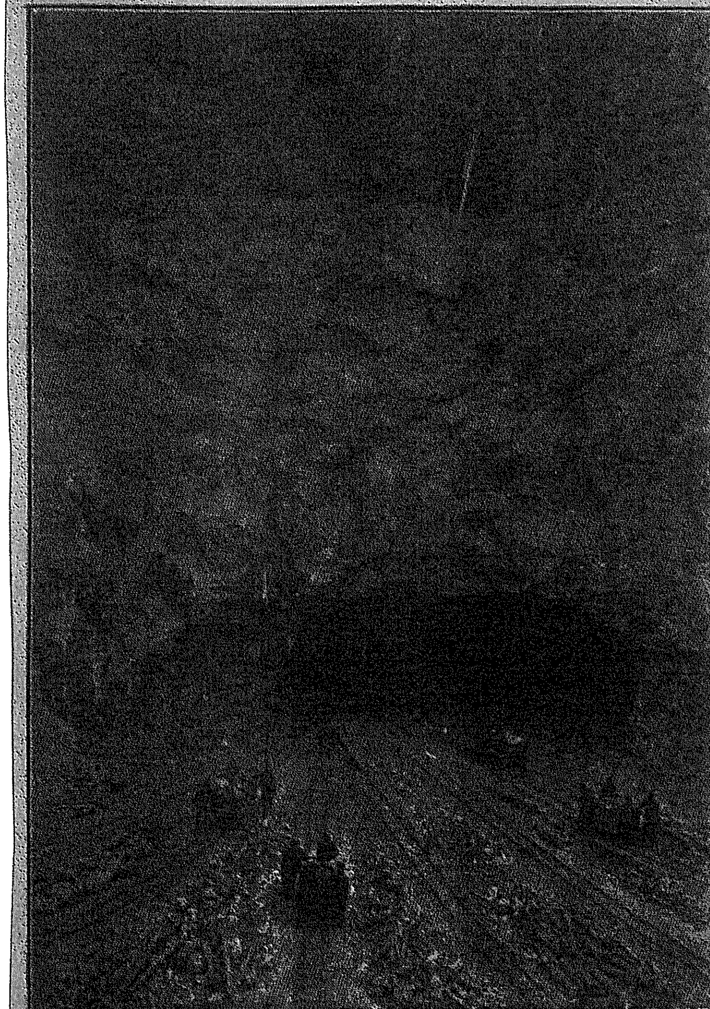
	Per cent.
SiO_2	60.15
Al_2O_3	18.28
Fe_2O_3	1.51
FeO	6.04
MgO	3.22
CaO	4.01
Na_2O	1.28
K_2O	1.68
H_2O (below 100°)	.19
H_2O (above 100°)	.86
TiO_2	1.34
P_2O_5	.28
MnO	.29
BaO	.25
ZrO	.14
NiO	.17
Cu	.16
S	.54
Total	99.79

From the analysis it will be seen that the rock cannot be called basic, the orthoclase or microcline and quartz present having raised the silica to over 60 per cent. A small amount of sulphides and of titaniferous iron ore are shown to exist, which is to be expected under the circumstances. If this rock were not in continuity with the norites east and west there would be doubt as to its position in the classification.

The rock associated with the Gertrude mine to the west is generally more weathered than at the Creighton, and seldom retains the hypersthene. On the whole it contains less quartz and little or no potash feldspar, so that it more nearly resembles the Murray mine norite. One specimen from near the Gertrude station contains a large amount of olivine in addition to hypersthene and diallage among dark minerals, but it is not certain that it belongs to the nickel eruptive; since a hill of "older norite" is a little to the south, and the immediate surroundings are drift covered.

The rock near North Star to the northeast of Creighton is the normal weathered quartz norite, and the same is true of examples from near the Victoria mine, the Chicago and the Sultana toward the western end of the southern nickel range.

Northeast of the Blezard mine the norite, where studied, is seldom dark gray in color and is frequently squeezed and sheared into schistose varieties, as at the Kirkwood and Cryderman mines. At the east end of the nickel range near Blue lake and the Whistle mines the band of eruptive is narrow and the noritic portion has suffered most, being only a few hundred yards wide. The norite is usually rather pale gray, though some areas of dark gray rock occur not far from the Blue lake mine. All the thin sections examined are greatly weathered, the pyroxenes having completely changed to uralite and even the feldspars showing to some extent the change to epidote, zoisite, etc., usually called saussuritization. The sections contain more than the normal amount of quartz, often in the form of micropegmatite, and if they had not been taken from near outcrops of ore they would probably be placed in an intermediate place between the norite and the micropegmatitic granites.



Creighton mine, second level.

The norites from the northern nickel range conform pretty well to those described from the vicinity of Onaping, having usually a paler gray color than the norites of the southern range, due to the absence of brown coloring matter in the feldspar. In general there is more quartz and micropegmatitic on the northern than on the southern range, probably because the basic edge of the eruptive is narrower there.

A few words should be said of the acid segregations occurring at various places in the norite, especially near Murray and Elsie mines. These may be small patches a square foot in diameter, or several feet in diameter, the outer edge dark green from an accumulation of hornblende, then a coarse mixture of hornblende and white plagioclase followed by plagioclase alone or with some quartz.

Sections from the green edge show the same minerals as the weathered norite, but the hornblende is in much larger amount than is usual in norite, and there is much quartz and less plagioclase; but no pegmatitic structure. The next band, with a mixture of green and white, differs mainly in having less hornblende and some orthoclase or microcline with the plagioclase; while the whiter parts contain very little hornblende and consist of feldspar and quartz. Varieties of the rock in these segregations are made up of very large crystals, the blades of hornblende sometimes reaching six inches in length.

NORITE OF THE OFFSETS

Norite projects as three long offsets from the basic edge of the laccolithic sheet, at Copper Cliff, Victoria mine, and from the middle of Bowell township to the middle of Foy. There is also an isolated band of norite running parallel to the basic edge, including the Frood and Stobie mines. These projections are somewhat dike-like, but are usually very irregular in width and may run out into small separate patches of norite completely enclosed in the country rock. In a general way the norite of the offsets has the same composition as that of the main range, but it is less fresh, very seldom retaining the pyroxenes, and usually is much finer grained. The Copper Cliff offset has been most carefully studied and will be taken as typical.

In general the norite is rather dark gray and fine-grained, frequently spotted with ore, but there are also very coarse-grained segregations on a small scale, like those at Murray mine, the central parts consisting of plagioclase crystals more than a square inch in cleavage surfaces. Thin sections show plagioclase (andesine or more often labradorite) in greatest amount, followed by secondary hornblende, quartz and biotite, with more or less titaniferous magnetite sometimes surrounded with leucoxene and apatite. The quartz is partly wedged in between the feldspars, but often intergrown with them in a way somewhat different from ordinary micropegmatite, having a slightly granular look, but with many grains oriented alike. Possibly this represents a poikilitic arrangement rather than micropegmatite.

At No. 2 mine, north of Copper Cliff the pyrrhotite-norite forms only a narrow band between the ore body and the walls of granitoid gneiss. A section from a specimen five feet from the gneiss is fine-grained and has the characters just described, but with an unusually large amount of micropegmatite and a tendency to zonal structure in the plagioclase crystals, which grow more acid at the edges.

Another specimen from the actual edge of the gneiss is compact in appearance, showing more rapid cooling than the former one, and is formed mainly of tiny strips of plagioclase with parallel strips of quartz having a rough fluidal structure. The dark minerals are hornblende and biotite.

Sections from the Mitchener mine near Worthington on the Victoria mine offset have the same character as those from the Copper Cliff, but portions of the band of norite have been much more completely changed at the Worthington mine itself, being reduced to a fibrous mass of actinolite with only traces of other minerals.

From the Foy apophysis only two sections have been studied, one at its starting point and the other at the western end six miles away. The specimen from the starting point on location W D 152 in Bowell township comes from a peculiar crush conglomerate of coarser norite, and sometimes other rocks, cemented by fine-grained norite

with sulphides. The matrix is very fine-grained quartz norite, without micropegmatite, the dark minerals being hornblende and biotite. The plagioclase crystals are often well formed and have a gradual change of composition from the centre outwards.

The rock from the end of this offset is fine-grained and spotted with small specks of ore. It differs from the other mainly in having an unusual amount of micropegmatite radiating from well formed plagioclase crystals.

Variations of the Acid Edge

The acid edge of the nickel eruptive shows less variety than the basic edge, but has certain differences from the typical examples already described, which were micropegmatites of about the composition of grano-diorite. In the northern range the rocks from near Blue lake deserve mention for their marvellously developed micropegmatite, ranging from almost invisible structures to comparatively coarse ones, centring about very complexly twinned plagioclase. Specimens from Trout lake are equally fine; but sections from Moose lake have only rude intergrowths of quartz and feldspar. Almost all sections from the northern range contain considerable amounts of epidote in large, compact individuals.

Along the southern range the acid edge on Fairbank lake and points to the west and north proved puzzling in the field, since it presented exactly the dark green, fine-grained appearance of a slightly schistose greenstone. However thin sections prove that this rock also is an acid phase of the nickel eruptive, since it consists largely of the finest possible micropegmatite, invisible except with fairly high powers of the microscope, with plagioclase crystals, chlorite and hornblende. It was thought that these dark green phases of the acid edge might have acquired their color by "overhand stoping" and absorption of the lower part of the overlying tuffs, since on Fairbank lake at least the basal conglomerate in places seems almost absent. An analysis of a characteristic specimen shows, however, that the composition is normal, having 69.95 of silica, 12.74 of alumina, 3.28 of potash and 3.80 of soda. Evidently the green color simply means that the fine scales of chlorite are distributed in such a way as to give the greatest effect.

A grey green, schistose variety is found northeast of the Cryderman mine at the northwest corner of Falconbridge township also; but in this the crushing seems to have gone so far as to destroy the micropegmatite altogether.

The acid edge in some places immediately beneath the Trout lake conglomerate shows small cavities with green epidote enclosed in a rim of flesh red, the whole an inch or two across and surrounded by the ordinary grayish flesh-colored rock; and similar green and red patches sometimes occur in the matrix of the conglomerate.

General Character of the Nickel Eruptive

Having taken up typical sections of the nickel eruptive and variations from the types along the basic and acid edges of the sheet, we may now sum up our knowledge and discuss the results of rock analyses from different parts of the region.

In a general way, the basic edge may be defined as quartz-norite of a somewhat acid type for a member of the gabbro series. Plagioclase running from labradorite to andesine, but generally the former, makes up more than half the rock, sometimes almost two-thirds. Along the southern range the plagioclase is usually pale brown in color and slightly opaque, on the northern range clear and transparent; and the crystals are often well shaped with a tendency to platy forms. Quartz occurs as bluish grains and also as a wedge-shaped filling between the plagioclases; also to a varying degree as micropegmatite. In the latter case there may be appreciable amounts of orthoclase or microline. The dark minerals, when fresh, are mainly pyroxenes, the rhombic species, hypersthene or enstatite, being in largest amount, making perhaps a sixth of the rock; but monoclinic augite in the form of diallage is almost always present, and often a pleochroic augite precisely like the hypersthene, but with a distinct extinction angle, occurs also. The hypersthene is often in fairly well formed elongated crystals. There is often some hornblende even in very fresh sections, and this in some cases at least is primary. It may form solid rims about the pyroxenes. Brown biotite in quite large individuals is almost always found, though it makes only a small proportion of the rock. Titaniferous magnetite and apatite are always present, and often pyrrhotite or chalcopyrite where the specimen is taken from near an ore body, and the freshest specimens are usually found in that position. Dr. Barlow has found a small amount of olivine in one thin section from Little Stobie,[38] but this mineral has been found nowhere else except in a doubtful specimen from Gertrude.

The weathered norite, formerly called diorite, is much more common than the fresh, but in general appearance the two scarcely differ, though the fresh rock more often crumbles with boulder-like forms under exposure than the so-called weathered rock. The change from the fresh norite is due mainly to the re-arrangement of the pyroxenes to form fibrous hornblende or uralite or less often chlorite or serpentine, with some separation of iron oxides. The labradorite is apt to be fresh long after the hypersthene has disappeared. Weathering is less pronounced close to ore bodies than at a distance from them.

The norite blends gradually into micropegmatitic quartz diorite or syenite, coarse-grained and flesh-red on weathered surfaces, gray on fresh ones. The main difference is the increase in the amount of quartz intergrown with feldspar and the partial or complete absence of hypersthene or augite. Large grains of epidote are generally present.

This intermediate rock passes on the acid edge into quartz-diorite, granodiorite or granite containing large amounts of micropegmatite, sometimes three-fourths of the whole. The nucleus of the granophyre structure is almost always a plagioclase not far from andesine, and there is generally some orthoclase in addition to that included in the micropegmatite. The plagioclases are often plate-like. As dark minerals there are always hornblende, mica and magnetite, usually also epidote. The macroscopic appearance of the rock is often that of a medium or fine-grained syenite or granite, but it may take the form of gneiss, or felsite schist or of fine-grained green schist, though the composition does not greatly vary.

In order to show the changes from the basic to the acid side of the eruptive Prof. Walker has published several analyses of samples from the Blezard-Whitson lake cross section;[39] and to complete our knowledge of the subject several more analyses are added here. The finding of micropegmatite and microcline in fresh norite at the Creighton mine made it desirable to have an analysis of the rock (No. 2), and it was also thought well to know the composition of the green schistose rock of the acid edge at Fairbank lake (No. 8). The analyses are given in the following table:

—	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
SiO	56.89	60.15	49.90	51.52	68.48	64.85	61.93	68.95	69.27	67.76
Al_2O_3	19.39	18.28	16.82	19.77	12.70	11.44	13.03	12.74	12.56	14.00
Fe_2O_3	.38	1.51	....	.47	2.41	2.94	.56	.46	2.89	....
FeO	7.11	6.01	13.54	6.77	4.50	6.02	8.00	5.15	4.51	5.18
MgO	2.11	3.22	6.22	6.49	.74	1.60	1.76	1.57	.91	1.00
CaO	8.11	4.01	6.58	9.16	1.41	3.49	4.02	1.72	1.44	4.28
Na_2O	3.31	1.28	1.82	2.66	3.72	3.92	3.18	3.80	3.12	5.22
K_2O	1.04	1.68	2.25	.70	3.36	3.02	2.80	3.28	3.05	1.19
H_2O	1.35	.55	.76	1.68	1.13	.78	1.95	1.50	.76	1.01
TiO_2	.43	1.34	1.47	1.39	.61	....	.84	.48	.78	.46
P_2O_5	.11	.23	.17	.10	.20	.24	.32	.20	.06	.19
MnO	.30	.29	trace	trace	.05	trace	.18	.13	trace	trace
BaO	....	.25	....	....	....	....	trace	trace	....	....
LrO	....	.14	....	....	....	....	....	....	....	....
NiO	....	.17	....	....	....	....	....	....	....	....
Cu	....	.16	....	....	....	....	....	....	....	....
S	....	.54	....	....	....	....	.19	....	....	....
Total	100.58	99.79	99.08	99.71	99.31	98.30	98.76	99.93	99.85	100.29
Specific gravity	2.834		3.026	2.832	2.673	2.788	2.757	2.694	2.724	2.709

38 G. S. C., Vol. XIV, Part H, p. 83.
39 Quar. Jour. Geol. Soc. Lon., Vol. LIII, p. 56.

In the above table of results of analyses, No. 1 is from the basic edge of the northern range near Onaping, Mr. E. G. R. Ardagh, of the Chemical Department, School of Science, Toronto University, being the analyst. No. 2 is from the basic edge at the Creighton mine near the ore body, analyst Mr. M. T. Culbert of the School of Science. Nos. 3 and 4 are from the basic edge of the southern range near Blezard mine, analyst Dr. T. L. Walker. No. 5 is from a syenitic-looking specimen taken from near the middle of the Onaping section, analyst Mr. Ardagh. No. 6 is from near the middle of the Blezard-Whitson lake section, analyst Dr. Walker. No. 7 is from the acid edge of the Onaping section, the rock being greenish gray, analyst Mr. Ardagh. No. 8 is from near the acid edge on the north shore of Fairbank lake, the rock being dark green gray and somewhat schistose, analyst Mr. Ardagh. Nos. 9 and 10 are from points near the acid edge of the Blezard-Whitson lake section, Mr. C. B. Fox, chemist of the Hamilton Iron and Steel Company, being the analyst of No. 9, and Dr. Walker of No. 10.

The table is so arranged as to give first analyses from near the basic edge (Nos. 1, 2, 3 and 4), next analyses of specimens from near the middle of the eruptive (Nos. 5 and 6), and finally analyses from near the acid edge. The results disclose a larger amount of variation than might have been expected, especially on the basic side of the eruptive, the silica running from 49.90 to 60.15. It is possible, however, that No. 3 is not a typical example of the norite, since it contains so large an amount of ferrous oxide (13.54 per cent) as to suggest the presence of unusual amounts of iron ore, or of pyrrhotite. It is probable also that No. 2, from the Creighton mine, errs on the other side, containing more quartz, microcline and micropegmatite than the normal, though thin sections from other parts of the rock enclosing the Creighton ore body almost all show considerable amounts of these minerals.

The intermediate rocks from the middle of the eruptive seem to differ little from the examples taken from nearer the acid edge, having silica contents of 64.85 and 68.48 per cent., as compared with 61.93 to 69.27 per cent., or on the average 66.66 to 66.98.

An average of the first four analyses as representing the basic phase of the rock, and of the last six as representing the acid phase will give a fair idea of the amount of differentiation which has taken place in the cooling of the laccolithic sheet. It is possible, however, that in the case of No. 2 the norite absorbed some of the adjacent granitoid gneiss. At the actual contact of norite and gneiss there is sometimes a reaction rim a few inches wide of coarse pegmatite between the norite and the more acid rock. It may also be that No. 7, from the acid edge near Onaping, has become somewhat more basic than the normal by "overhand stoping" and absorption of the overlying tuff, since it is less acid than No. 5 from the middle of the section. However No. 2 may not more than counterbalance No. 3, which contains so large an amount of iron, and No. 7 will not greatly affect the average of the six examples of the acid phases.

	Basic Average.	Acid Average.	Average of whole eruptive.
	Per cent.	Per cent.	Per cent.
SiO_2	54.615	66.878	61.970
Al_2O_3	18.437	12.745	15.022
Fe_2O_3	.590	1.548	1.362
FeO	8.365	5.562	6.683
MgO	4.510	1.263	2.542
CaO	6.715	2.727	4.822
Na_2O	2.267	3.827	3.203
K_2O	1.417	2.787	2.239
H_2O	1.085	1.188	1.147
TiO_2	1.157	.502	.763
T_2O_5	.152	.202	.182
MnO	.122	.060	.065
Minor substances	.320	......	......
	99.752	99.279	99.500

In a general way about one-half of the southern edge of the laccolithic sheet is basic, while the basic portion of the northern range, including the Blue lake portion, is very much narrower, perhaps averaging not more than a quarter or even an eighth of the full width of the eruptive. An estimate of the relative areas of the basic and acid phases respectively gives about one part of basic rock to one and a half of acid rock. Accepting these proportions as approximately correct the average composition of the whole sheet is given in the third column above.

In this computation the pyrrhotite and chalcopyrite of the ore bodies have not been taken into account. Although 2,000,000 tons of ore have been mined and the amount of ore "in sight" may be reckoned at several millions more, it would be rash to attempt to estimate the total amount of sulphides originally contained by the magma, since we do not know how many millions of tons have been removed by erosion during the ages since the eruption, which took place not later than Cambrian times; nor do we know how much ore exists in the depths, as downwards continuations of known ore bodies or in ore bodies which do not reach the surface. However we can hardly assume that the sulphides existed to the amount of cubic miles, and the eruptive sheet still remaining after the vast period of erosion is estimated at 600 cubic miles, so that the sulphides in the total magma formed probably only a fraction of one per cent., and so are of relatively little account. Prof. Vogt speaks of the Sudbury gabbro as containing originally about 0.05 per cent., which may serve as a guess at the true proportion.[40]

According to the new classification of rocks the average composition of the basic, and acid phases work out as Harzose, and Adamellose. The norm for the basic and acid phases, and for the average rock is as follows:

		Basic.		Acid.		Average rock.	
Quartz		9.24		20.76		17.94	
Orthoclase		8.34		22.24		12.79	
Albite		19.39	51.92	31.06	37.73	27.25	47.27
Anorthite		32.53		6.67		20.02	
Diopside	$CaO \cdot SiO_2$	......		2.44		.22	
	$MgO \cdot SiO_2$	......		.70	3.99	.08	.46
	$FeO \cdot SiO_2$	......		.85		.16	
Hypersthene	$MgO \cdot SiO_2$	11.30	24.10	2.40	8.74	6.40	16.17
	$FeO \cdot SiO_2$	12.80		6.34		9.77	

Omitting unimportant ingredients, such as titanic iron ore, apatite and water, we see that the basic phase consists essentially of 52 per cent, of labradorite, 8 or 9 per cent. each of quartz and potash feldspar, and 24 per cent. of magnesia and iron silicates.

The rock of the more acid phase consists of 21 or 22 per cent. each of quartz and potash feldspar, 38 per cent. of oligoclase and 13 per cent. of magnesia-iron silicates.

The average of the whole eruptive, as represented in our analyses and weighted by taking two parts of acid to one of basic rock to correspond with the field relations, works out as Harzose of an acid kind.

The norm of the rocks worked out above corresponds fairly with the mode in the basic edge norite except that monoclinic augite replaces some hypersthene, and in the average acid phase of the eruptive hypersthene is largely replaced by hornblende.

Older Norite and Lavas

Associated with the basic edge for a number of miles along the southern nickel range, but evidently much older than the nickel eruptive, is a range of hills often high and rugged, which have been generally referred to and mapped as greenstones. Their extraordinary mixture of characters, including rocks such as norite, greenstone,

[40] Trans. Am. Inst. Min. Engineers, Vol. XXXI, 1901, Problems in the Geology of Ore Deposits, p. 129.

diorite porphyrite and amygdaloid, with some slaty graywacké undoubtedly of sedimentary origin, make it difficult to define the rocks as a whole. The frequent occurrence of "pillow structure," often with an amygdaloidal edge to the pillows, shows that at least a part of the series consists of lava flows.

The only rock which is at all fresh is the norite, which may now be described. Macroscopically and microscopically, it differs entirely from the nickel-bearing norite. It is usually very fine-grained and rather dark gray on fresh surfaces, and on weathered surfaces pale gray with numerous raised bands or narrow ridges of green, often in two or more directions, forming meshes. In some places the fine ground-mass contains hornblende crystals from a third to a half inch in diameter, which project from the weathered surface. Less often there are irregular white patches of about the same size along with the hornblende, giving a pale gray surface speckled with dark green and white blotches, suggesting a porphyrite. There are all transitions from the fresh gray norite through rocks half changed, to greenstones or hornblende porphyrites completely changed to green minerals, and it is probable from the field relations that part or all of the greenstones was originally norite.

Thin sections of the gray rock are usually surprisingly fresh in appearance except for narrow bands of green hornblende along minute fissures, and four minerals in small equi-dimensional grains or crowded crystals usually make up almost the whole of the rock, hypersthene or enstatite, a monoclinic augite, plagioclases (bytownite) and magnetite. Usually the two pyroxenes are very much alike, with strong outlines against the feldspars, pale brownish gray in color with faint greenish and reddish change of color or none at all, and a suggestion of crystal outline. Here as in so many other norites certain pleochroic sections, in general appearance exactly like the hypersthene, have a considerable angle of extinction from the cleavages or the edge of a prism, so that they are really monoclinic. It seems as if the hypersthene is merely a monoclinic pyroxene with 0° extinction angle, and with transitions to an unnamed monoclinic form of the same composition, but with large extinction angles. The rhombic variety of pyroxene is generally in largest amount, and the two pyroxenes make up as a rule more than half the section. The plagioclase is in short stout crystals with few twin planes, and in many cases the crystal form is fairly perfect. The magnetite makes up perhaps a twentieth of the whole rock.

Beside the ordinary even-textured variety of norite, or micro-norite, there are porphyritic ones in which a few large and generally elongated crystals of hypersthene or augite are embedded, and these may be poikilitic, including small grains of the feldspar. In other sections the porphyritic crystals are hornblende, green or brown, rough edged and always poikilitic, sometimes thickly crowded with clear feldspars. They may represent former augites, though this seems doubtful, since both minerals sometimes occur porphyritically in the same section. The magnetite is often in good crystal forms, the grains being relatively large. In most cases none of the minerals show a trace of weathering except as mentioned before, along thin seams where hornblende develops.

The rarer variety of micro-norite, which has white patches like porphyritic feldspars, shows the same composition as the others, the white areas being formed of labradorite in the same short stout crystals as elsewhere, but without pyroxene or magnetite. There are occasionally sections wholly or almost wholly composed of the plagioclases, so that there are varieties of rock having the same general character which might be named norite, gabbro (where monoclinic pyroxene outweighs the rhombic), and anorthosite, with norite porphyrite or hornblendic norite and rarely biotite norite.

Some of the green rocks associated with the gray ones seem to be merely the same rock weathered, secondary hornblende replacing pyroxene, but the short equi-diametered plagioclases remaining. In other cases, however, the greenstones consist mainly of fibrous hornblende with some magnetite, and occasionally quartz, but with little or no feldspar; where one cannot assume that they have descended from the norite.

The "pillows," if large, are sometimes formed of characteristic micro-norite in the middle and hornblendic material on the outside, the supposed amygdules consisting of about equal parts of plagioclase and unstriated feldspar, with a little quartz. The contents hardly seem characteristic for an amygdule, but the bomb or pillow form and the development of the white spots only near the outside of the mass and not in the middle may be taken as proof that they are really surface eruptives.

The hornblende porphyrite associated with the older norite is probably derived from it, though this is not always certain. Those which have a fine-grained ground-mass with minute crystals of plagioclase mixed with hornblende and large poikilitic crystals of hornblende enclosed are probably derived from the porphyritic variety of norite. Others with hornblende alone or with quartz instead of feldspar can hardly be accounted for in this way.

In addition to the very fine-grained older norites in the complex, there are some coarse-grained ones, gray with dark green and sometimes white mottlings, which look very different from those described, but sections show the same minerals only differently arranged. The plagioclase is in minute grains almost as if crushed, but the pyroxene is always in large irregularly-shaped poikilitic crystals. As it is mainly monoclinic the rock must be called gabbro. The dark green patches are of secondary-looking hornblende.

The older norite or the micro-norite as it has been named in this report must have antedated the nickel eruptive by a very long time, since the sedimentary series 10,000 feet thick was piled up on them before the irruption of the laccolithic sheet; yet they are so uniformly confined to a comparatively narrow band along the southern nickel range and a few points on the northern range that one cannot resist the idea that they came from the same hearth. They are, however, much more basic than the nickel range rock, since pyroxene generally makes up half their bulk, magnetite is present in considerable amounts, and quartz or potash feldspars scarcely occur. They are not known to contain nickel except where an ore body lies against them sending small stringers into the older rock.

An analysis of a typical specimen from near Murray mine has been made by Mr. J. A. Horton of the Chemical Department, School of Science, Toronto, with the following results:

	Per cent.
SiO_2	46.69
Al_2O_3	14.23
Fe_2O_3	2.00
FeO	12.82
MnO	.11
MgO	8.15
CaO	13.82
Na_2O	.98
P_2O_5	.19
TiO_2	1.28
Moisture	.08
Sulphur	.12
	99.97
Specific gravity	3.24

This corresponds normally to the following mineral composition:

	Per cent.
Bytownite	42.57
Diopside	25.73
Hypersthene	20.76
Olivine	5.34
Titanic Iron Ore	4.98
Apatite	.34
Pyrite	.27

The mode of the rock does not differ greatly from the norm. No olivine has been recognized, but a small amount may really be present, as the rock is very fine-grained, and part of what has been taken for augite is not unlike olivine in appearance. If I have worked it out correctly by the new system, it is a percalcic rock of the order Gallare, under the subclass Salfemone of the class Salfemane; and may be named Kedabekase.

It is curious that the sulphide commonly found in the older norite is pyrite and not pyrrhotite. In composition this rock comes much closer to the European norites with which pyrrhotite is associated than does the acid norite of the Sudbury nickel eruptive.[41]

NORITE OF THE INTERIOR BASIN

While the characteristic norite of the nickel eruptive is confined to the basic portion of the sheet, it is known that in one place at least norite of a somewhat different kind occurs near the acid edge, penetrating the basal conglomerate. At the southwest end of Trout lake in Bowell township, near a small zincblende deposit on location W D 252, a specimen of dark green rock weathering brown, taken as representing a part of the country rock, proves to consist of hypersthene, diallage and labradorite, the latter making less than half the section. There are also a very little interstitial quartz and still less micropegmatite. Some of the rather lath-shaped feldspars are of earlier crystallization than the hypersthene, but other parts are later. The feldspars, though decidedly fresh, are rather untransparent at the edges because of a brown coloration, the centres, which have a different extinction angle, being clear. The hypersthene seldom shows good crystals with elongated forms as it does in the basic edge norite. This norite was not distinguished from greenstone in the field, and no detailed work was done to define its boundaries or its relations to the nickel eruptive.

PERIDOTITE

Beside the comparatively basic older norites and greenstones in a few localities along the northern range still more basic rocks have been found as part of the country rock of ore bodies and are therefore probably older than the nickel eruptive. The freshest example is from test pits in Levack township about five miles north of Onaping, where a dark gray green fine-grained rock accompanies the ore. A thin section proves that the rock consists chiefly of olivine, more than half of which has been changed to serpentine and magnetite, which not only encloses the olivines but cuts across its crystals wherever fractures existed. There are in addition small quantities of augite and of brown biotite.

On location W D 155, in Bowell township, part of the rock beside the ore deposit is dark gray serpentine weathering rusty white. A thin section shows only a remnant of olivine and a few crystals of striated feldspar in the mass of serpentine and iron ores.

There is no direct evidence to show that the peridotites belong to the family of rocks connected with the nickel eruptive beyond the fact that they occur beside the basic edge.

LACCOLITHIC NORITE SOUTHEAST OF SUDBURY

An irregular mass of norite rising laccolithically to the east of Sudbury and extending several miles southwest from Ramsay lake to the north side of Kelly lake, has no apparent connection with the laccolithic sheet of the nickel-bearing rock and seems to be older than it, though this is not easy to prove positively, since it nowhere comes within three miles of the southern nickel range, with which it is roughly parallel. The last outcrop of the Copper Cliff offset, at Evans mine, is, however, only a quarter of a mile from its northwest side near Kelly lake, but there is so little likeness between the band of rock here described and the norite rich in ore of the offset that they probably have no direct relationship.

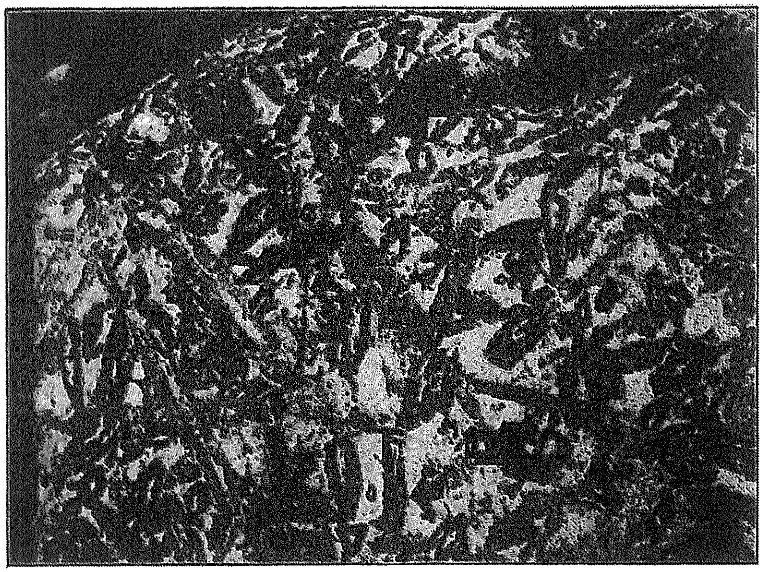
It may be that this irregular band, half a mile wide and more than seven miles long, is really the edge of a sheet, but if so there is no evidence of differentiation of the sheet into a lower, basic, edge and an upper, acid, edge as in the nickel eruptive.

[41] Zirkel, Petrographie, Bd. II, pp. 790-1-2.

The rock is commonly medium to coarse-grained, greenish gray, and so far weathered as to contain no remnants even of the original pyroxene. Only one of my thin sections, from a point on the hill east of Sudbury, is fresh enough to show that the rock is really norite, though of a somewhat different type from that of the "basic edge." It is never dark gray in color, does not contain blue blebs of quartz nor large biotite scales, and is never spotted with ore, like the nickel-bearing norite, though a little pyrrhotite has been found in it.

The freshest section consists to the extent of about one-half of labradorite, the pyroxenes making up the rest of the rock, diallage probably in slightly larger amounts, so that the rock should perhaps be called gabbro instead of norite. The rhombic pyroxene has an exceedingly pale dichroism, so that it is enstatite rather than hypersthene. There is very little magnetite, no apatite was observed, and quartz is almost absent. The sections of weathered rock have the pyroxene completely changed to pale green hornblende or sometimes partly to chlorite. A little quartz is occasionally found in interstices and rarely also micropegmatite.

The most interesting feature of this band of norite or gabbro is the immense white segregations which run irregularly along the hill tops and perhaps represent the acid phase of the nickel eruptive though in much smaller proportion. Similar but much



Hill east of Sudbury; concretionary structure in gabbro.

smaller formations are found along the basic edge of the main nickel range near Elsie and Murray mines, but there the differentiation is much less complete, never resulting in large masses of solid quartz in the middle.

Very good illustrations of these segregations are found on the hills just east of Sudbury and at the quartz mine south of Copper Cliff, from which already hundreds of tons of quartz have been taken. At the latter point the width of the segregations is about 100 yards and the somewhat discontinuous row of white outcrops is at least half a mile long.

The ordinary gray green gabbro passes rapidly into a darker green band much coarser in texture and containing little feldspar. The cleavages of the hornblende are often curved or twisted. Then there is a band of mixed hornblende and white feldspar in very large crystals, the hornblende often as prisms several inches long, the centre of the prism being filled with white feldspar. Next comes a considerable width of white binary granite, very large-grained, and also graphic granite, the quartz often in larger quantity than the feldspar. At the centre of the large segregations there may be fifty feet of almost pure glassy quartz. With the inner white parts of the mass there are frequently sulphides, pyrrhotite especially, but never in workable amounts.

Thin sections representative of these exceedingly coarse rocks are hard to make, since a single section may be all of one material. The hornblende is secondary-looking and rather pale green, not far from actinolite; the white minerals are plagioclase (oligoclase towards albite), orthoclase (or at least an unstriated feldspar), and quartz, the latter often in comparatively wide bands in the feldspar, causing the graphic structure. A very little muscovite occurs also. Different parts of the mass might be called amphibolite, malchite, acid anorthosite, binary granite, pegmatite and vein quartz.

These curious masses of coarse white minerals much richer in alkalies and silica than the average rock, but cut off from it by the ring of hornblende, probably represent the last remnants of the magma, accumulated and consolidated in the centre of the band after the outer parts had already taken shape; resembling in origin the coarse pegmatite dikes which end an eruption of deep seated granite, but without the outlet into fissures which the hot pegmatite solution finds for itself.

It is possible, however, that the apparent segregations are really large masses of quartzite or arkose incompletely digested by the gabbro.

GRANITES ASSOCIATED WITH THE NICKEL ERUPTIVE

Beside the granite and granitoid gneiss of the Laurentian, which are much older than the sheet of nickel eruptive and underlie it, there are coarse and medium-grained granite and granitoid gneiss, probably not very different in age from the nickel eruptive, but sometimes a little older and sometimes younger. As they occur in bands parallel to the southern nickel range and at no great distance from it, they may be supposed to have some connection with the nickel rock in origin, perhaps having segregated from the same magma before or after the magma of the laccolithic sheet reached its present position. The coarse-textured granitoid gneiss, often porphyritic, is in my opinion generally older than the nickel rock, but is younger than the micro-norite described above, since it has swept off masses of greenstone and green schist supposed to be derived from them.

The granitoid gneisses are best shown along the railway between North Star and Creighton mines, where they are coarse in texture with porphyritic flesh-colored orthoclases sometimes an inch in length crowded together with an equal amount of gray finer-grained ground-mass. Thin sections show an ordinary hornblende granite, consisting of quartz, orthoclase, microperthite, a little plagioclase, much hornblende and a little biotite. There is no micropegmatite in the sections studied. The porphyritic crystals are orthoclase, sometimes a little crushed at the edges. While micropegmatite seems absent from the normal rock there is a reaction rim an inch or two wide at the contact of norite with this granite in the Creighton open pit, which shows coarse pegmatitic intergrowths, forming crystals often more than an inch in diameter. As the norite at this mine contains appreciable amounts of micropegmatite, such a reaction rim is not surprising.

The rock just described passes by gradations into a darker gray rock with much more hornblende and less quartz, which should be called syenite.

Near Copper Cliff there is a porphyritic granitoid gneiss, paler in color and with smaller phenocrysts, which has been used as building stone in the town. It contains more quartz than the Creighton rock, and little or no hornblende, but biotite in small quantities. The feldspar is mainly microcline, but there is some orthoclase and oligoclase.

Similar gneiss has been collected from other places, but has not been studied in thin sections.

While the coarse granitic rocks are generally older than the norite, there is a medium-grained flesh-red granite covering considerable areas from near Elsie to Little Stobie, which is undoubtedly later in age, since it penetrates the edge of the norite at Murray mine. The rock is normal granite with much quartz and microcline, some microperthite and orthoclase, a little oligoclase, a small amount of biotite and still less muscovite. No micropegmatite was observed.

As this granite occurs close to both the nickel eruptive and the older norite it is probably a later member of the same family of rocks. An analysis by Mr. James Horton gives the following results:

	Per cent.
SiO_2	75.62
Al_2O_3	11.02
Fe_2O_3	3.17
FeO	1.29
MgO	.12
MnO	.26
CaO	.58
K_2O	5.33
Na_2O	3.11
TiO_2	.16
H_2O	.10
	100.76

Specific gravity, 2.59.

It is evidently a quite acid granite. Calculating the normal minerals for the chemical composition we find the following:

	Per cent.
Quartz	35.76
Orthoclase	31.14
Albite	26.20
Anorthite	3.06
Hypersthene	.62
Ferric oxide	.63

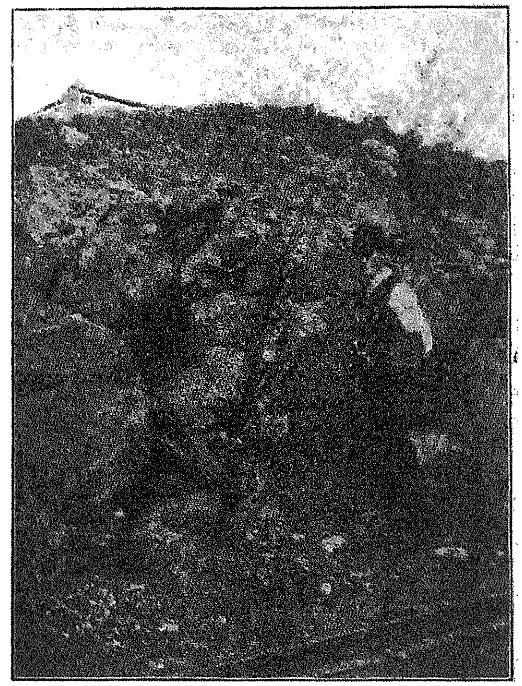
Probably part of the sodium belongs to the orthoclase, since the extinction angles of the plagioclase correspond to oligoclase and not to albite. According to the new system the rock may be called Omeoze, a dopotassic, peralkalic rock belonging to the order Britannare, but near the boundary of Columbare. It is the most acid of the rocks supposed to have sprung from the hearth of the nickel-bearing eruptive.

GRANITE FROM DIKES

Several dikes of granite near Copper Cliff are evidently later than the norite, since they cut the nickel rock. They are gray, and consist mainly of quartz, orthoclase and oligoclase with some biotite and muscovite. A few masses of flesh-colored granite enclosed in norite, probably as dikes, northwest of Murray mine and of Little Stobie are of much the same character.

As small dikes in larger dikes of diabase, a grayish fine-grained granite forms the latest rock in the region, perhaps a last upflow of the original magma from which the eruptives described above had their origin. It consists essentially of quartz and orthoclase with a little oligoclase, the only dark mineral being biotite, which in two out of three sections is changed to chlorite. Except for the slightly porphyritic habit of a few feldspar crystals, there is little to mark this as a dike rock.

It is surprising to find all the granites associated with the nickel eruptive, representing as they do at least three ages, so very different from the acid edge of the eruptive itself. The latter almost always consists to the extent of more than one-half of micropegmatite, the feldspar being orthoclase with a larger amount of plagioclase; while the other granitic rocks never have a micropegmatitic structure except for an inch or two in contact with the norite at a few of the mines. The granites have always a much larger amount of potash than of soda feldspars also, which makes another point of contrast. It is clear that they are not direct derivatives of the nickel eruptive magma, though they probably originated in the same source at earlier or later times.



Granite dike in diabase, west of Sudbury.

DIABASE

Except for the few small dikes of granite which cut them, diabase is the youngest rocks of the Sudbury district, cutting all the others as dikes. The dikes are numerous and generally contain very fresh material, which, however, very readily weathers into spheroidal forms. Professor Walker[42] and Dr. Barlow[43] have paid considerable attention to these handsome rocks, the former having analysed a specimen, and the latter having mapped a number of the dikes near Sudbury. Some of the dikes are very porphyritic, containing tabular plagioclase crystals of all sizes up to a square inch in area, but other dikes near by are not porphyritic. The larger dikes are very fine-grained at the edge and gradually become coarse-grained in the middle; and where the dikes cut ore, as at the Creighton mine, their edges may be chilled so far as to become glassy. In the ore there are curious boulder-like projections from the dikes, as if occupying rounded cavities in connection with the fissure filled by the diabase.

[42] Quar. Jour. Geol. Soc. Vol. LIII, pp. 62-65.
[43] Geol. Sur. Can. Vols. XIV, Part H, pp. 90-92.

There are probably diabase dikes of two ages in the region, one the exceedingly fresh rock just referred to, and a less numerous class, now greatly weathered, the porphyritic dikes belonging to the first class. The coarser parts of the dikes consist of plagioclase (labradorite), at least one-half, lilac or reddish brown augite a quarter, olivine one-fifth, and biotite, magnetite and apatite for the rest. The plagioclase is distinctly ophitic and often imbedded in the augite or even the olivine. The order of succession is magnetite and apatite, olivine with plagioclase partly overlapping it, plagioclase, augite; all the other minerals being sometimes enclosed in the last mineral.

In smaller dikes or near the edge of larger ones, plate-like phenocrysts of plagioclase are enclosed in a fine-grained ophitic ground-mass of the minerals named above; and at the edge of dikes against ore the porphyritic crystals of plagioclase and also of augite are contained in a glassy basis pierced in every direction by minute plagioclases. Many of the larger laths of the second crop of plagioclase have narrow inclusions of glass in the centre.

The type just described is best displayed at Creighton mine, but the coarser-grained varieties are widely spread in the region.

The dikes which are thought to be older may occur with the other ones, but it has not been proved that the others cut them. They are not porphyritic, are less ophitic than the fresh diabases, and the augite and olivine, if any of the latter mineral existed, are completely changed to secondary hornblende, magnetite and leucoxene. There is present also a little quartz, which is entirely absent from the fresher rock.

The results of an analysis of fresh olivine diabase from a dike near Murray mine is given as follows by Prof. Walker:

	Per cent.
SiO_2	47.22
Al_2O_3	15.52
Fe_2O_3	3.32
FeO	12.40
MgO	8.33
CaO	9.61
Na_2O	3.40
K_2O	.67
H_2O	.80
TiO_2	3.62
P_2O_5	.33
MnO	.04
BaO	.01
CuO	trace.
NiO	.0275
CoO	.0055
Total	100.803
Specific gravity	3.01

The analysis shows that the rock is very basic, much more so than the nickel-bearing norite, but that it contains only a little nickel. The large amount of titanium accounts for the peculiar lilac or reddish color of the augite.

Whether the diabase is to be looked on as almost the last member of the succession of segregations from the great nickel-bearing magma is not certain. Dr. Barlow suggests that the weathered diabase containing some quartz near Copper Cliff is connected with the norite of the eruptive. These dikes are undoubtedly later than the norite, which they cut sharply across, but they may belong to the succession. The fresh olivine diabase seems to me more probably distinct from the main hearth, since very similar olivine diabase porphyrite occurs as dikes at various places to the west, e.g. north of Lake Superior, where no connection with any nickel eruptive can be assumed. Exactly why such similar dike rocks should have been erupted from point to point along a distance of hundreds of miles is hard to explain. The western dikes are generally supposed to have a connection with volcanic activity during Keweenawan times, when they penetrated the Animikie and lower rocks, and it is not improbable that the fresh Sudbury olivine diabases are of the same age and conected with similar phenomena.

It should be mentioned that olivine diabase is not confined to well defined dikes in the Sudbury region, though that is its commonest mode of occurrence. On the south half as lot 11, con. VI, of Denison township an irregular mass of fresh olivine diabase spreads out as hills to the width of 1,200 feet, cutting across the Worthington nickel-bearing offset, forming a boss instead of a dike, or possibly resembling on a small scale the Logan sills of olivine diabase in the Animikie near Port Arthur.

Petrography of the Sedimentary Rocks

LOWER HURONIAN SEDIMENTS

As mentioned previously the oldest rocks in the region are sediments belonging to the iron formation, which occur a short distance north of the northern nickel range near Clear lake in the northern part of Wisner township, near the outlet of Wahnapitae river in the lake of the same name, and to a much larger extent in Hutton and other townships several miles to the northward. These sedimentary rocks, consisting of granular silica or jasper interbanded with magnetite, are interfolded with greenstones and green schists. As they have been described in former reports of the Bureau of Mines, they will not be further discussed here except to state that they belong to the upper part of the Keewatin of the latest classification (Lower Huronian of previous reports of the Bureau).[44]

The oldest rocks in contact with the nickel ranges belong to the next formation above, now called the Lower Huronian, including arkose, quartzite, graywacké and slate, older than the Laurentian and underlying the nickel-bearing sheet. Their petrography has been touched on by several writers, Prof. T. G. Bonney[45] and Prof. G. H. Williams[46] being probably the earliest, followed by Prof. Walker in his Inaugural Dissertation (1897), the present writer in various reports of the Bureau of Mines, and Dr. Barlow in his report on the Sudbury mining district in 1904.

Bonney is greatly puzzled with these rocks, which he hurriedly visited soon after the Canadian Pacific railway reached the locality. In reality it is clear from his account that he has confused two or three distinct series in his work, and naturally had difficulty in harmonizing matters. He is inclined to think the quartzitic rocks sedimentary, but finds them so completely re-crystallized that they might be granite. He refers to the numerous crush breccias, but seems not to distinguish them from true conglomerates.

Williams describes a number of sections of quartzite or arkose near Copper Cliff and elsewhere, but hesitates whether to call them clastics or felsites, which is not surprising when his material consisted only of small specimens with no assistance from the field relations.

Dr. Barlow gives a good description of the microscopic characters of these rocks and admits that some of them are altered sandstones, but thinks the larger part were volcanic ash.

In my own opinion the major part of them are water-formed sediments, sandstone or arkose, largely re-crystallized, the materials being of eruptive origin, though not as ash, but as derived from granitic rocks by ordinary clastic methods.

Part of these rocks are pale flesh-colored and very fine-grained, having the look of felsite and presenting little evidence of bedding; though they are associated with beautifully stratified rocks and seem at times to pass by transitions into them. The rocks near Copper Cliff, which have sometimes been taken for felsite or syenite, are good examples of the variety showing hardly any bedding.

Sections consist of completely interlocking grains of quartz, orthoclase, microcline and a little plagioclase. There is seldom a hint of waterworn fragments, though occasionally the centre of a grain is a little cloudy. Regeneration has gone to the extreme,

[44] Bur. Mines, Ont., 1903, pp. 318-321; also 1904, pp. 216-221.
[45] Jour. Geol. Soc., London, Vol. 44, 1888, pp. 32-44.
[46] Geol. Sur. Can., 1890, Appendix I, Part F, pp. 65-82.

and sections have quite the look of a fine-grained granite. There are, however, small dirty particles that do not seem to belong to a granitic rock. Occasionally large grains are bedded in the finer matrix with a suggestion of porphyritic structure, but they have no crystal outlines and are generally composite. In more highly metamorphosed parts long blades of green hornblende are developed, suggesting a variety of coarse syenite. Thin sections show the hornblende to be in very imperfectly formed crystals.

Specimens from points between Copper Cliff and Sudbury have more of a granular arrangement than near Copper Cliff, with fine debris between the grains, and are banded with finer and coarser layers and seem to contain minute rounded pebbles slightly different from the ground-mass. In addition to granules of quartz and feldspar, epidote and a considerable amount of biotite in minute scales can be determined.

Specimens taken from between Stobie and Blezard mines are formed of interlocking grains of quartz, orthoclase, a little microcline and a little oligoclase. There are a few shreds of hornblende also and a little of a dark mineral, probably magnetite.

On the whole these flesh-colored re-crystallized arkoses are very unsatisfactory rocks to study, and they pass into rocks so completely re-arranged that they might properly be called re-composed granites, applying the term used by Dr. Barlow.

On the other hand, there are transitions to pure quartzites in which feldspar is almost absent and only quartz and some scales of chlorite or biotite with a little indefinable dirty-looking material can be distinguished. Good examples of the last variety are found on the hill near Headquarters, in Garson township.

There are also transitions to graywacké, in which the muddy materials containing fragments of quartz and feldspar are to an extent re-crystallized into chlorite.

GRAYWACKE

The other main type of Lower Huronian sediments has been referred to in previous parts of this report as graywacké, though it includes also impure quartzite and slaty varieties, interbedded with the graywacké. These rocks are fine-grained, never flesh-colored, but always some tone of light or dark gray, and in hand specimens are often so uniform in appearance that they might be taken for a fine-grained basic eruptive. Weathered surfaces are lighter gray and disclose structures evidently water-formed. On glaciated parts the more quartzose layers retain their smoothness, but the softer layers of a somewhat slaty character may be deeply attacked, bringing out sharply the bedding of the original sandstone, sometimes also cross bedding and cross sections of ripple marks. Still more common are the pseudomorphs after silicates rich in alumina, such as staurolite, whose outlines are often very distinct and of all dimensions from a grain of rice, in the so-called "rice rock," to forms five inches long. In many cases the pseudomorphs are pale gray or even white and stand out strikingly from the darker tone of the rock. Specially good examples of these pseudomorphs are found near Stobie and Frood mines.

Thin sections of these rocks show much the same minerals as are found in the arkose, but generally more quartz and always more of the micaceous minerals, sericite (or talc), chlorite, and biotite, as well as indefinable somewhat opaque materials. The shapes of the original sand grains are often distinct. In the same section there may be coarsely granular quartz with dusty materials between, and finer-grained layers of minute grains of quartz and feldspar confusedly mixed with sericite and chloritic scales.

The pseudomorphs are often of nearly pure finely granular quartz, but sometimes of sericite or chlorite. No trace has been found of the unchanged staurolite, though the six-sided cross sections and St. Andrew's cross twins are conclusive as to the original mineral. As this is a mineral usually formed in slaty rocks near an eruptive contact, we may suppose that the slaty graywacké was locally metamorphosed by adjoining gabbro or norite masses, or perhaps in some cases by bands of granite.

Parallel with the graywacké having porphyritic pseudomorphs after staurolite near Frood and Stobie mines is a band of graywacké of a coarser texture, seemingly made of obscure fragments of rock with concretions of paler color scattered through it, and containing large oval or eye and eyebrow-like masses of quartzite. There seem to be gradations between the apparent concretions and the larger quartzite masses. The latter are as well rounded as pebbles, but generally have a concave hemispherical slice shifted half an inch away from them, in cross section showing a large oval eye and crescent-shaped eyebrow. The cause of these curious shapes is not known.

Thin sections of the graywacké consist of quartz, orthoclase, microperthite, much biotite, and some epidote, mostly as completely interlocking crystals. The vague pebble-like or concretionary forms seen on weathered surfaces differ from the matrix only in a slightly different size of the grains and a less amount of biotite. The "eyes" are of quartzite with sharp margins.

A section of graywacké with rather distinct concretions but no "eyes," consists of the same minerals, the vaguely edged concretions having finer-grained materials and less of the dark minerals.

This rather narrow band of rocks has more of the feldspars than the graywacké described before, and is somewhat more completely re-crystallized, perhaps because nearer to eruptive rocks. Whether they are related to the singular hornblendic rocks containing crowded pea or bean-like white spots is uncertain; the different composition of the latter seems to set them apart. Beside the graywacké containing pseudomorphs or concretions there are near Frood mine mica schist and fine gray gneiss that probably present a still more completely re-arranged sediment, in which no water-formed structure remains. They consist of quartz with small amounts of clear feldspar, muscovite, biotite, chlorite and a little magnetite, the grains interlocking and showing no evidence of rounding by water.

GRAYWACKE CONGLOMERATE

Near Ramsay lake and at some other points in the region there is graywacké of a different kind from the rocks hitherto mentioned, with no marked stratification, but occasional angular or rounded pebbles or boulders, of more than one sort of rock, especially a reddish granite with very little in the way of dark minerals, and quartzite of different varieties. Near a small lake north of Ramsay lake fragments of the well stratified graywacké described on a former page occur in this rock near its margin, but they may have reached their place by faulting. On the shore of Ramsay lake a small promontory consists largely of a crowded conglomerate of the rocks mentioned with the stratified graywacké overlying it, as if a basal conglomerate had been overturned, but the evidence is not clear.

Since the graywacké conglomerate contains quartzite very like some of those which have been described as belonging to the Lower Huronian, it must be considered later in age, but the real relationships of the two rocks cannot be settled positively at present.

The ground-mass of the conglomerate is very dark gray on fresh surfaces, and shows small broken grains of quartz or of fine-grained quartzite. Thin sections contain fragments of quartz, angular or well rounded, of various sizes, embedded in a ground of much finer particles of quartz and perhaps feldspar with minute scales of brown biotite. The quartz grains are generally of a single crystal, though some are compound. Less numerous than the quartz grains are small fragments of plagioclase (oligoclase) and orthoclase or of felsite or quartzless porphyry. No marked amount of re-crystallization is to be seen except for the tiny scales of mica thickly scattered through the feldspar and felsite.

In macroscopic appearance the rock is more like boulder clay than anything else among modern rocks, and the microscopic characters do not conflict with this idea; but it might be rash to assume glacial action so early in the world's history.

THE TROUT LAKE CONGLOMERATE

The rock mapped as the Trout lake conglomerate, which is older than the nickel eruptive, but much younger than the previous sediments, lies between the acid edge of the eruptive and the Onaping tuff, and in a sense is intermediate between them, the lower part being so changed by the presence of the eruptive during its long period of cooling as to resemble it closely, being distinguished often only by the presence of coarser-grained and redder patches with vague edges, which were pebbles or boulders of granite. In the upward direction the conglomerate may contain thin bands of white quartzite, gray chert or a green gray fine-grained rock; but finally passes into gray, fine-grained, crystalline-looking rock, containing angular or rounded fragments of chert and less often pebbles or boulders of granite and quartzite. This has no sharp boundaries separating it from the dark gray vitrophyre tuff.

The whole of the different phases mentioned above are considered to be ordinary water-formed sediments with little or no volcanic matter, but greatly modified by solutions coming from the laccolithic sheet beneath.

Where typically developed, but somewhat rolled out, the base of the conglomerate suggests certain Laurentian gneisses, being generally flesh-colored or gray with some parallelism of structure, the matrix like a fine-grained gneiss, the flattened boulders having a coarser grain and sometimes porphyritic feldspars. This phase soon passes into a fine-grained, somewhat speckled green gray rock with numerous flesh-colored or paler gray inclusions, the whole having the look of a variety of the Keewatin agglomerate of Rainy lake.

The less altered conglomerate has generally a darker gray fine-grained matrix and boulders or pebbles of lighter colored rocks with well defined outlines.

Thin sections of the matrix of the conglomerate near the acid edge of the eruptive have quite the appearance of a massive rock of the same composition as the acid edge itself, but with little or none of the micropegmatitic structure so characteristic of that rock. In fact every transition can be found between micropegmatitic grano-diorite of the typical acid edge and the matrix of the conglomerate, containing undoubted but vaguely edged granite boulders, so that the boundary between the eruptive and the sedimentary rock is no more sharp in thin sections than in the field.

At the very edge of the acid phase of the eruptive there are often small flesh-colored areas with a number of green epidote crystals and sometimes a space unfilled, and these patches are found also in the more altered phase of the conglomerate. Good instances of the transition are seen near Joe's lake. A specimen of gray fine-grained rock containing a pink granite pebble taken from near the eruptive edge at the outlet consists of quartz, orthoclase and much plagioclase in long strips with a little chlorite. The quartz is mostly granular, but partly in rude micropegmatitic intergrowth with feldspar, and in general appearance under the microscope the rock can be matched with specimens from the eruptive, and would be classed with it but for the enclosed granite pebbles.

A section from a sample taken 100 yards from the eruptive edge, containing a fine-grained granite pebble and numerous fragments of pale flesh-red and of green rocks, is much like the last one except that it is finer-grained and has a few large crystals of green epidote. At 180 yards the characteristic dark grayish tuff occurs, crowded with glass fragments.

A series of specimens taken from south of Moose lake shows more variety. The acid edge is coarse and reddish gray, with patches of red enclosing green epidote or small vugs with epidote crystals, and is made up to the extent of more than one-half of very elaborate micropegmatite about plagioclase crystals. Forty paces south there is undoubted conglomerate with granitic boulders in a matrix of the same minerals as the acid phase of the eruptive, but with only rough intergrowth of quartz and feldspar, and with numerous patches of greatly weathered orthoclase. Forty paces farther south there is a band of white quartzite or arkose about 60 feet wide, consisting of greatly crushed quartz and feldspar. One hundred and fifty paces from the edge the rock is fine-grained, bluish-gray, and contains pebbles of granite and quartzite with indistinct edges, one flesh-colored pebble enclosing green epidote. A thin section of the matrix might easily be taken for the acid eruptive, being made up of the same minerals, with micro-

pegmatite developed to various degrees, sometimes very elaborately, at others only hinted at by a rough intermixture of quartz with feldspar or by a tendency of the quartz to grow out with rounded projections into the other minerals.

The next specimen , 180 paces from the acid edge, is much like the one just described, but a thin section shows no micropegmatite, though the curious growth of the quartz in bunchy masses is more pronounced than in the former, and feldspar is present in less amount.

The next specimen is of a quite different kind, bluish gray and cherty in appearance with many angular fragments of whiter cherty fragments, proving in thin sections to consist of quartz with innumerable tiny crystals of epidote. This rock, 200 paces from the acid edge, is thought to belong to the overlying tuff rather than to the conglomerate.

A specimen of conglomerate near the acid edge at Onaping is much less granitic looking and in thin sections shows no resemblance to the acid phase of the eruptive, consisting of quartz and feldspar blending into one another with chlorite scales and often radiating bundles of actinolite. This matrix encloses grains of quartz and some angular fragments of a rock like very fine-grained quartzite.

A good series of specimens of the conglomerate comes from south of Windy lake, where the band is wide, and resembles that from Joe's lake, but thin sections of them have not been made. Another interesting collection comes from a small lake near the middle of Trill township, comprising arkose and a cherty rock as well as conglomerate. A section of the last rock is made up of quartz, orthoclase, epidote and chlorite, with embedded fragments of quartzite, and does not resemble the acid eruptive.

Specimens of schistose conglomerate from the north shore of Whitewater lake have numerous pebbles of granite and quartzite, and a few of green schist in a fine-grained gneissoid ground-mass, too much sheared or squeezed to show original structures.

In a general way it may be stated that the Trout lake conglomerate has been greatly metamorphosed near the acid edge of the nickel eruptive, the process often going so far that the matrix, probably arkose in the beginning, is completely re-crystallized into a rock containng the minerals of the acid eruptive, even the micropegmatite structure being produced to some extent. The enclosed pebbles, being of crystalline rock such as granite and quartzite, have undergone less change, but their boundaries have been blended with the matrix to a considerable degree.

THE ONAPING TUFF

No rock in the Sudbury district except the nickel-bearing eruptive itself has attracted more attention than the tuff (or vitrophyre tuff) which runs as a range of hills round the outer edge of the basin with the conglomerate between it and the acid edge of the eruptive. This rock appears to have been noticed first by Prof. Bonney at the High falls of the Onaping, being described as a "fragmental rock like a volcanic ash. . . . . The finer matrix is almost opaque, a very dark dust; the smaller fragments are quartz (not abundant) and altered feldspar or devitrified glass. The larger have probably been a moderately acid glass, sometimes vesicular. . . . . The zonal arrangement of some of the evitrification-structures suggests that the changes have taken place *in situ*."[47]

Dr. Bell was struck with the rock and sent specimens to Prof. G. H. Williams, who gave an excellent description of their microscopic characters, with an illustration, naming the rock vitrophyre tuff.[48] He found the ingredients to be mainly glass fragments, now largey silicified. The present writer, having a larger amount of material, added a number of substances, largely clastic, to the list contained by the tuff;[49] and Prof. Walker and Dr. Barlow have described them in their reports on the region, the latter quoting Williams' account of them.[50]

[47] Quar. Jour. Geol. Soc., London, 1888, Vol. 44, p. 40.
[48] Geol. Sur. Can., 1890, pp. 74 and 5 F.
[49] Bur. Mines, 1903, p. 291; also Can. Rec. Sc., 1893, p. 344.
[50] Geol. Sur. Can., 1904, p. 73 H

The rock is very dark gray and compact with many specks and angular fragments of paler material and also of pyrrhotite. It weathers to brownish and whitish surfaces which are very rough, since some of the glass fragments weather out sooner than the matrix. Here and there pebbles or boulders of red granite and of gray quartzite occur in the tuff, and also blocks of a grayish cherty rock, which takes a streak from steel, but which sometimes weathers in a way unlike chert. No bedding has been observed by me, though the well rounded pebbles enclosed suggest strongly that the ash was deposited in a body of water. Prof. Walker has noticed stratification, however, near Whitson lake.

The rock breaks with a conchoidal fracture and is very hard and brittle, many of the included fragments being changed to chalcedony, and as Bonney notices, having occasionally a concentric arrangement due to water action since the rock was formed.

In thin sections angular fragments of different sizes are crowded together with a small amount of almost opaque material between. The sharp-edged splinters and fragments of glass are very striking, some showing fluidal structure, others apparently pumice or slaggy glass with round or oval inclusions now filled with green serpentine, while the clear parts are chalcedony. Some of the fragments consist entirely of serpentine, others entirely of chalcedony, and still others of chalcedony on the outside and serpentine in the middle. There are also fragments with chalcedony on the outside and crowded epidote crystals in the middle, the latter mineral occurring also as radiating forms in round masses like tiny amygdules. Beside the glass sherds, now completely devitrified, there are fragments of quartz and less often of feldspar, both striated and unstriated, some fibrous hornblende, and also calcite or some other carbonate, either as single individuals or as composite masses. The carbonates may be products of re-arrangement of some volcanic rock, and all the other substances mentioned may be of eruptive origin; but the small pebbles of quartzite and of fine-grained granite must be clastic materials, and the same is true of the large masses of the same rocks enclosed as rounded boulders in the tuff. The source of the blocks of cherty rock in the tuff is not clear unless they come from cherty developments near the top of the next lower series, the Trout lake conglomerate.

The best examples of vitrophyre tuff in my collection come from Onaping, near Trout lake in Bowell township, and the southern part of Wisner township. Good examples are found also north of Whitson lake, where Prof. Walker obtained the example which he analyzed with the following results:[51]

SiO_2	59.93
Al_2O_3	12.12
FeO	10.56
MgO	5.19
CaO	4.49
Na_2O	3.80
K_2O	.97
MnO	trace
Loss by ignition	1.57
Total	98.63

A partial analysis of the rock from Onaping, by Dr. Hoffman gives 60.23 per cent. of silica, which does not differ greatly from 59.93.

The dark gray or black variety of tuff described above passes downwards into a paler gray rock with lighter fragments scattered through it, the lighter portions sometimes containing darker streaks and spots. The edges of the included fragments are not quite as sharp as in the variety described above, but in the earlier stages the main difference to be seen under the microscope is the loss of the dark coloring of the matrix and the disappearance of the smaller chips of glass, the larger one still showing their flow structure, etc., and consisting of serpentine and chalcedony.

Still nearer the conglomerate, at Moose lake, sections of the gray rock show fewer structures which can be referred to devitrified glass fragments, and the whole rock is

[51] Quar. Jour. Geol. Soc., Vol. 53, p. 45.

changed to chalcedony or a mosaic of crystalline quartz with much epidote and some chlorite or mica. Evidently the change is due to proximity of the acid edge of the nickel eruptive, which at this stage is only a few hundred or a thousand feet away. Very similar changes are seen at Onaping but no thin sections of them have been studied.

On the opposite side the vitrophyre tuff passes into slaty phases, black, with paler and also darker flakes, probably representing flattened fragments of some kind, perhaps volcanic. Occasionally there is a small grain of quartzite also. The slaty cleavage, while distinct, gives rather rough surfaces unlike those of the Onwatin slate into which this rock grades.

Thin sections show plainly that the slaty rock is related to the tuff, since there is a black, almost opaque ground with many light-colored angular fragments of glass changed to serpentine and chalcedony, sometimes perlitic, but there are many specks and larger areas of carbonates, and pyrite crystals, often with chalcedony radiating from them. The black coloring matter seems to be carbon as in the slate, and is confined to rounded flakes too opaque for determination. It is surprising to see so little crushing or stretching of the glass sherds in a rock showing such marked slaty cleavage.

In general the slaty tuff contains more of the ordinary clastic sedimentary material than the harder variety, such as grains of quartz and of a dolomitic rock, both of which are present in large numbers, as well as the carbonaceous flakes mentioned above. In fact, the glass fragments form less than half the rock, which is really a transition toward the slate.

THE ONWATIN SLATE

The black slate into which the slaty variety of tuff merges is free from visible fragments of any kind, compact in appearance and very cleavable, the cleavages crossing the stratification, as shown by slight dfferences in texture. The surface weathers gray owing to the slow oxidation of the carbon which gives the black color to the fresh rock. Near Vermilion lake there has been a great deal of faulting and slickensiding in places, and here the polished surfaces have the feeling of graphite and soil the fingers; the color, however, is darker than that of graphite. Thin slivers turn pale gray when held in a flame and lose several per cent. of their weight, while a specimen analysed by Dr. Ellis contained 6.8 per cent. of carbon. If the carbon is estimated at 5 per cent. of the Onwatin slate, which has a thickness of 3,700 feet, the total amount is 460,000,000 tons per square mile. The area of slate is about 140 square miles, and it would be a very respectable coal field which should contain as much fuel as this sheet of slate. It is probable that the carbonaceous matter was originally of a bituminous kind, since the vein of anthraxolite mentioned in a previous chapter could only have been formed in that way.

Thin sections are not very satisfactory, since they are untransparent unless exceedingly thin. The minerals recognized are quartz, sericite, chlorite and the dark colored, opaque, carbonaceous matter. No rutile needles have been observed.

THE CHELMSFORD SANDSTONE

Overlying the slate and to a slight extent interbedded with it is the gray sandstone or arkose rising as anticlinal hills in the centre of the basin. The rock is monotonous in color and in compositon, but in places contains a vast number of concretions from a few inches to three or four feet in longest diameter, with half that width. Except that the concretions weather more quickly than the surrounding rock and form oval, somewhat rusty depressions, the surfaces of the outcrops are singularly uniform. To the naked eye the composition of the rock is not evident, except that grains of quartz and sometimes feldspar cleavages and scales of mica are visible in the coarsest parts, where in rare instances small pebbles may occur. Thin seams of gray slate often part the sandstone beds, and may be squeezed into small folds and contortions. Slaty cleavage is marked in these finer seams and is often visible in the sandstone as well.

Thin sections of the slaty layers have the same composition as the Onwatin slate except for the lack of the dark carbonaceous substance. The sandstone consists largely of angular or rounded grains of quartz, though there are also decaying grains of orthoclase and microcline, and fresher ones of oligoclase, all imbedded in a dirty matrix, while biotite occurs sparingly. Thin sections of the concretions contain grains of the same minerals to the extent of about a third, the rest being a carbonate, which effervesces with cold acid, so that the concretions have the composition of impure limestone.

The longest axis of the concretions is always parallel to the strike, probably indicating compression, and the flattening of the concretions and the imperfect slaty cleavage must have been caused by the lateral pressure which produced the folds.

In previous maps of the region the four subdivisions of the sediments overlying the sheet of nickel eruptive have not been distinguished, and in some cases the conglomerate, which is schistose in many places, has been placed with the older Huronian sediments, the large amount of metamorphism which it has undergone near the acid edge of the eruptive giving it a much more ancient appearance than the other sediments. The widest part of the conglomerate, south of Gordon lake, was formerly included with the schistose edge of the nickel eruptive in the general Huronian color, which extended as a band from Gordon lake to the southwest end of lake Wahnapitae. The rest of the conglomerate was included with the tuff and part of the black slate under one color, the remainder of the slate and the sandstone having a separate color in the interior of the basin. Until our work of mapping the acid edge of the eruptive in detail was complete it was not known that the conglomerate formed a continuous, if sometimes narrow, belt round the other sedimentary rocks.

DEVELOPMENT OF THE NICKEL FIELD

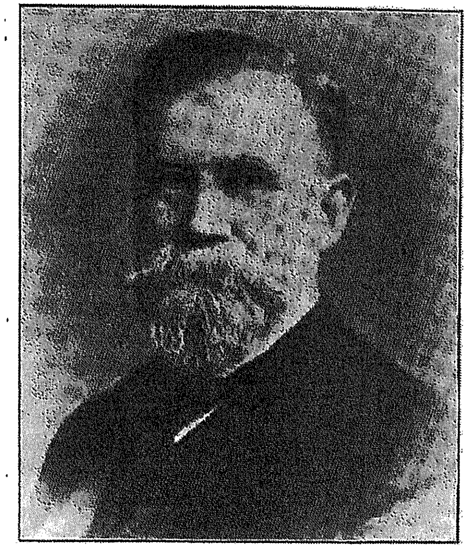
The literature bearing on the development of the Sudbury nickel mines has grown to be very voluminous. Most of the articles will be found referred to in previous reports of the Bureau of Mines; and a very complete resumé of the subject with its literature will be found in Dr. Barlow's report of 1904.[52] It will be unnecessary therefore to cover the whole of the ground in detail. It is intended to give here a brief, but fairly complete, account of the work done in the district, drawing on all sources of information, including personal accounts of participants in the work, not hitherto in print. Though the history of the region is comparatively short, since the first discovery leading to mining operations was made in 1884, there are doubtful points in regard to it and occasional conflicts between the statements of different authorities. The sources of information will be referred to as the chapter progresses, but the most important authorities relied on are Dr. Bell, Dr. Barlow, Dr. Peters and Capt. James McArthur. Most of the earlier statements are contained in the Report of the Royal Commission on the Mineral Resources of Ontario, the Annual Reports of the Bureau of Mines, and the Reports of the Geological Survey of Canada.

Though nickel and copper were discovered in the Sudbury district in 1856 by Murray, near what is now the Creighton mine, no importance was attached to this occurrence as long as the region was inaccessible by railway; and the history of mining in the district dates from the construction of the Canadian Pacific railway in 1883, when Dr. Howey found the deposit since called the Murray mine.[53] Early in the next year a cutting on the railway opened up the same deposit, and in the same year numerous other ore deposits were found, such as the Stobie, Copper Cliff, Evans and Blezard mines.

[52] Geol. Sur. Can., 1904, Part H, pp. 147, etc.
[53] Ibid., pp. 23 and 24.

These properties were all taken up for copper, the pyrrhotite being looked on as of no value, though it was suggested by Selwyn and other geologists that the mineral sometimes contained a little nickel.

It is surprising how many of the more important mines were found within the first year or two, but the fact that most of them were indicated by rusty hills of gossan no doubt accounts for the ease with which they were discovered. Even the Creighton mine, the latest of the large mines to be operated, was re-found in 1884. It is stated by Mr. Thomas Frood that the land surveyor, Mr. John McAree, who surveyed the township in 1884, noted the hill of gossan. Mr. Frood examined it in 1885 for other parties; and in 1886 it was secured by the Canadian Copper Company.



Dr. Robert Bell, Acting Director Geological Survey of Canada, Ottawa, Ont. Dr. Bell's paper on the Sudbury Mining District published in the Report of the Geological Survey for 1890-91 gave the results of three seasons' labor in the field by himself and assistants. It was accompanied by the first geological map of the region.

The work of indefatigable prospectors, such as Thomas Frood, Henry Ranger, William McVittie, A. McCharles and others deserves appreciative recognition in this connection. It is astonishing how quickly and accurately they grasped the important geological relationships, the association of ore bodies with the diorite, as the norite was then named. It may be doubted if many ore deposits of value, except those which have no outcrop upon the surface, have escaped their keen eyes.

Recognition must also be made of the great assistance furnished by the map of the region published by the Geological Survey in connection with their 1890-91 Report. This was naturally defective in various respects, since it simply embodied the rough results of reconnaissance work in a wild, bush-covered tract of rocky and swampy country. Drs. Bell and Barlow with their assistants furnished an excellent foundation for the prospector, and wherever they mapped the diorite, the ground was very carefully scanned, thus aiding in the rapid development of the country from the mining standpoint.

Railways

Until there were means of communication no development of mines could take place, nothing more important than stripping and prospecting operations being possible; so that the development of the various mines was dependent on the building of branches from the new Canadian Pacific railway, which fortunately intersected the region. The Sault branch, running southwest from the junction at Sudbury, was easily connected with the Copper Cliff, Evans mine and other adjacent mines by short switches. The Stobie and Blezard required a branch five miles long to the north; and a short spur from Stobie provided an cutlet for the Frood, or No. 3, mine. The Murray mine was already on the line of the C. P. R. and required only a siding. These early mines were easily and cheaply put in connection with the railway; but before the Gertrude, Creighton and North Star mines could be operated it was necessary to build eleven miles of expensive track to the west of Sudbury, so that their development had to await the construction of a part of the Manitoulin and North Shore railway.

Dr. Edward D. Peters, Dorchester, Mass. Dr. Peters is a well-known authority on modern processes of copper smelting, and was general manager of the Canadian Copper Company from June, 1888, to May, 1890.

The northern nickel range is still without railway connections, and so cannot develop beyond the exploration stage.

The Canadian Copper Company

The history of the development of the Sudbury nickel region is very largely the history of the operations of the Canadian Copper Company, and one naturally takes this

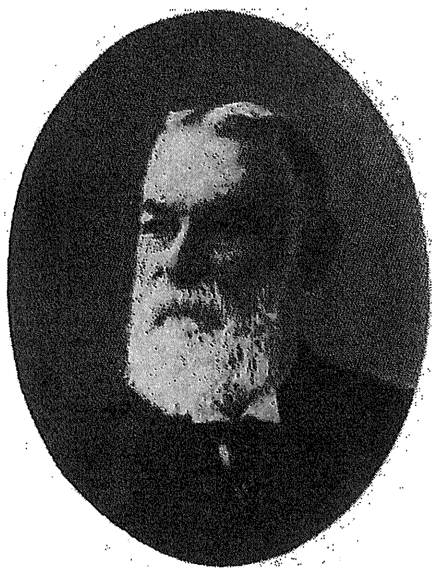
up first. In 1885, before the company was organised, Mr. S. J. Ritchie was interested in the region and employed Mr. John D. Evans to survey several locations containing copper deposits. The Lady Macdonald mine, now mine No. 4, north of Lady Macdonald lake, was the first property on which work was done; but the Evans mine, south of what is now the Sault branch of the Canadian Pacific railway, near Copper Cliff, was soon after opened up. Early in 1886 the Canadian Copper Company was organized, with Mr. Ashman as superintendent, and Mr. Evans as engineer, and work began on the Copper Cliff mine in lot 12, con. II, of McKim township. Mr. Evans states that a road was cut through second growth woods from the Sault branch to the mine, which was then known as "The Buttes." On the 20th of May a cutting was started about half way up the slope, and as soon as the rock was reached rich ore was exposed. Then another horizontal cutting was made near the bottom of the slope reaching ore. Quarrying of ore then began from the nearly vertical outcrop, and continued uninterruptedly all the season, and 3,000 tons of ore were shipped at one time to New York for treatment. Up to this time nickel was not suspected, but in the treatment of this large lot of ore the nickel contents were discovered.

Capt. James McArthur, for many years general manager Canadian Copper Company's smelting works, Copper Cliff.

The first ore taken from the Copper Cliff is said to have contained 15 to 20 per cent. of copper, the ore having been enriched in copper above the water level, below which it gradually ran down to 8 or 10 per cent. of copper and nickel. It has proved to be the richest in copper of the large mines, though surpassed in percentage of nickel by the Creighton.

Two other mines, the Stobie and the Evans, were opened up later in 1886, and the three mines supplied most of the ore treated by the company until 1899, when the Evans was shut down. The Evans was worked mainly as an open pit, and with the exception of two idle years furnished ore from the beginning of operations till it was closed. The Stobie mine, six miles to the northeast, in lot 5, con. I, of Blezard township, was much the largest producer in the district until the opening of the Creighton. It was worked, with the exception of one year, from 1886 to 1901, when it was closed down finally after producing more than 400,000 tons of ore. It was worked partly in open pits and partly by under ground mining. The ore, though not high grade, was less mixed with rock than usual, and was useful in fluxing the richer but more silicious ores of the other two mines, since it consisted largely of solid sulphides.

In 1898 two new mines became producers, No. 1, a short distance southwest of Copper Cliff, and No. 2, north of Copper Cliff; the former providing rich ore for a year, and the latter average ore in much large quantity. No. 2 has been worked mainly as an open pit, the opening giving a very impressive idea of the size and shape of an offset



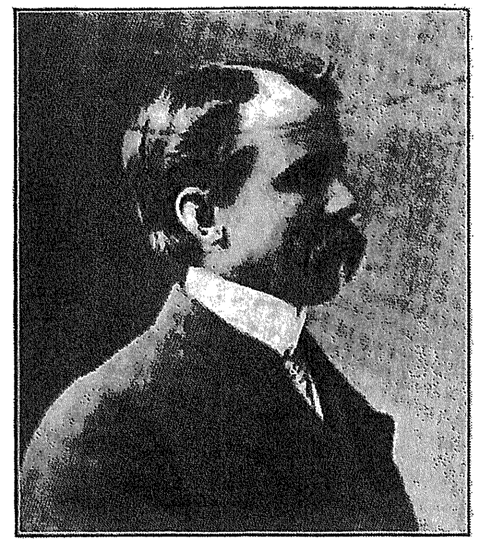
John D. Evans, Trenton, Ont. Mr. Evans was the Canadian Copper Company's first engineer, and as such assisted in opening up the Copper Cliff mine in 1886, 3,000 tons of ore being shipped to New York for treatment in that year; he had charge of constructing the first smelting works for that Company under Dr. E. Peters in 1888, the first shipment of matte being made therefrom 22nd March, 1889; and was general manager of the Company from May, 1890, to June, 1893.

ore body, but one or two levels have been opened up beneath the bottom of the pit by underground mining. When the Creighton came into full operation in 1903 this mine closed down.

In 1899 and two following years mines No. 4 and 5, northwest of No. 2, yielded some ore, and in 1900, No. 3, a mile southwest of the Stobie, often known as the Frood mine, began to supply considerable quantities of ore containing some intermixed rock, making it a useful flux for the solid pyrrhotite and chalcopyrite of the Creighton mine.

In a year or two it also was closed down. The ore from the Frood and Stobie mines was brought by rail to Copper Cliff, where it was mixed with the ore of other mines on the roast heaps.

In 1900 the great Creighton mine, six miles west of Copper Cliff, was stripped, and in the following year began to ship ore via the Manitoulin and North Shore railway to Copper Cliff. As the deposit is immense and can be worked cheaply as an open pit, while the ore averages higher in grade than any other in the district except the Copper Cliff, this mine has supplied almost the whole requirements of the company for the last three years, and the other mines have practically ceased operations. In spite of the richness of the Copper Cliff, which has produced some ore very high in nickel from its deepest workings, it has been closed down after reaching a depth of more than 1,000 feet.



A. E. Barlow, of the Geological Survey of Canada. Dr. Barlow's Report on the Nickel and Copper Deposits of the Sudbury Mining District, published in 1904 as Part H of the Geological Survey's Fourteenth annual volume is a full and adequate treatment of the subject.

During the summer of 1904 the Creighton produced about 18,000 tons of ore per month, and in total amount of ore it already far surpasses any other mine in the district or in the world. The closing of all the other mines is stated to be due to the ease of mining and richness of the Creighton, not to exhaustion of the ore bodies. If the Creighton becomes worked out in the process of years, there are supposed to be large reserves of ore still left in some of the other mines.

SMELTING OPERATIONS

The first smelting works was begun in July 1888, under the direction of the well known metallurgist, Dr. Peters, Mr. James McArthur and Mr. J. D. Evans being his assistants; and the furnace was blown in on the 22nd of December. This was the east smelter, which has now been out of operation for several years. The first shipment of matte was made on the 22nd March 1889.

In 1890 Dr. Peters was succeeded as manager by Mr. Woodbury, who retained the office only three months, when Mr. Evans was appointed manager and continued in that position till the end of June 1893. A bessemer plant was commenced in 1891, and completed in January 1892.

Mr. James McArthur succeeded Mr. Evans as manager in 1893, and continued in that position until 1902. During his regime the west smelter was erected near No. 2 mine in 1899, and the old, or east, smelter about three years later suspended operations. In 1900 a new method of changing the low to high-grade matte was adopted, and the Orford Copper Company put up the Ontario Smelting works, a short distance southwest of the Copper Cliff mine. In this plant the low-grade matte was roasted in Brown calciners, and then smelted a second time in a water jacket furnace, changing a 30 per cent. matte to one averaging 75 per cent. of nickel and copper, corresponding nearly to the former bessemer matte.

In April 1902, the Canadian Copper Company passed under the control of the International Nickel Company, organized to take over this and a number of other companies. Mr. A. P. Turner was made president of the Canadian Copper Company, and Mr. John Lawson, superintendent.

A. P. Turner, Copper Cliff, president Canadian Copper Company.

The second annual report of this company describes it as a consolidation of mines and smelters in the United States, Canada, Great Britain and New Caledonia, including the Canadian Copper Company, Orford Copper Company, Anglo-American Iron Company, Vermilion Mining Company, American Nickel Works, Nickel Corporation, Limited, and the Société Miniere Caledonienne. According to its statement of capital account in 1904 "the total assets of the company were $30,896,167, divided as follows: Property of constituent companies, $26,864,275; Ray Copper mine, $40,000; advances to New Caledonia companies, $348,363; inventories, $2,827,774; cash and accounts, $815,755; total assets, $30,896,167; common stock, $8,912,626; preferred stock, $8,912,626; stock of constituent companies, $55,643; first mortgage 5 per cent. bonds, $10,221,836; loans, accounts, etc., $1,617,476; depreciation fund, $412,709; surplus account, $763,251; total, $30,896,167. The income account for the year shows the folowing receipts: Earnings from constituent companies, $936,471; other income, $29,754. Charges were: For general expenses, $112,185; interest, $512,938; total, $625,123. The net balance carried to surplus account amounted to $341,102."[54]

Following the combination just mentioned many changes took place in the work of the company. Mining was gradually limited to the Creighton mine, and experiments were made in regard to new methods of treating the ore, such as pyritic smelting in place of roasting the ore before smelting. Many improvements were made in the town of Copper Cliff, and the removal of most of the roast beds from the vicinity of the town to a swamp behind the hills to the north permitted to some extent the growth of vegetation, so that the town was once more in sight of grass and green trees.

It was decided to build a new smelter on much improved and extended plans half a mile to the east of the west smelter, and the work was brought to completion in the fall of 1904. Meantime both the Ontario Smelting works and the west smelter were burned, hampering operations for the time. After this the low-grade matte was shipped to Victoria mines, whose smelter had been leased for six months from the Mond company, and there bessemerized, pending the completion of the converter plant of the new smelter. The two 550-ton furnaces of the new smelter are far larger than those of the old ones, and it is expected that they will permit an approach to pyritic smelting, so that a smaller proportion of the ore will require roasting than formerly.

The new works are very advantageously placed on a hill side, so that all ore and supplies may come in by rail at a high level, while tracks at the level of the valley below take charge of matte and slag, giving plenty of opportunity for disposing of the latter without clogging up the immediate surroundings of the smelter.

The company is now developing a large water power on Spanish river with which to supply electric power for all purposes at the smelter, thus saving fuel for steam, which is very expensive in the Sudbury region.

After a long period of conservative but prosperous work in the past, the company under new and progressive management, is making fresh departures in various directions; and it is to be hoped that the new methods will prove even more successful than the old.

H. H. Vivian and Company

Although the Murray mine was discovered before the Copper Cliff and Stobie mines, it was not worked until it passed into the hands of the famous Welsh metallurgical company, the Vivians, who began to develop it in 1889. With one or two short interruptions it was worked until 1894. In 1890 the first blast furnace was blown in, and the ore was treated in the usual way, by roasting in heaps, smelting in water-jacketed furnaces to a low-grade matte, and bessemerizing this to a high-grade matte. The Manhé converter was first used in the concentration of nickel matte at the Murray smelter. The low-grade matte is said to have contained only 9.4 per cent of nickel and 4.7 per cent of copper, giving cleaner slags than by the Copper Cliff method, which produced matte containing about 30 or 35 per cent. of the two metals. The bessemer matte at the Murray reached nearly the same grade as that of the Copper Cliff, running from 70 to 75 per cent. of the two metals. The high-grade matte was shipped to Swansea for final treatment.

Since 1894 the mine has remained closed down, but 5,000 or 6,000 tons of roasted ore were smelted in 1896, the matte being sent to the Whartons of New Jersey.

The ore is said to have contained 35 per cent. of iron, 23 per cent. of sulphur, 2 per cent. of nickel, 0.8 per cent. of copper, and about 40 per cent. of matrix. The pure sulphides averaged 3.6 to 3.75 of nickel and nearly half as much copper.

[54] Mineral Industry, 1903, p. 276.

Since then the only work done has been exploratory by diamond drilling at the Murray mine and also at the Lady Violet mine, on the north half of lot 1, con. IV, of Snider, about a mile and a half southwest of the Murray mine.

The Ontario Government drill was used toward the end of 1898 and the first half of 1899, but no definite statement has been made as to the results.[54]

Though the Murray mine was not one of the richest, it is probable that competent local management would have given better results than were obtained by management from England; and the failure and withdrawal from the region of so well known a firm does not necessarily condemn the mining district.

Dominion Mining Company

The Dominion Mining Company owned and worked for some time the Blezard mine, a mile north of the Stobie, in lot 4, con. II, Blezard township, and the Worthington mine at the station of the same name on the Sault branch about 25 miles west of Sudbury. The former mine was opened up in 1889, and in the following year the Inspector of Mines states that 50,000 tons of ore had been raised. A smelter was constructed and the ore, after being roasted in heaps, was smelted in Herreshoff furnaces to a matte averaging 27 per cent. nickel and 12½ per cent. copper, which was marketed without bessemerizing. The ore from the Worthington mine which was opened shortly after was partly rich enough in nickel to be shipped direct to market, while the rest was smelted with the Blezard ores. In 1893 the mines were shut down.

Mr. Robert McBride, who was in charge of the Blezard mine in 1892, says that for about a year and a half under his management the mine produced 3,000 tons of ore per month, but he was unable to estimate the amount raised before that. However, it seems probable that more than 100,000 tons had been raised before the mine was closed. The ore is said to have contained 5 to 7 per cent. of nickel and copper, the nickel being more than double the copper in amount, and apparently rivalling that of the Creighton in richness. Very little ore is left on the rock dump, showing that the work was done with unusual care.

The smelter treated not only the ore from the Blezard, but also that from Worthington, which began work in 1890, and continued to produce ore till September, 1894. Since then the mine has been shut down. The Worthington has produced the richest nickel ore in the district, running from 8 per cent. upwards; and specimens of nickelite occurring there reach 43 or 44 per cent. of nickel. The total amount of ore mined is, however, small, being estimated at only 25,000 tons.

Mond Nickel Company

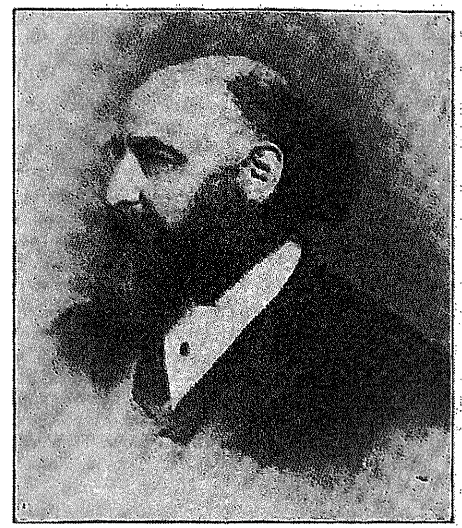
Dr. Ludwig Mond is known as the inventor of the carbon-monoxide method of refining nickel by volatilizing it in connection with this gas, and then depositing it again by suitable changes of temperature. Having found a method of refining the metal, he became interested in obtaining a deposit of the ore, and in 1899 bought the McConnell mine on the north half of lot 8, con. IV, of Denison township, about three miles northeast of Worthington.

The smelting works were located two miles south at what is now Victoria Mines station, on the Sault branch. The ore is transported 11,000 feet by an aerial tramway from the mine to the smelter, and mine and smelter are under the management of Mr. H. W. Hixon. At first the ore was roasted near the village on the railway, but later the roast beds were removed to a point about half way to the mine, and the vegetation, partly destroyed near the village, is reviving again.

Until the completion of the new Copper Cliff smelter, the plant at Victoria Mines was the most modern and complete in the district.

54 Bur. Mines, 1901, p. 56.

The roasted ore is smelted in much the usual way to a low-grade matte, which is run into bessemer converters and blown until a matte of about 80 per cent. of nickel and copper is produced. This is shipped to the Mond nickel refinery at Clydach, Wales. It is said that difficulties arose in the refining process at first, so that the works at Clydach, were unable to refine the matte as fast as it was produced at Victoria mines. The mine and smelter were shut down, probably on this account, in December 1902, and were not in operation, except for a few months in the summer of 1903, until the latter end of 1904. It is believed that the difficulties have been overcome, so that the work of the mine and the smelter may now go on continuously.



Dr. Ludwig Mond, London, Eng., President Mond Nickel Company and inventor of the carbon monoxide method of refining nickel.

In 1902 the Mond company took an option on the North Star, or McCharles mine, on lot 9, cons. II and III, of Snider township, and also on the Little Stobie, two miles west of Blezard mine; and the ore from these mines was shipped to Victoria mines for treatment. Mining operations have been continued on the North Star, which seems to have developed into a good mine, but work was not long continued on the Little Stobie.

Lake Superior Power Company

The Lake Superior Power Company opened up two mines on the main nickel range, the Gertrude about two miles west of the Creighton, and the Elsie just west of the Murray mine. Their work began in 1899 with the Gertrude mine, which at that time showed pyrrhotite with very little chalcopyrite; and it was intended to use this ore for the production of the sulphur dioxide required in making sulphite pulp at Sault Ste. Marie; the roasted ore being afterwards electrically smelted to ferro-nickel. A considerable amount of copper pyrites was encountered later, and most of the ore of the Gertrude and also of the Elsie had to be treated according to the methods usual in the district.

Roast beds were prepared at Gertrude, where the ore from Elsie mine was treated also; and the roasted ore was melted to matte in water-jacketed furnaces.

The Elsie mine produced more than 35,000 tons of ore and the Gertrude 16,000, but all work on the mines and smelter ceased at the time when the company collapsed early in the summer of 1904. The matte was stored at the smelter, and methods of refining it have yet to be devised. A long series of experiments in the refining of nickel, electrolytically and otherwise, was made at the company's works at Sault Ste. Marie, apparently without finding a satisfactory process.

Other Companies

In addition to the companies whose history has just been sketched a number of ventures in mining and treating nickel ore have been made in the Sudbury district; but none have proved successful, and few of them were of much importance. The Drury Nickel Company, having purchased the Travers or Chicago mine, on lot 3, con. V, Drury township, did some mining in 1891, and roasted and smelted some thousands of tons of ore in that year and in 1896. The matte was carried by a one-rail overhead tramway to Worthington station, seven miles away, to be shipped to the United States; but in 1897 the work was finally closed down.

At several other mines shafts have been sunk and considerable development work done, but none of them have raised any large amount of ore; nor have any of them operated smelters. References to them will be found in Dr. Barlow's very complete history of the development of the region;[55] so that details need not be given here.

Two attempts at novel methods of smelting and refining the ores should perhaps be mentioned. The Great Lakes Copper Company made an experiment of this kind at the Mount Nickel mine, on lots 5 and 6, con. II, of Blezard, between the Little Stobie and Blezard mines. The mine is stated to be well supplied with ore but the smelting works, planned by Anton Graf, of Vienna, were a failure, and work soon ceased. The Hoepfner Refining Company of Hamilton, undertook the electrolytic refining of nickel and copper in 1899, and constructed works just west of Worthington; but the process was unsuccessful, and a later attempt by Mr. Hans A. Frasch was likewise a failure; so that operations ended in 1901.

Some mention should be made of Mr. Edison's persistent endeavors to locate nickel properties in the region by dip needle methods. Mr. Edison's invention of what is stated to be an exceedingly light and efficient storage battery in which nickel plays a large part gave the incentive for the exploration. Three season's work covered most of the likely spots, where swamps or drift covered the ranges, and therefore where ordinary prospecting methods must fail of success; but the results have been negative. Several test pits and diamond drill holes have been sunk at points where there were notable disturbances of the dip needle, but no ore of importance was discovered. Similar work, but with more delicate instruments, has been carried on by the Mond and Lake Superior Power companies, in the first case by the well-trained Swedish engineer, Mr. Erik Nystrom; but the results leave doubts as to the value of this method of prospecting for pyrrhotite, though it is of great value in exploring for magnetic iron ore. The methods are described in detail and in a thoroughly scientific way by Dr. Eugene Haanel in a report on the "Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements," issued by the Department of the Interior, Ottawa.

At the present time only two companies are actually at work, the Canadian Copper Company and the Mond Company. Both seem to be firmly established with good mines and satisfactory methods of smelting and refining the ore, so that the future should be prosperous. Most of the companies which have failed did so because of lack of capital

[55] G.S.C. Vol. XIV, Part H, pp. 34-38.

or of experience, or because they had no well worked out method of refining the matte. The smelting of roasted ore to make standard matte and the treatment of this matte in bessemer converters, so as to raise its contents of nickel and copper to 70 or 80 per cent., is comparatively simple; the real difficulty comes in the refining of the bessemer matte, and up to the present only two processes seem to be successful on the large scale, and both are in the hands of companies which have their own supplies of ore. There appears to be no market open for even the high grade matte, though the metal is in demand.

Of the two companies at work in the Sudbury district the Canadian Copper Company has much the largest holdings of nickel properties, including the greatest nickel mine in the world, the Creighton mine. There are still numbers of nickel deposits in the region in other hands, some of them large and promising; but the possession of the Creighton mine gives the Canadian Copper Company a distinct advantage over its possible rivals, since at present there is no prospect that any other deposit will equal that famous mine.

It is natural that the Canadian Copper Company should have aroused some hostility and jealousy in its long and successful career; but it is only fair to add that its steady persistence in developing the nickel resources of the region has been the mainstay of mining in the Province of Ontario for a number of years, and a fair reward should be reaped for its constancy in going on with its work under discouraging conditions in its earlier years.

Other Nickel Regions

Nickel is a widely spread metal, but very few regions contain its ores in quantities that can be profitably mined. Outside of the deposits connected with the great eruptive sheet which has been described in earlier pages, pyrrhotite with some nickel has been reported from many other points in northern Ontario, especially at the east and south west of the main nickel region. Numerous small deposits of pyrrhotite occur near Nairn Centre, southwest of Worthington, and a small amount of work in the way of stripping has been done upon some of them, without important results; though ore containing 1.95 of nickel is reported from lots 1 and 2, con. III, of Nairn. The deposits here and in Lorne may really be connected with the Worthington offset, though the ore found in them is much lower in nickel.

To the east of the nickel eruptive, northeast of lake Wahnapitae, several locations were taken up years ago for nickel. Ore from Boucher's mine gave 1.57 per cent. of nickel, or 2.1 per cent., if pyrrhotite free from gangue be taken. Similar small bodies of pyrrhotite occur south of Ramsay lake. All these deposits have a possible connection with the main nickel eruptive, but all are small in size and low in grade.

Much larger masses of pyrrhotite have been found in other parts of northern Ontario, as between lake Temagami and Net lake, but of too low a grade to be of importance.[56]

Much more promising are the extraordinary deposits of native silver, cobalt and nickel ores of Coleman township near lake Temiskaming, where considerable quantities of one of the richest ores of nickel occur. Mixed with smaltite one finds large masses of nickelite; so that nickel is one of the valuable ingredients of the ore, though cobalt and silver are of much more importance. Unless much larger deposits of this ore are found, the Temiskaming mines will not prove serious competitors of the Sudbury region as nickel producers. Detailed accounts of these remarkable deposits are given by Prof. W. G. Miller in this and former reports of the Bureau of Mines.[57]

Nickel ores have been reported from many other parts of Canada, especially British Columbia and New Brunswick. Near St. Stephen in the latter province pyrrho-

[57] Bur. Mines, 1904, pp. 96-101. [56] Bur. Mines, 1900, pp. 173-4.

tite with a little copper pyrites is found in masses of gabbro cutting slate, the amount being considerable; but the ore contains only from .92 to 2.62 nickel, with some cobalt and copper, so that the ore is low as compared with Sudbury ores.[58]

Dr. Barlow mentions numerous other localities in Canada where trifling amounts of nickel ore have been found, usually much lower in nickel than the Sudbury ore, and none of them likely to be of practical importance.[59] With his very complete account there are tables showing the results of a large number of assays of such ores, made in Dr. Hoffman's laboratory at Ottawa.

UNITED STATES NICKEL DEPOSITS

The first nickel produced in America was obtained in 1863 from the Gap mine in Lancaster county, Pennsylvania; and it has a special interest to Canadians, since the methods adopted by Joseph Wharton in refining the metal were later of importance in the treatment of our own ores. The mine contained mainly pyrrhotite and chalcopyrite, and, like the Sudbury deposits, was first taken up for its copper ore, the nickel contents of the ore being discovered later. It is associated with an eruptive mass of a much more basic kind than the Sudbury norite, and like the Sudbury ore deposits, was probably due to magmatic segregation. The ore was of much lower grade than the Canadian, yet for a number of years it was the most important nickel mine in America. After running from 1863 to 1891 it was finally closed down in the latter year.[60]

Nickel ores of an entirely different type, resembling those of New Caledonia, have been found in Oregon and North Carolina. The Oregon deposits, in Douglas county, are irregular masses of hydrated silicates of nickel and magnesia in serpentine, formed by the alteration of peridotites or related rocks. The ore occurs as loose boulders on the surface and in veinlets in the serpentine, but, up to the present, no ore bodies of workable dimensions have been found. In North Carolina, the relationships are similar, and the pale green mineral genthite, a hydrous silicate of nickel and magnesia was discovered there. No ore of importance has been mined, however.

A small quantity of nickel occurs with the lead ores of Mine la Motte in Missouri; and the metal is recovered as a by-product in the treatment of the ores. In 1903 the United States is reported to have produced from domestic ores 57 tons of nickel, apparently from this mine.

Though the United States has dropped out of the race as a producer of nickel ore, it is still one of the most important countries for the refining and utilisation of the metal nickel; much the greater part of the Canadian matte being treated at Constable Hook, New Jersey.

EUROPEAN NICKEL DEPOSITS

The metal nickel was first produced in any quantity at Schneeberg in Saxony; and ever since the discovery of the metal a small amount of nickel and cobalt has been obtained at the Freiberg smelters as a by-product in the treatment of silver-lead ores. A little has been produced also from the deposits of Varallo, in Piedmont, Italy, where the ore is pyrrhotite, which occurs with basic eruptive rocks, as in so many other places. In Austrian Silesia nickel is extracted from a silicate forming veins in serpentine, resembling the New Caledonian deposits; but the amount is small.[61]

At Schaud on the Spree in Germany comparatively rich ore, with 5.52 to 6 per cent. of nickel and a little cobalt and copper, is found beside a dike of diabase-gabbro

58 G.S.C., Sum. Rep. 1903, pp. 166-9; also 1904, Part H. p. 151-3.
59 Ibid., Part H, pp. 147-166.
60 Kemp, Ore Dep., U.S., and Can., p. 432; 2nd Geol. Sur. Penn., Rep. CCC, 1880; G.S.C. 1904, Part H, pp. 174-6.
61 References to many of the localities are given by Dr. Barlow in the report previously mentioned.

(proterobase); but Beck, who describes it, thinks the deposit was not formed by segregation but by ascending waters. He objects also to Vogt's theory regarding Sudbury and Norwegian ores. However, conclusions drawn from the small deposits he refers to should hardy overturn those formed from more numerous and larger deposits elsewhere.[62]

Scandinavia has hitherto proved much the most important nickel mining region in Europe, and before the importation of New Caledonia ores most of the world's nickel came from the mines of Norway and Sweden. Since 1894 these countries have fallen off greatly in their output of the metal, however, and during some years nickel mining ceased altogether. The Scandinavian deposits are of pyrrhotite, like our own, and are associated with gabbro or norite, but of a more basic type than the Sudbury norite. They have a special interest to students of the Canadian region, since the true theory of the relationship of ore to rock was worked out first in Norway, by Professor Vogt of Christiania, and afterwards applied to our deposits by Dr. Adams, Dr. Barlow, and others.[63]

In Norway there are about 40 deposits, and quite a large literature has sprung up about them, partly written by Canadian observers,[64] but it will be impossible to do more than give a general account of the ore deposits as compared with those of Sudbury. Nothing resembling the great eruptive sheet of the Sudbury region has been described in Norway, though the ore always appears as segregations at the edge of masses of gabbro. Between the ore and the rock there is pyrrhotite-gabbro, showing every stage of mixture of the sulphides with the rock. The sulphides are mainly pyrrhotite, but include also chalcopyrite, though in less amount than in some of our offset mines. Pyrite is more frequent than with us, but the rarer elements, gold, silver, and platinum seem to be present in less amounts, though they always occur. In richness the ore is much like our own, running from 2.5 to 5 per cent. of nickel. At Evje, for instance, the ore contains from 2.90 to 4.87 per cent. of nickel and 1 to 1.30 per cent. of copper. The deposits, however, are much smaller than the Canadian ones, so that their competition is not to be feared.

In Sweden very similar deposits exist, but the number exploited is smaller. At Kuso pyrrhotite has segregated from gabbro-diorite, and, as worked, runs 1.14 to 1.82 of nickel, the pure pyrrhotite containing 2.51 to 3.42 per cent.[65]

In 1893 and 1894 Scandinavia produced more than 100 tons of nickel, but the opening up of the New Caledonia and later the Sudbury mines have almost destroyed the nickel mining industry in those regions.

NEW CALEDONIA

The only real competitor of Ontario as a nickel producer is the French penal colony, New Caledonia, in the south seas. Nickel was discovered there in 1865 by M. Jules Garnier, and it was through his exertions that the nickel mining industry sprang up. Many accounts of the region have been given, the most complete description of the mines and their conditions being by M. E. Glasser, who examined them for the French government;[66] but a good sketch of the subject is given by Dr. Barlow in the report so often referred to. The following account is drawn from M. Glasser.

The island consists of ancient schists and mesozoic sediments, penetrated by numerous eruptives, of which the most important is a very basic rock, peridotite, consisting of

62 Die Nickelerzlagerstätte von Schaud au der. Spree u. ihre Gesteino, zeitschv. deutsch. Geol. Ges., 55, 1903, pp. 296-330.
63 Nikkel forekomster og Nikkelproduktion, Geol. Soc. Nor. Christiania, 1892; Ueber die Bildung von Erzlagerstätten durch Differationprocesse in Eruptivmagmaten, International Geol. Congr., Zurich, 1894; Problems in the Geology of Ore-Deposits, in Genesis of Ore Deposits, Posepny, 1901, p. 636, etc.; Formation of Eruptive Ore Deposits, Min. Industry, 1895, p. 743, etc.; and various other papers.
64 Macfarlane, Can. Nat., Vol. VII, p. 13, Nickel ore at Ringerike; Major Leckie, Nickel Deposits in Norway, Can. Min. Rev., Vol. XVIII, No. 8, p. 151-3.
65 Löfstrand, Slattberg's och Kuso Nickelgrufnor, Geol. För. in Stockholm Förh. 25, 1903, pp. 103-122.
66 An. des Minis, 10 Séries, Tome IV, 1903, pp. 299-392, and 397-536.

olivine and enstatite, now more or less transformed into serpentine. Deposits of nickel, cobalt and chromium are associated with the serpentine. The original peridotite is no doubt the source of the ore, and analyses show that the fresh rock contains small percentages of nickel and cobalt. A specimen of olivine from one of the mines contains 0.11 per cent. of nickel and cobalt oxide, while the enstatite associated with it in less amount contains 0.4 per cent. Examples of peridotite are said to have been found containing as much as 2½ per cent. nickel. The peridotites cover most of the southeast end of the island and form a discontinuous chain of outcrops running nearly to the northwest end, as a mountain range rising in places to 5,500 feet. In most cases serpentization has advanced far, and at many points the serpentine has changed into a red clayey material, which is associated with nickel ore.

The ores are all hydrated silicates in which nickel has replaced magnesia to a greater or less extent. The richest silicates, which are green and soft, may contain even 48.6 per cent. of nickel oxide, and are called garnierite and noumeaite, the two varieties seeming to blend into one another. Their composition varies greatly, but their nickel contents averages higher than that of the genthite referred to as occurring in Oregon and North Carolina.

The green minerals occur as small veins in the serpentine or peridotite, as a scaly covering of fragments of the rock, or as concretionary masses. The color varies from pale to deep green or almost black, and the garnierite is associated with a chocolate brown mineral, which was at first rejected, but is now known to be a similar nickel ore colored with iron oxide, and forms the larger part of the ore mined. There are also silicious masses of a green color, containing, however, only 9 or 10 per cent. of nickel.

As examples of the best garnierite the following analyses may be given from M. Glasser's report:

——	I.	II.	III.	IV.	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	42.61	35.45	44.40	37.78	38.35	37.49	47.90
NiO	21.91	45.15	33.61	33.91	32.52	29.72	24.00
MgO	18.27	2.47	8.45	10.66	10.61	14.97	12.51
$Al_2O_3+Fe_2O_3$	.89	.50	1.68	1.57	.55	.11	3.00
FeO	....	....	.43	....	....	....	....
CaO	....	....	1.07	....	....	....	trace
H_2O	15.40	15.55	10.84	15.83	17.97	17.60	12.73
	99.08	99.12	99.98	99.75	100.00	99.89	100.14

There may be every gradation from specimens like these, which come from different parts of the island, to silicate of magnesia with only a small percentage of nickel, so that the ore has the composition of serpentine in which a variable amount of nickel has replaced magnesia.

M. Glasser distinguishes four varieties of ore deposits, vein-like deposits, brecciated deposits, masses of altered serpentine impregnated with nickel, and nickeliferous earths.

While the pure garnierite is very rich, most of the ore is of very much lower grade, and the miners mix rich and poor ore so as to adjust the output to an average of 7 per cent. of nickel, after drying at 100° C. This means practically that the hydrous ore, before drying, runs about 5¼ to 5½ per cent. of nickel, since the percentage of water is high. The waste dumps may contain 3 or 4 per cent. of nickel.

The veins are seldom large, and are never worked to any important depth, so that there are few underground mines. Most of the deposits form sheets covering the surface, nowhere more than 15 or 20 feet thick, and are worked as open pits. The largest group of mines mentioned by M. Glasser, on the plateau of Thio, had produced

up to the time of his report 250,000 tons; and during its greatest prosperity, in 1890-1894, had reached a production of 25,000 or 30,000 tons per annum, which later had fallen off to 10,000 tons. The tenor of the ore in early days was 10 to 12 per cent. but latterly had fallen to 6½ per per cent. of nickel. A large amount of waste rock has now to be rejected, and the group of mines is approaching exhaustion.

The deposits are always found on gentle slopes or basins on the flanks of the mountains and lie between the red clay mentioned before and the rock. They have resulted from the superficial weathering of the rock, accompanied by a concentration of the nickel as silicate by surface waters, the nickel being precipitated more readily than the magnesia. Under these conditions none of the deposits can be expected to cover continuously a large surface. The largest of the bands of ore are not more than about a half mile long, and they are comparatively narrow. Many of the deposits are already worked out, but a large number still furnish ore, and probably many new deposits will yet be found. If the grade of the ore required were lowered to 5 per cent. of nickel, the amount which could be furnished would greatly increase.

As the ores generally occur high up on the mountains where roads are difficult to construct, transportation is a serious difficulty, and cable tramways have often to be provided. Another drawback is the thickness of red clay which has to be stripped from many of the deposits before they can be worked by open quarrying, which is the usual method. The poor character of the labor available, Kanakas, convicts, or sometimes Japanese, is another drawback mentioned by M. Glasser; who adds that the long ocean voyage and the remote situation of the island greatly hamper the marketing of the ore at a profitable rate.

At present all the ore is shipped to Europe for treatment, but it is thought that a great economy in freight could be accomplished by smelting to matte in the island, thus reducing the weight, though smelters erected years ago proved unsuccessful.

Though nickel was discovered by Garnier in 1865, scarcely any mining was done until 1875, and the output did not rise to great importance till 1889, when 21,000 tons of ore were shipped. This amount had increased to 108,908 tons in 1899, and to 128,653 tons in 1902, according to statistics furnished by M. Glasser. In 1889 the contents of nickel in the ore sent from New Caledonia rose to 1,680 tons, while previously it had not reached 1,000. In 1902 the nickel contents were placed at 7,045 tons, though M. Glasser doubts the correctness of the return.

The most productive mines are still the old ones in the neighborhood of Thio on the northeast side of the island near its southeast end, but their output is diminishing and the total is kept up by the working of a large number of small veins in different parts of the island.

M. Glasser discusses interestingly the formidable competition of the Canadian nickel mines, though he states that "thanks to a more or less complete understanding between the producers, New Caledonia preserves her rank; but it is none the less true that the nickel industry is developing in Canada and that the production of its mines has been rapidly increasing of late years. Must one say that New Caledonia has much to fear from this competition? We do not think so; for, so far as we can judge from the documents at our disposal, the natural conditions of the Canadian deposits are, in themselves, much less favorable than those of our colony." He goes on to show that the Sudbury ores are sulphide ores of nickel and copper, variable in the percentage of the two metals and requiring a complex method of refinement. Quoting the statistics of the Bureau of Mines, he admits that the nickel resources of the region are considerable, though the tenor of the ore seems to be diminishing.[67] He was influenced in his view by the absurdly high estimate of our ore reserves given by an official report to the United States Secretary of Marine in 1890.

[67] The statistics quoted reach only to 1901, before the rich Creighton ores had produced an effect.

While M. Glasser thinks our prospects less bright than those of New Caledonia, he admits certain advantages. "On the other hand the general industrial situation of Canada appears to be very favorable, and has permitted in late years an important development in mining and treating the ores, in consequence of which the production of nickel in Canada is steadily increasing."

There is one apparent advantage for purposes of treatment, which the New Caledonian ore has over ours, in the absence of sulphur, and another real advantage, in its freedom from copper. The first advantage is, however, neutralized by the fact that the New Caledonian ore must be smelted with coke, which always contains appreciable quantities of sulphur. Owing to the great affinity of nickel for sulphur, this is taken up by the metal, and must later be separated from it. This fact interfered with Garnier's original idea of direct smelting of the nickel; and it is now smelted with sulphur compounds, such as gypsum, and made into a matte which must afterwards be refined in ways not very different from our own. The absence of copper makes its separation unnecessary, but the copper, when separated, is an element in the value of the Sudbury ores.

TYPES OF NICKEL ORES AND DEPOSITS

From the account just given of the New Caledonian ore deposits it will be seen that they are of an absolutely different type from those of Sudbury; and, if we omit the few rich arsenides and sulphides of nickel found in some Saxon mines and the Coleman deposits, in relatively minute quantities, all nickel deposits may be divided into two classes, pyrrhotite ores which occur as segregations at the margin of eruptive rocks such as norite and gabbro; and hydrous silicates, such as garnierite and genthite, which result from the weathering of serpentine derived from a very basic eruptive rock, peridotite.

Though both kinds of deposits have their source in eruptive rocks, one comes directly from the molten magma, by segregation at its bottom or edge; the other by a complex process of decomposition carried on in two stages, hydration into serpentine, and weathering of serpentine into red clay, with the accumulation of the minute quantity of nickel in the original rock as secondary deposits of the green or chocolate brown hydrous silicates of nickel and magnesia. In the Sudbury region the silicate ore of nickel is unknown, though genthite has been found on Michipicoten island in lake Superior[68] in trifling quantities. We have numerous areas of serpentine in Canada, especially in the Eastern townships of Quebec, and minute amounts of nickel occur in them, but the conditions have not been favorable for the accumulation of secondary ore deposits, even if the amount of nickel contained in the serpentine was sufficient in quantity. The scouring of the Ice Age would have removed any such residual deposits.

The Scandinavian nickel regions have, of course, passed through the same conditions as our own. It is a little surprising that the millions of tons of nickeliferous pyrrhotite destroyed in past ages by weathering in the Sudbury region should not somewhere have given rise to secondary deposits, but none are known; and we must suppose that the nickel solutions due to weathering and gossan formation have not met with the proper re-agents to precipitate the nickel. Its compounds are in general very soluble, only the hydrous silicate showing a tendency to permanence.

On the other hand sulphide of nickel is practically never found in New Caledonia, the only reported occurrence being a little millerite found in the Esperance chromium mine.

We have then in Ontario very large deposits of sulphide ores going to depths of more than 1,000 feet, comparatively little changed from the form they assumed on cooling from the molten magma; while in New Caledonia we find thin, flat, shallow sheets of ore entirely of secondary origin, the accumulation of ages of superficial changes in a region too near the equator to be affected by the glacial period.

68 G.S.C., 1890-91, Part E, p. 47; also Dr. Barlow, 1904, Part H, p. 149.

For completeness sake a reference should be made to the occurrence of native nickel, associated with native iron, in certain basic rocks, as at Ovifak on Disco island, on the Greenland coast. The masses of iron found there and partly removed by Nordenskjold to be deposited in the Scandinavian capitals, run up to 20 tons in weight. They contain only small amounts of nickel, from 0.34 to 2.85 per cent., but almost enough for nickel steel. Meteoric iron, it is well known, always contains nickel, reaching even in one case, 59.69 per cent., as at Octibbeha Co., Miss.

Native nickel with a percentage of iron has been found, also, the example best known being the awaruite of Gorge river in the south island of New Zealand. This contains 67.63 per cent. of nickel, 0.70 per cent. of cobalt, and 31.02 per cent. of iron. It is found with gold and platinum, etc., in river gravel, and was probably derived from a partially serpentinized peridotite.[69] Even more interesting is the souesite, or native iron-nickel alloy described by Dr. Hoffman from Lillooet in British Columbia. It was found with platinum and a little gold, etc.; and has the composition nickel 76.48, iron 22.30, copper 1.22.[70] Closely related to this are the metallic grains found by Sella in gold-bearing sand at Elvo, near Biella, in Piedmont; which contain 75.2 per cent. of nickel and 26.6 per cent. of iron.[71]

Distribution of Metals in the Sudbury Ores

By far the most important of the metals in the Sudbury district, so far as quantity is concerned, is iron; but it is always combined with sulphur, chiefly in the form of pyrrhotite, which contains from 60.4 to 61.6 of iron when pure. If it were not for the difficulty in completely removing the sulphur, pyrrhotite would be a valuable ore of iron, and the nickel mines would also be iron mines, some of them comparable in tonnage and percentage of the metal to important iron mines in other regions. Some day the iron of the pyrrhotite may be in demand, but that day is probably distant.

Next in amount comes nickel, which may be looked on as sometimes replacing a part of the iron in the pyrrhotite, though in most cases it is known to belong to pentlandite disseminated through the pyrrhotite. This occurs in quite variable amounts, running, in mines which have been extensively worked, from 1.5 per cent. of the ore to over 5 per cent.; and in some smaller mines to 8 or more per cent. for a few thousand tons. These statements apply, however, to the ore as mined, always including more or less rock. The pure sulphides would, of course, run higher. In the Murray mine 55 to 60 per cent. of the ore was sulphides; at the Copper Cliff nearly 40; at No. 2 about 60; at the Frood 78; and at Creighton 79 or 80, the highest in the region.

Close after nickel comes copper, derived from the chalcopyrite almost always mixed with the pyrrhotite; but the proportions of the two metals vary greatly.

Next in quantity, but far behind the others, is cobalt, present in all the ores to the extent of from 1-40 to 1-133 of the nickel present, according to the few analyses on record showing the percentage of cobalt in high-grade matte. If we take the returns of cobalt from the statistics for 1903-4, we find only 25.8 tons to 11,727 tons of nickel, the cobalt representing only 1-455 of the nickel; however, cobalt is more easily slagged off than nickel, and no doubt has been quite disproportionately removed in the refining process. For the same reason the proportion of cobalt in the bessemer or high-grade matte is no doubt lower than in the original ore.

The precious metals are present in still smaller quantities, silver coming first, with 2¼ to 7 oz. per ton of high-grade matte; the platinum metals next, with from 0.17 oz. to 0.5 oz., and gold last, with 0.02 to 0.3 oz. per ton.

69 Dana's System of Mineralogy, pp. 28 and 29.
70 Am. Jour. Sc., Vol. XIX, 1905, pp. 319-20.
71 Dammer, Handbuch der Anorganischen Chemie, Vol. III, p. 469.

Matte Analyses

The results of the most complete analyses of bessemer or other high-grade matte available are given in the following table:

——	I.	II.	III.	IV.	V.	VI.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nickel	} 48.82	41.58	40.37	} 41.18	39.96 {	41.88
Cobalt		0.71	0.78			40.33
Copper	25.92	24.99	24.95	44.87	43.36	37.37
Iron	2.94	9.82	9.64	0.94	0.80	1.07
Sulphur	22.50	....	....	11.63	18.76	....
Gold	0.02oz.	0.15oz.	0.10oz.	0.30oz.	0.1 to 0.2 oz.	0.66oz.
Silver	3.14 "	....	2.50 "	5.10 "	7.0 "	4.87 "
Platinum	0.13 "	0.50oz.	0.44 "	....	0.5 "	.40 "
Iridium	0.02 "	....	....	....	....	....
Osmium	0.02 "	....	....	....	....	....
Rhodium	trace	....	....	....	....	....
Palladium	trace	....	....	....	....	....

I is by T. L. Walker of Murray mine bessemer matte.[72]

II and III are by Donald Locke, of Ontario Smelting Works matte,[73] mainly from Creighton ore.

IV is by J. W. Bain, of Copper Cliff matte in 1899, from Stobie, Copper Cliff and Evans mine ore.[74]

V is by Titus Ulke in 1894, of Copper Cliff and Evans ore, probably with some ore from Stobie.[75]

VI is by Donald Locke, of Victoria mines bessemer matte.[76]

Analyses I, II and III are of matte whose ore came chiefly from large marginal deposits, the Murray and Creighton mines. IV and V are partly of ore from mines of the Copper Cliff offset (Copper Cliff and Evans), but partly from Stobie mine. VI is from an offset mine, but very close to the margin of the nickel-bearing eruptive, Victoria mine. It will be noticed that nickel predominates over copper in the ratio of about 2 to 1 or 5 to 3 in matte from marginal mines, while copper outweighs nickel in offset mines, except at Victoria mine, where nickel is a little in advance.

Assays of ore from the different mines show this even more strikingly. The Creighton runs about 5 per cent. of nickel to 2 of copper; the sulphides at the Murray mine about 3½ to 1¼; the Blezard mine about 4 of nickel to 2 of copper; and similar proportions are found in the Gertrude, etc., all marginal mines. At the Copper Cliff the ore averages 4.20 of nickel to 5.68 of copper, and the offset mines as a whole contain nearly equal amounts of nickel and copper, except the Stobie offset, where nickel is 2.21 to 1.55 of copper. The last offset is of a peculiar kind, showing no direct connection with the main eruptive, but running parallel to its edge at a distance of about three-fourths of a mile to the southeast, so that it seems to follow a different law, and may be really a sheet of norite and ore projecting from the main range away below the surface.

It appears then that a certain amount of segregation of the ores took place where offsets projected from the edge of the eruptive into the cooler country rocks, the process being aided probably by circulating hot water arising from the eruptive magma.

Assays or analyses are not available to show how the rarer metals were affected, beyond the general fact that they seem to have been concentrated in a still higher degree than the copper, as may be seen from the table. The first three analyses show

72 Am. Jour. Sc., Vol. 1, 4th Series, 1896, p. 112.
73 Dr. Barlow, p. 206.
74 Bur. Mines, 1900, p. 218.
75 Min. Industry, Vol. III, p. 460.
76 Dr. Barlow, p. 206.

2½ or 3 ounces of silver per ton of matte and from 0.19 to 0.65 of gold and the platinum metals; the last three have from 5 to 7 ounces of silver and from 0.6 to 1 ounce of gold and platinum. The amount of the precious metals is more than doubled, while the percentage of copper is increased from 25 to about 42.

In the case of Vermilion mine the gold and platinum metals are increased in a much greater degree, but the small amount of the ore known to exist makes it of little importance. No analyses of Worthington matte are available, unfortunately.

The Precious Metals

The proportions of the rare metals thus far referred to are the results of analysis of the high-grade matte. To bring them into relationship with the respective ores from which the matte was obtained it is necessary to know the grade of the ore, and in many cases this is not on record. At the Murray mine the ore contained in 1891 about 1.5 per cent. of nickel and 0.75 per cent. of copper; so that a ton of matte containing 74.74 per cent. of the two metals represented the concentration of about 33 tons of ore. If 20 per cent. be allowed for loss in treatment, this would raise the amount to 40 tons. Of this about 60 per cent. was sulphides, making 24 tons of pyrrhotite and chalcopyrite to furnish 3.14 oz. of silver, 0.17 oz. of platinum metals and 0.02 oz. of gold. Probably 12 tons of the Creighton sulphides produced a ton of the matte analysed by Mr. Locke (II and III); while about 18 tons of the sulphides from Stobie, Evans, etc., were needed for IV. In the case of V probably 12 tons of the rich sulphides from Copper Cliff and Evans provided a ton of matte. I have no definite information as to the number of tons of sulphides required to produce a ton of the Victoria mines matte (VI).

Arranged as a table the amounts of the rare metals to a ton of sulphides are roughly as follows:

	Silver.	Gold.	Platinum metals.
I. Murray mine	0.13 oz.	0.0009 oz.	0.007 oz.
II and III. Creighton mine, etc.	0.21 oz	0.0083 oz.	0.037 oz.
IV. Copper Cliff, Stobie, etc.	0.28 oz.	0.0166 oz.	
V. Copper Cliff, Evans, etc...	0.583 oz.	0.0125 oz.	0.0146 oz.

II and III included some ore from the offset mines of the Canadian Copper Company, and do not represent the Creighton alone.

In concluding this discussion of the distribution of the rare metals the returns of platinum and palladium from the Canadian Copper Company's matte must be referred to. In 1902 there were 2,375 ounces of platinum and 4,411 ounces of palladium recovered, which may be looked on, however, as belonging partly to the ore mined in former years. Assuming that it came from the ore of 1902 there were 0.0102 ounces of platinum and 0.0189 ounces of palladium to the ton of ore mined, or 0.0291 of both metals. Probably 60 or 70 per cent. of the ore was sulphides, so that the number of ounces per ton should be increased proportionately. In 1903 the amounts are 0.0077 platinum and 0.0144 palladium, the total being 0.0221 ounces. In 1904 there was a falling off to 0.0052 and 0.0093, with a total of 0.0145 ounces of the platinum metals per ton of ore. In the last year most of the ore was from the Creighton mine and 75 per cent. of it may have been sulphides, which would raise the total to 0.0193 ounces per ton.

Estimating roughly the amount of sulphides in the ore each year, the following relationship results:

1902—Platinum metals per ton of sulphides, 0.0468 ounces
1903— " " " 0.0323 "
1904— " " " 0.0193 "

A portion of the ore from which the metals were obtained in 1904 probably came from the Copper Cliff in the previous year, so that we cannot assume Creighton ore that the statistics of the rare metals do not represent the complete change from offset to the statistics of the rare metals do not represent the complete change from offset to marginal ores in this respect.

One naturally compares our ores with the similar ones of Norway, but in comparing the ratios of the metals in the two countries it must be kept in mind that their deposits correspond to our marginal ones and not to our offset deposits. Prof. Vogt gives the composition of two Norwegian bessemer mattes as follows:

	Ringerike. Per cent.	Evje. Per cent.
Nickel	51.16	41.50
Cobalt	1.96	0.97
Copper	16.40	23.00
Iron	10.37	(13)
Sulphur	19.58	(20)
Gold	0.0145 oz. per ton	0.029 oz. per ton
Silver	2.46 " "	4.06 " "
Platinum	0.075 " "	0.09 " "
Iridium, Osmium } about	0.003	

If this is compared with the table of analyses of Sudbury mattes given on a previous page, it will be seen that the proportions are quite like analyses I, II and III, from marginal ore deposits, but that the other three show higher percentages of the rare metals. It will be noticed, too, that the percentage of copper in the three offset deposits is much greater than in the Norwegian mattes.

Palladium has not, so far as I am aware, been reported from the Norwegian nickel ores.

Prof. Vogt states that in Norway the proportions of the metals are one part of gold to 120 of silver, one of platinum to 30 of silver, one of silver to 5,000 of nickel.[77] In our ores it would be more natural to compare the precious metals with copper than nickel, since their percentage increases with that of copper, though somewhat more rapidly.

It is well known that platinum occurs always in connection with basic rocks, but the native metal in Russia, British Columbia, etc., is considered to be derived from rocks consisting of olivine and proxene, now largely turned to serpentine, rocks of a much more basic character than our norite; and it seems that the native metals of the platinum group go with ultra-basic rocks, while the arsenical compound, sperrylite, is associated with less basic rocks like norite and gabbro. New Caledonian peridotites, from which their nickel ore is derived, should contain a small amount of the platinum group of metals, but in the native state and not as arsenides, if the relationship just mentioned is correct.

Statistics of Nickel Production

SUDBURY DISTRICT

Year.	Ore		Nickel			Copper.			Cobalt.		
	Tons raised.	Tons smelted.	Tons Ni.	Ni. %	Value $	Tons Cu.	Cu. %	Value $	To's Co.	Co. %	Value.
Before 1890	100,000										
1890	130,278	59,329									
1891	85,790	71,480									
1892	72,349	61,924	2,082	3.36	590,902	1,936	3.19	234,185	8½	.0137	3,713
1893	64,043	63,944	1,653	2.21	454,702	1,431	2.38	115,200	19	.0299	9,400
1894	112,037	87,916	2,570½	2.92	612,724	2,748	3.14	195,750	8¼	.0087	1,500
1895	75,439	86,546	2,815¾	2.67	404,861	2,365½	2.73	160,913			
1896	109,097	73,505	1,948½	2.67	357,000	1,868	2.54	130,660			
1887	93,155	96,094	1,999	2.08	359,651	2,750	2.86	200,067			
1898	123,920	121,924	2,783¾	2.28	514,220	4,186¾	3.43	268,080			
1899	203,118	171,230	2,872	1.67	526,104	2,834	1.68	176,236			
1900	216,695	211,960	3,540	1.67	756,626	3,364	1.58	319,681			
1901	326,945	270,380	4,441	1.64	1,859,970	4,197	1.55	589,080			
1902	269,538	233,388	5,945	2.54	2,210,961	4,066	1.74	616,763	6.1	.0026	2,873
1903	152,940	220,937	6,998	3.17	2,499,068	4,005	1.81	583,646	13.1	.0058	6,123
1904	203,388	102,844	4,729	4.60	1,513,280	2,042	1.98	285,966	12.8	.0124	6,060
Totals.	2,388,782	1,938,401	43,877½	2.434	12,660,069	37,798½	2.09	3,876,177	62.⅗	....	29,969

[77] Zeitschrift f. prakt. Geol., Heft 8, Jahrgang, 1902, pp. 258-60.

For the nine months ending 30th September 1905, the production of nickel from the Sudbury mines was returned as 7,136 tons. worth in the matte $2,522,593, and of copper 3,810 tons, worth $507,440.

In addition to the metals given in the table there are returns for platinum and palladium from 1902 to 1904, as follows:

——	Platinum.			Palladium.		
——	Oz.	Oz. % or ton	Value	Oz.	Oz. per term %.	Value.
1902	2,375	0.0102	46,323	4,411	0.0189	86,015
1903	1,710	0.0077	33,346	3,177	0.0142	61,951
1904	536	0.0052	10,453	952	0.0092	18,564
	4,621	....	90,110	8,540	....	166,530

The statistics as given are taken from the reports of the Bureau of Mines, and represent the returns sent in by the companies. For some reason not accounted for, the statistics given in the Geological Survey Reports differ considerably from those of the Bureau of Mines, being generally lower. The values in the two sets of statistics vary still more, since the Bureau of Mines reports spot values of the nickel and copper in the matte as it is shipped from Ontario, while the Survey reports the final value of the refined metal.[78]

Certain interesting changes in the tenor of the ore smelted may be observed in the table given above, such as the gradual falling off in the nickel and copper per ton, from 3.36 and 3.19 respectively in 1892 to 1.64 and 1.55 in 1901; followed by a rise in the next three years to 4.60 and 1.98. This may be accounted for by the fact that the ores came largely from differnt mines at different times. In the early days the rich Copper Cliff mine provided a large part of the ore; later lower-grade ores from the Stobie and other mines came in plentifully and lowered the average. For the last three years the comparatively rich Creighton ore has been replacing that from other mines, raising the percentage; but as this mine produces much more nickel than copper, about 5 per cent. to 2, the proportions of the two metals have changed. The Copper Cliff supplied about equal quantities of nickel and copper, usually rather more of the latter metal.

The absence of cobalt from the statistics from 1895 to 1900 does not imply that the ore contained none, but only that it was not reported, perhaps because not separated from the nickel. The amounts reported from 1892 to 1894 were from a company which ceased work in the latter year.

The most curious part of the table is that referring to platinum and palladium. Platinum has long been known to occur in the matte, but except in one assay of Copper Cliff matte, palladium has been reported only in traces.[79] It is therefore a surprise to find nearly double as much palladium as platinum, and the fact is not easily accounted for, since no palladium mineral has been found in the district. The platinum comes, of course, from sperrylite.

The falling off in the percentages of these rare metals from 1902 to 1904 may have been caused by the closing down of most of the offset mines, such as the Copper Cliff, confining the ore to marginal mines, such as the Creighton. Offset depcsits, like the Copper Cliff, Victoria mine and Vermilion, are much richer in the rare elements than the large marginal mines.

[78] For survey statistics see Dr. Barlow's report, p. 232; and also the successive reports of the survey.

[79] As quoted by Barlow, p. 203; in the article quoted, Min. Industry, Vol. IV, p. 460, no palladium is mentioned by the analyst, Titus Ulke.

In regard to the rarer metals it should be said that there is a considerable lapse of time between the mining of the ore and the recovery of the metals after the refining has taken place, so that the returns of the metals are perhaps a year or more behind those of the ores mined.

The quantities of platinum and palladium obtained during the last three years are stated to have been extracted from the accumulations or residues of former years as well as from the mattes actually treated during those years. For this reason, as well as from the comparative leanness in the rare metals of the Creighton ore, the yield of platinum and palladium as well as of gold and silver, is likely to be less in the immediate future. Cobalt is almost entirely removed from the matte during the bessemer process as now carried on in the new smelters of the Canadian Copper Company.

In the statistics given the mines of the Canadian Copper Company must be credited with at least four-fifths of the output of ore and even a larger proportion of the nickel and copper; and the apparent sudden decline in the output in 1904 is explained by the stoppage of the old west smelter while the new one was being completed.

Dr. Barlow has estimated the total value of the metals produced from the Sudbury mines, including nickel, cobalt, copper, gold, silver and platinum, at $52,717,846. On the authority of Mr. Turner he gives the amount of ore produced by the three most important mines up to the 1st of June 1904, as follows:[80]

Stobie mine	419,000 tons.
Copper Cliff mine	366,000 tons.
Creighton mine	310,000 tons.

It is probable that the last mine has now produced more than 500,000 tons. Of the other mines belonging to the company, three, the Evans, No. 2, and No. 3 (Frood) have produced between 100,000 and 200,000 tons. Of mines belonging to other companies the Murray mine produced 62,193 tons, the Blezard about 100,000 tons and the Victoria mine more than 80,000 tons.

It should be mentioned in connection with the statistics given in the main table that the total quantity of the metals reported is the quantity actually recovered, not the total quantity originally contained in the ores. There is a large loss during roasting and smelting of the ores, variously estimated at from 15 to 25 per cent. of the nickel and copper originally in the ore. Messrs. McDonald and Paris of Victoria mine put the loss between green ore and 80 per cent. matte at from 10 to 20 per cent., with an average of about 15 per cent., most of the loss of copper being in roasting, and of nickel in smelting. In other mines of the district good authorities make the loss greater, as much as 25 per cent. in most cases. To get the true contents of the ore from the returns of metals reported it will be necessary then to add probably one-fifth to the percentages given in the table. As the statistics of other countries usually give the metallic contents of the ores as determined by assay, this correction is necessary in comparing our statistics with theirs.

STATISTICS OF OTHER COUNTRIES

The statistics of the nickel production of other countries than Ontario are in a very unsatisfactory state, since there are numerous small mines whose returns seem to be made up in different ways. The most important mining region, New Caledonia, ships almost all its ore raw to various countries of Europe, though a little of it has come to the United States, also; and the returns of the nickel produced in these countries do not agree with the amount estimated in the raw ore. Some portion of the ore probably remains in stock from year to year, so that the output of Europe should follow the New Caledonia returns after a lapse of perhaps a year for ocean transport and the time needed for smelting and treatment.

[80] Ibid., p. 230-1.

The following table is taken from M. Glasser's report on the mineral wealth of New Caledonia, the values being changed from francs to dollars by dividing by five, which slightly overstates them. The tons are metric, slightly less than our long tons, and tons enclosed in parentheses were smelted to matte on the island. M. Glasser thinks the values for 1898, 1899 and 1900 are exaggerated, having been obtained by multiplying the number of tons of moist ore by the value per ton of dry ore.[81]

New Caledonia

Year.	Tons of Ore.	(Smelted on the island)	Value.	Tons of Nickel.	(Smelted on the island)
			$		
1875	327		65,400	39	
1876	3,406		340,600	408	
1877	4,377		344,400	525	
1878	155		9,200	18	
1879					
1880	2,528	(5,058)	101,200	253	(506)
1881	4,069		162,800	407	
1882	9,025	(6,392)	324,800	812	(537)
1883	6,881	(6,768)	248,000	620	(315)
1884	10,888	(7,994)	315,752	871	(637)
1885	5,228	(1,095)	146,384	418	(99)
1886	921		36,840	92	
1887	8,602		515,000	688	
1888	6,616		165,400	530	
1889	21,000	(1,250)	525,000	1,680	(114)
1890	24,590	(1,900)	565,400	1,960	(174)
1891	54,081	(160)	1,135,600	4,326	(15)
1892	35,951		644,700	2,507	
1893	45,613		775,400	3,180	
1894	40,089		561,246	2,795	
1895	38,976		389,760	2,484	
1896	37,467		317,208	2,888	
1897	57,639		403,473	3,458	
1898	74,614		671,526	4,356	
1899	103,908		1,101,425	5,640	
1900	100,319		1,175,400	5,975	
1901	133,676		916,000	7,218	
1902	129,653		915,800	7,045	
Total	960,599	(30,617)	12,576,009	60,693	(2,697)

To conclude the statistics of nickel production, Dr. Barlow's table, mainly derived from the Metallgesellschaft und Metallurgische Gesellschaft (Frankfort-on-the-Main), Aug. 1903, p. 23, for Europe; and from U. S. and Canadian authorities for America, is given below:[82]

WORLD'S PRODUCTION OF NICKEL

(In metric tons)

Year.	Sweden and Norway.	Nickel contents of New Caledonian ores. Germany.	France.	Britain.	Total New Caledonia.	Canada.	U. S.	Grand total.	Average price per lb. in New York.
1889	80	282	1,050		1,332	377	114.60	1,904	60 cents.
1890	100	434	1,200		1,634	651	101.27	2,486	65 "
1891	125	594	1,900		2,494	1,830	58.75	4,530	60 "
1892	97	746	950		1,696	1,095	41.84	2,930	58 "
1893	90	893	1,600		2,493	1,807	21.41	4,412	52 "
1894	90	522	1,900		2,422	2,226	4.36	4,742	38⅝ "
1895	40	698	1,850		2,548	1,764	4.67	4,357	35 "
1896	20	822	1,545	340	2,707	1,541	7.79	4,276	35 "
1897	....	898	1,245	715	2,858	1,818	10.75	4,682	35 "
1898	....	1,108	1,504	1,000	3,648	2,503	5.05	6,166	33 "
1899	....	1,115	1,740	1,350	4,205	2,605	10.22	6,820	36 "
1900	....	1,376	1,700	1,450	4,526	3,211	4.41	7,741	47 "
1901	....	1,660	1,800	1,750	5,210	4,168	3.04	9,381	50 "
1902	....	1,604	1,110	1,310	4,024	4,850	2.61	8,877	47 "
1903	....	1,600	1,500	1,650	4,750	6,348	51.80	11,150	40 "

[81] An. des Mines, 10 Series, Tome IV, p. 512.
[82] G.S.C., 1904, Part H, p. 236.

A comparison of the total output of nickel in Europe from New Caledonian ore with the quantity of nickel shown by assay of the ores exported shows that the metal refined in Europe almost always falls much below the amount estimated from the assays, and only in one year, 1896, runs beyond it. What percentage of loss there is in smelting the New Caledonian ore is not stated; but the loss during heap roasting should, of course, be avoided, so that the total loss of nickel from the New Caledonia ore should be less than from Canadian ore.

The advance from year to year in the production of nickel from Canadian ore is more rapid than that from New Caldonian ore, so that our mines appear to be gaining ground as compared with those of our rivals.

Minerals of the Sudbury Nickel District

PYRRHOTITE

The characteristic sulphide of the Sudbury mines is pyrrhotite or magnetic pryites, which has already been described in connection with the ore deposits. It is a mineral of somewhat variable composition, running, according to Dana, from Fe_5S_6 to $Fe_{16}S_{17}$, but always containing a little more sulphur than iron. In the Sudbury region it is almost always massive, with little hint of crystal form, though at a number of mines it shows a platy structure suggesting a basal cleavage. Almost the only crystal on record is one obtained by Prof. G. R. Mickle from a miner at Worthington. He describes it thus: "The crystal is evidently a hexagonal prism showing strongly marked basal cleavage; two of the sides are intact and portions of two others remain. The dimensions are 1 3-10 inch, or 32 mm., by ½ inch, or 13 mm.; the weight 26.4 grams; and an analysis of a very small fragment from the crystal gave 2.3 per cent. of nickel."

In general it is stated that the pyrrhotite itself contains no nickel, the metal being carried by enclosed pentlandite; but the above analysis shows that apparently pure and crystalline pyrrhotite may contain it. Experiments in magnetic separation of the finely pulverized ore, carried out by Dr. Barlow, Dr. Dickson and others, show, however, that in general the nickel belongs to a non-magnetic mineral, which must be pentlandite.

PYRITE

Iron pyrites, FeS_2, is found at many of the mines, its pale brassy yellow color and its hardness distinguishing it from the previously mentioned sulphides. It occurs as well formed octahedra embedded in the pyrrhotite at the Blue lake and other mines; and cubes of pyrite are found in small fissures with quartz and calcite at Elsie mine. An assay of the latter pyrite showed no nickel. Prof. T. L. Walker has found pyrite with the pyrrhotite from the Murray mine, and believes that nickel is contained in it, replacing part of the iron.[83] His analysis of the pyrite gives 4.34 per cent. of nickel, 39.70 of iron, 49.31 of sulphur, and 5.76 per cent. of insoluble matter.

MARCASITE

The rhombic variety of FeS_2 occurs in several mines and is common in ore from the Worthington offset, especially at openings northeast of the mine. It has not been found in crystal form, though its whitish color and general appearance are characteristic. An assay of the Worthington marcasite by Prof. Walker showed 4.5 per cent. of nickel, and similar results were obtained by Dr. Hillebrand of the U. S. Survey, who found 4.57 per cent. It is probable that pentlandite is mixed with the marcasite.[84] It should be mentioned that the mineral here spoken of as marcasite, shows no crystal forms; so that it is somewhat uncertain whether it is really marcasite or a massive variety of pyrite.

83 Am. Jour. Sc., 3rd Series, Vol. XLVII, pp. 312-14.
84 G. S. C., 1890-91, Part SS, p. 116.

PENTLANDITE

The most important mineral belonging to the Sudbury ore deposits is pentlandite (FeNi)S, since in most cases this is the actual nickel-bearing constituent. Though it is supposed to be mixed intimately with all the nickeliferous pyrrhotite, it cannot be distinguished in the ore at most of the mines. The best localities to find it are the Worthington, Creighton and Evans mines, but even in these ores one must often search carefully to see the paler, slightly yellowish patches characterized by a distinct octahedral cleavage. No crystals have been found, but cleavage surfaces of a third of an inch in diameter may be obtained. The ratio of nickel to iron in pentlandite is generally given as variable, but with more iron than nickel, as a rule. The Sudbury pentlandite contains, however, a larger amount of nickel than of iron, as may be seen from the following analyses, No. I by Prof. Penfield[85], Nos. II to IV by Dr. Dickson.[86]

	I.	II.	III.	IV.
Ni..	34.23	34.82	33.70	34.98
Co...	.85	.84	.78	.85
Fe..	30.25	30.00	29.17	30.04
S....	33.42	32.90	32.30	33.30
Gangue	.67			
	99.42	98.56	95.95	99.17

MILLERITE

Millerite, NiS, crystallising in hair-like forms or slender prisms of brass yellow color, is the richest nickel mineral found in the region, since it contains 64.6 per cent. of the metal. It is, however, very rare, though in earlier studies of the deposits it is sometimes referred to as disseminated through the pyrrhotite. It has been found at Copper Cliff by Dr. Peters and Dr. Dickson, the latter considering it secondary after pentlandite. Prof. Walker and the writer found slender crystals of it in the rich nickel ore of the Vermilion mine.

POLYDYMITE

This mineral has been described from the Vermilion mine by Messrs. Clark and Catlett,[87] who gives it the composition Ni_4FeS_5. Analyses are given below, I from authors mentioned, II from Mr. Browne:[88]

	I.	II.
Ni..	41.96	36.85
Fe..	15.67	18.17
S..	40.80	38.43
Cu..	0.62	4.47
SiO_2	1.02	
Totals....	99.97	98.45

The mineral from the Vermilion mine is gray, very easily tarnished and very soft. On the ore dump it quickly decomposes and loses its metallic lustre. Quite large lumps may be obtained almost free from other minerals, though there are generally streaks of chalcopyrite running through it.

NICKELITE OR NICCOLITE

Kupfer-nickel, NiAs, was the earliest source of the metal and is one of the richest ores, containing 43.9 per cent. of nickel. Its pale copper red color and metallic lustre make it a striking mineral, and suggest the presence of copper, from which the original name given it by the German miners was derived. In the Sudbury region it has been found only on the Worthington property and some openings on the same offset to the northeast. The recent finds in the silver-cobalt-nickel mines near lake Temiskaming are often very rich in this mineral.

85 Am. Jour. Sc. (3rd Series) Vol. XLV, 1893, pp. 493-4.
86 Trans. Am. Inst. Min. Eng., Vol. XXXIV, 1904, p. 21.
87 Am. Jour. Sc., Vol. XXXVII, 1889, p. 372-4.
88 Eng. Min. Jour., Vol. LVI, p. 566.

GERSDORFFITE

This mineral is also an arsenide of nickel, NiSAs, but with a larger amount of arsenic and sulphur, so that it contains only 35.4 per cent. of nickel. It is white to steel gray in color and is found associated with nickelite in the Worthington offset, where its name has been given to a prospect, the Gersdorffite mine.

The foregoing minerals are the only nickel minerals proper occurring in the Sudbury district, and apparently the only really important one is pentlandite. The others are never found in the larger mines along the margin of the nickel eruptive, but only along the offset deposits, and usually at a distance from the edge of the norite.

In 1892 Dr. S. H. Emmons described three new nickel-iron sulphides from the Sudbury region, folgerite, whartonite and blueite, with amounts of nickel running from 3.70 per cent. in the last to 31.45 in the first;[89] but later writers hold that his determinations were made from mixtures of minerals. Prof. Penfield considers the folgerite really pentlandite, the blueite nickeliferous pyrite and the whartonite a mixture.[90] Mr. Mickle gives the following account of specimens resembling the blueite as described by Dr. Emmons:

"A peculiar grayish-green bronze-colored, non-magnetic mineral, which tarnishes to a dull bronze, was found by Mr. McVittie on the location where the Gertrude mine now is. The mineral occurred massive, with small crystals of magnetite and specks of chalcopyrite disseminated through it, in a streak about six inches wide adjoining the granite. An analysis of the mineral after removing the magnetite gave the following results:

	Found.	Calculated.
Iron..	37.28 per cent.	41.48 per cent.
Sulphur..	46.54 per cent.	51.79 per cent.
Nickel	5.95 per cent.	6.62 per cent.
Copper	0.10 per cent.	0.11 per cent.
Insol..	9.66 per cent.	
	99.53	100.00

"Assuming the composition to be FeS_2, NiS and $CuFeS_2$:

41.48	per cent. of	iron	requires	47.41	per cent.	of sulphur.
6.62	"	nickel	"	3.65	"	"
0.11	"	copper	"	0.11	"	"

which agrees fairly closely with the amount of sulphur found in the calculated composition, viz.: 51.79 per cent.

"Polishing one side of the specimen shows that the piece is not homogeneous but resembles a porphyry in structure, consisting of a ground-mass with crystals imbedded in it, the crystals having a more yellowish color than the ground-mass. Etching reveals a cellular structure in the ground-mass of alternate light and dark lines somewhat like the surface of meteoric iron or certain steels when similarly treated. Surrounding the crystals is always a dark rim. A similar peculiar grayish-green bronze mineral from Calumet island, Ottawa river, came to my notice, containing 2.64 per cent. of nickel; also one from the ninth level of the Copper Cliff mine, the light colored mineral forming a band in this case. In the examples at hand it does not seem possible to separate the different components in order to analyse each separately. Emmons' blueite with a probable composition of 3.70 per cent. of nickel, 41.01 of iron and 55.29 of sulphur agrees in description with the mixed sulphides just referred to. The percentage of nickel no doubt varies according to the relative amounts of crystals and ground-mass."

We may conclude therefore that the three supposed new minerals should be omitted from the list of nickel-bearing minerals of the region.

CHALCOPYRITE

Chalcopyrite or copper pyrites is always found associated with our nickel ores, though sometimes in small amounts. Pyrrhotite and chalcopyrite are often intimately mixed, as shown in previous chapters, though there is a tendency for the copper pyrites to occur as narrow stringers in fissures of the country rock more often than pyrrhotite,

[89] Eng. Min. Jour., 1892, p. 609. [90] Am. Jour. Sc., Vol. XLV, 1893, pp. 493-7.

as if the copper pyrites were the more mobile of the two minerals. Good crystals of copper pyrites have not been found in the Sudbury region. The composition of copper pyrites, Cu Fe S_2, is constant, and the greenish yellow color and general character of the mineral are familiar. Its irridescent colors when tarnished are striking, and may be noticed on any waste dump at the mines.

ORNITE

The Vermilion mine, which differs so much from the others in the district, is the only one in which this mineral has ben noticed. It occurs with quartz and chalcopyrite, but in small quantities only. Chalcocite, the pure sulphide of copper, also, has been reported from this mine, and native copper was found at the mine in early days.

MOLYBDENITE

Among the minerals at Worthington occasionally a seam of lead gray molybdenite is found crossing the pyrrhotite or partly enclosed in the greenstone, but the amount is very small. It seems to have been a later deposit in fissures cutting the ore and country rock.

GALENA

The only other sulphide mineral in addition to those described above is galena, PbS, which occurs in small amounts as narrow seams with a little quartz or enclosed in the ore without quartz in the Copper Cliff and other mines. The galena may account for a part of the silver always found in assays of matte, the rest being contained in the copper pyrites.

SPERRYLITE

The platinum arsenide, named by Penfield and Wells, sperrylite, ($PtAs_2$), was first obtained from the gossan of the Vermilion mine, but afterwards from the Victoria mine, then called the McConnell property. It was named for Mr. F. L. Sperry of the Canadian Coper Company. As the first natural compound of platinum, it has naturally attracted much attention from mineralogists. It is a tin white, metallic looking mineral in tiny crystals belonging to the isometric system and showing many of the planes found on pyrite. Although the crystals are minute, the largest not exceeding a diameter of 1½mm, or about 1-18 of an inch, the planes are perfect enough to measure a large number of angles.[91] The specific gravity is 10.6, so that it is probably the heaviest mineral known except the native metals. It is generally obtained by panning the gossan of the mines mentioned, where it occurs along with gold.

An investigation of the McConnell property by Mr. Mickle in 1897, showed that sperrylite was generally distributed through not only the gossan but also the solid ore, his assays demonstrating that the platinum is associated with the copper rather than the nickel ores, though some is found in the latter also. The average of six samples of solid ore gave a trifle over 3 dwt. of platinum and a little gold per ton, while pyrrhotite with little copper pyrites gave considerably less than the average, and one example of ore with much chalcopyrite gave 7 dwt. 12 gr. of platinum and a trace of gold. His highest assay showed 1 oz. 3 dwt. of platinum and 3 dwt. of gold from decomposed ore resting on the solid ore.

These results suggest an appreciable increase in the value of the matte from Victoria mine as compared with the other mines in the district, where the amount of gold and platinum in the ore seems to be much less, since these metals and also the silver are concentrated along with the nickel and copper in the matte, and should be recoverable.

[91] Nicol and Goldschmidt, Ueber Sperrylite, Zeitschrift für Kryst., Band 38, Heft 1 and 2, p. 58.

It is of interest to see that Dr. Dickson found quite a large number of sperrylite crystals in almost pure chalcopyrite from the Victoria mine, but not in the other Sudbury ores examined.[92]

Sperrylite may be looked on as the source of the platinum always found in Sudbury mattes, and perhaps also of other metals of the platinum group, though the large amount of palladium recently reported from the matte is not accounted for by the chemical composition as given below, the mean of two analyses:[93]

	Per cent.
Arsenic	40.98
Antimony	0.50
Platinum	52.57
Rhodium	0.72
Palladium	trace
Iron	0.07
Cassiterite	4.62
Total	99.46

Since its description from the Sudbury region sperrylite has been found associated with copper ores in various other parts of the world, so that it can no longer be looked on as a unique or specially rare mineral.

The only other known locality for it in Canada is Copper mountain, British Columbia, where it was found with bornite and copper pyrites by Mr. Jules Catherinet.[93]

Its presence in the nickel ores of Norway is inferred by Vogt, since analyses of matte show that platinum is present, but the actual sperrylite has not been found in Scandinavia.

MAGNETITE AND TITANIFEROUS IRON ORE

In basic rocks, such as norite, magnetite or titaniferous iron ore or ilemenite is always present, and, as might have been expected, these minerals are often disseminated in the nickel ores. Well formed octahedra are common embedded in the pyrrhotite from the Levack mine, and a mass of magnetite five tons in weight was found completely enclosed in the ore at Clara Bell mine north of Copper Cliff. Specimens are readily attracted by the magnet, so that it is not highly titaniferous; and it contains grains of pyrrhotite and chalcopyrite as well as small portions of a green silicate. Titaniferous iron ore was found in small quantities by Prof. Walker in ore at the Murray mine, and many of the thin sections made from the nickeliferous norite contain magnetite surrounded by leucoxene, showing that the unweathered mineral contained titanium.

CASSITERITE

The only other oxide of interest in the nickel ores is cassiterite, or oxide of tin, which was found by Messrs. Penfield and Wells along with the sperrylite from Vermilion mine. The quantity is insignificant, however.

NATIVE METALS

Native copper has already been mentioned as occurring in the Vermilion mine, no doubt as a gossan product. Gold is more commonly found, as small colors, in the gossan at the Vermilion and Victoria mines, as shown in a previous paragraph. In early days it could be panned without difficulty at both localities, and the small amount of gold obtained from the nickel matte of all the mines is no doubt to be accounted for by the presence of free gold in the ore.

Whether the very considerable amount of palladium obtained from Copper Cliff matte occurs native or belongs to some compound resembling sperrylite is not known. A small part of the silver in the matte probably occurs native, alloyed with the gold.

92 Am. Jour. Sc., Vol. I, 1896, p. 112; and Trans. Am. Inst. Mining Eng., Vol. XXXIV, p. 11.
93 Am. Jour. Sc., Vol. XXXVII, 1889. 93 E. M. J., 1905, p. 125.

GOSSAN MINERALS

Almost all the nickel deposits have been acted on by the weather since the glacial period, and are more or less covered with gossan. One might naturally expect to find nickel and copper compounds in the gossan, but apparently these compounds are more soluble than the iron oxides, and up to the present only traces of them have been reported from the region. The gossan consists, apparently entirely, of limonite or hydrous sesquioxide of iron, whose rusty brown color characterizes the deposits. Part of the limonite shows a dark brown, concretionary appearance, while other parts are earthy and yellower. At the Creighton there are in places very pretty concretionary growths in the cavities of the gossan, while other parts have a brecciated appearance, angular fragments of brick red or yellow limonite being cemented by dark brown or even metallic-looking black limonite, the lighter-colored blocks, first deposited as mud, having dried and split, allowing the dark variety to fill the spaces. Some of the gossan deposits might almost be used as iron ores, so completely have the sulphides been decomposed.

When damp there is a peculiar odor connected with the pyrrhotite deposits, coming from the sulphates resulting from the action of oxygen and water on the ore. Ferrous sulphates and doubtless sulphates of copper and nickel, are formed in nature, like the sulphates which appear in cavities in the roast heaps. The only mineral of the kind which has been described is Morenosite or nickel vitriol ($NiSO_4+7H_2O$), which occurs as a greenish-white and pale apple-green incrustation at the Gersdorffite and Worthington mines.[94]

GANGUE MINERALS

In almost all ore deposits the gangue minerals are much in evidence and require description; but in this respect the Sudbury nickel region is an exception. Leaving out of view the rock-forming minerals of the norite and the granite or greenstone of the country rock on the opposite side of the ore deposits, gangue minerals are practically absent in the marginal type of deposit, and play a very inconspicuous part in most of the offset deposits. There are a few later fissures at Creighton, Elsie and other marginal mines in which quartz and carbonates, such as calcite, dolomite and ankerite, are found; but, as they are not connected with the formation of the deposit and do not affect its character appreciably, they may be neglected.

In the offset deposits, such as Copper Cliff and Victoria mine, quartz and the carbonates are more common, but still form only a trifling percentage of the deposit. At the Vermilion and Worthington offsets, however, there is often much quartz with a varying amount of carbonates, suggesting a considerable re-arrangement by circulating water. In some of the offset deposits, as at Worthington and Clara Bell, with the quartz and carbonates blade-like crystals of actinolite are found.

USES OF NICKEL

The metal nickel was discovered by Cronstedt in 1751, in the mineral kupfernickel (niccolite or nickelite), obtained from a cobalt mine in Helsingland, Sweden, and in 1754 he further investigated the substance and described the properties of the metal. The mineral kupfer-nickel looks like copper but does not contain that metal, disappointing the miners, who gave the name in derision; and Cronstedt applied the name to the metal. It was not until 1775 that Bergman prepared the pure metal, however, and even then he doubted its purity because it was attracted by the magnet, which suggested that it contained iron.[95] It was long before a use was found for the metal in Europe, though its alloy, packfong, containing copper, nickel and zinc, had been known to the Chinese from time immemorial; and it is said that "the Bactrian king

94 G. S. C., 1892-3, R. p. 27. 95 Kopp, Geschitche der Chemie, Vol. 4. pp. 156-9.

Euthydemos who reigned about 235 B. C., employed an alloy of nickel for coinage purposes, containing 77.58 per cent. of copper, 20.04 per cent. of nickel and 1.72 per cent. of impurities."[96]

Alloys of nickel were used then long before the pure metal was known, very much as bronze, the alloy of copper and tin, was used for ages before the metal tin was put to use.

Nickel alloys with many metals but its alloys with copper and zinc are the commonest, being used under various trade names, such as German silver, maillechort, argentan, white metal or queen's metal. German silver usually contains 5 parts of copper, 2 of nickel and 2 of zinc; and packfong, mentioned before as a Chinese alloy, contains about 40 per cent. of copper, 15 per cent. of nickel and 45 per cent. of zinc. An alloy of 20 per cent. of nickel with 80 per cent. of copper is much used for casing bullets. For subsidiary coinage an alloy of 75 per cent. copper with 25 per cent. of nickel is used by the United States, Germany, Belgium, Brazil and Venezuela ; and similar alloys are used by other countries.

Within the last few years several nations have adopted pure nickel instead of the nickel-copper alloy for their coinage, and the pure metal has many points in its favor. It does not tarnish and change color like the alloy; but keeps a bright, attractive color; and, as it is harder, the imprint stands wear much better. It is more difficult to counterfeit, since the minting requires more powerful presses. Switzerland was the first country to adopt the pure nickel coinage, in 1883, when 20-centime (four cents) coins were struck. In 1892 Austria-Hungary put in circulation four new nickel coins; Italy came next with 25 centesimi (five cents) coins, but they resembled the silver lira (20 cents) so much that they were withdrawn. In France a bill was passed in 1903 authorizing the issue of 25 centime pieces (five cents), and in 1904 coins of the same value but of different design were issued.[97]

The fineness of nickel used for coinage is from 97 to 98 per cent. pure, and the diameters of the coins mentioned are from 19 to 24 millimeters (from ¾ to nearly an inch), so that they correspond nearly to Canadian bronze cents. The numbers of these coins issued by the nations mentioned already reaches into the hundreds of millions; and they are so preferable in every way to the dull and unpleasant smelling coins of copper or of copper-nickel alloy that other nations may be expected to follow their example.

Why should not Canada, the producer of half the nickel of the world, replace her ugly cents by clean, untarnishable, nickel coins, almost as handsome as silver and much more durable? Canada is presently to have a mint, and it should begin its work by coining one-cent and five-cent pieces of pure nickel; making use of a distinctively Canadian metal.

A new use for pure nickel, which may grow to be of great importance is in the manufacture of Edison's latest storage battery, which is very much lighter than the old lead storage batteries.

The uses of pure nickel, other than for coinage, are not at present of great importance, though various small articles are made from it, but its use in plating iron or steel and zinc is very wide-spread, on account of the untarnishable white surface it gives; and nickel plated articles are in use everywhere.

NICKEL STEEL

The value of nickel as the pure metal and in its alloys with copper, zinc and other metals, where the percentage of nickel is considerable, depends largely on its white color, and the fact that nickel has a very high power of impressing its whiteness on alloys in which other metals, such as copper, are in preponderance.

96 G. S. C., 1904, part H, p. 524; where Dr. Barlow refers to Austen's Historical Sketch of Nickel as his authority.
97 See an interesting article in The Iron Age, Vol. 75, No. 14, pp. 1175-6.

In its alloy with iron and steel the usefulness of nickel turns on the great improvement in strength and other properties which it imparts to the alloys, even when present in quite small amounts. It is singular that iron and nickel, with their close relative cobalt, should be so regularly divorced in ordinary ore deposits, for the three form a natural group of metals very much alike in many of their properties, and probably once intimately associated. In meteorites iron plays the largest part, but always contains a small percentage of nickel and a much smaller percentage of cobalt. In a few examples of basic eruptive rocks we find the native metals associated also, but iron ores are almost always devoid of nickel or cobalt. The ores of iron have undergone processes which have removed the nickel, probably because of the greater solubility of its compounds, if the two metals were associated in the beginning, as seems likely. One of the most striking advances in metallurgy of late years has been the restoration of the partnership of iron and nickel by the production of nickel steel.

The idea of using a nickel-iron or steel alloy was suggested by more than one scientific man, and samples of such an alloy were made and more or less experimented with long ago, as may be seen from the following extract from Mr. Albert Ladd Colby's valuable paper on Nickel Steel: its Properties and Applications.[98] Searching through proceedings of scientific societies for the past 80 years, he has found a number of references to the subject.

In 1822 Stodart and Faraday published their experiments made at Sheffield in the alloying of nickel and iron. A little later Berthier made some similar experiments in France.

"In 1830, Wolf, of Schweinfurt, Germany, put some nickel-iron alloys on the market, which he called 'Meteoric Steels.' They were damasked, and Liebig comments on their magnificent appearance in a note in the *Annalen der Pharmacie*, and states that this alloy is destined to be developed in the near future.

"In 1835 Fairbairn published some experiments undertaken to determine the strength of some alloys of nickel and iron similar in composition to meteoric iron.

"At the Exposition held in New York, in 1853, Philip Thurber exhibited several samples of nickel steels produced from a nickeliferous limonite.

"In 1858 Sir Henry Bessemer made an experimental 3 per cent. nickel-iron alloy, with a view to making what he termed 'Meteoric Iron Guns.' He did not, however, pursue the subject, nor publicly refer to the matter until 1896.

"Percy in his Metallurgy, published in 1864, refers to experiments conducted by Richardson in his [Percy's] laboratory on nickel-iron alloys varying from 1 to 50 per cent. in nickel.

"In 1870 Alex. Parkes, of Birmingham, took out several patents for the production of alloys of iron and nickel; in 1883 John Gamgee made nickel-iron alloys in Connecticut; in 1884 A. M. Clark, of London, patented the manufacture of a malleable ferro-nickel.

"In 1885 ferro-nickel was manufactured at Marbeau's works at Montalaire, France, under the supervision of Berthesult.

"In 1887 highly carboniferous nickel steels were made experimentally at the steel works at Imphy, France; and in 1888 and 1889 several French and English patents for the manufacture of nickel steel, and its applications, were granted to Marbeau, Schneider, Riley and Hall.

"It is therefore evident that the advantages of alloying nickel with iron and steel have been known for some time. The credit of making the first systematic series of practical tests on nickel steel belongs, however, to Mr. James Riley, then of Glasgow, whose elaborate paper on 'The Alloys of Nickel and Iron' was read by him on May 8 1889. From a discussion of this paper it appears that J. W. Hall, of Sheffield, had been working on similar lines, but his results had not been publicly put on record. Mr. Riley's paper gave the impetus to the introduction of nickel steel in a commercial way."

It should be mentioned that nickel prepared by the Mond company is now being used in the manufacture of armor plates for the British Government, so that the former prejudice in the Old Country against Sudbury nickel has been overcome.

The importance of nickel steel to the Province of Ontario as an outlet for its nickel was early recognized by the Bureau of Mines, and papers on the subject may be found in the volumes for 1893 and 1894[99]; showing its value for various purposes, especially in the manufacture of armor plate.

98 Proc. Am. Soc. for Testing Materials, Vol. III, 1903, pp. 141 and 2.
99 1893, pp. 147-163; 1904, pp. 182-198.

Since that time almost all navies have been clothed in nickel steel armor, and there have been many applications of the alloy to other purposes, such as the bicycle manufacture, the making of shafts for steamships and the making of steel rails on curved parts of railways where there is heavy traffic causing great wear. No doubt the great improvement in the strength, elasticity, etc., of steel imparted by 2 to 4 per cent. of nickel would have caused its use on the large scale in structural steel if the cost of the metal had been lower. Further instances of new uses for this alloy will be found in Mr. Colby's paper[100] and in Dr. Barlow's report.[101]

Henry Ranger, Sudbury, a well-known prospector of the nickel field.

APPENDIX:

Nickel and Nickel Steel

Although much has been written on nickel steel, the subject is of sufficient importance to Ontario to warrant taking it up here, particularly as some new documents in the history of the subject have been secured, through the kindness of Mr. S. J. Ritchie, of Akron, Ohio. Mr. Ritchie was specially interested in the development of our nickel deposits as one of the early owners of nickel properties in Ontario, and was

S. J. Ritchie, Akron, Ohio, a pioneer in developing the Sudbury nickel field.

instrumental in drawing the attention of the Navy Department of Washington to the value of nickel steel in armor plates. He has been good enough to provide copies of the correspondence on the subject, part of which is here reproduced. The work of John Gamgee in applying nickel-iron or steel has apparently been somewhat overlooked. It will be observed that his idea of using it was derived from the properties of the nickel-iron meteorites. The report of Sir Charles Tupper, then High Commissioner for Canada in London, is of special interest. Mr. Ritchie's communication dealing with the origin and early history of the nickel industry in Ontario and Gamgee's experiments at the Washington Navy yard is as follows:

[100] Am. Soc. for Testing Materials, Vol. III, pp. 163 and 165. [101] G. S. C., 1904, Part H, pp. 227-8.

Nickel and Yellow Fever

"The discovery of nickel and the origin of the nickel industry in the Sudbury district is in itself quite unique. My first knowledge of nickel, as an alloy with iron or steel, was in 1876. In that year, I think, yellow fever was epidemic in the cities of the lower Mississippi and Gulf states. It is well known that the germs of this disease are killed by frost. At the date named, I was spending a good deal of time in the city of Washington. At the same hotel, and occupying the room adjoining my own, was one of the most fertile-brained Englishmen I ever met, whose name was John Gamgee. He spent much of his time in my room. He was resourceful in experiment and demonstration, but his imagination went far beyond his laboratory tests. He had remedies for tuberculosis in animals and for yellow fever among human beings. His remedy for yellow fever was the building of a large refrigerator ship on which a frost temperature was to be maintained. This ship he proposed to move around to the different cities where the fever existed, and to take the patients on board where they were to be cured by the frosty atmosphere.

'He laid his plans before the United States Senate Committee on Epidemic Diseases, and convinced that Committee of the feasibility of his enterprise. He asked me to go with him to that Committee, several of the members of which I was very well acquainted with, and aid him in securing a government appropriation for the building of his refrigerator ship.

"I did succeed in getting a promise from the Committee that an appropriation of $250,000 would be given to Gamgee, provided he could actually demonstrate to the committee that he could successfully produce and maintain the proper temperature, and for the purpose of making the necessary experiments and demonstrations a large room and all the necessary machinery was placed at his disposal in the Navy Yard at Washington.

"He erected a large machine in the Navy Yard buildings built by the Wilmington Car Works of Delaware. It must be remembered that all this was 28 years ago, when cold storage was not so well known as now.

"Of course Gamgee had to use liquid ammonia in producing his frosty temperature, and this substance, as is well known, will generate gas at a temperature much below the zero point. Gamgee conceived the Utopian idea that he would drive his machine with the gas generated from his liquid ammonia by the heat of the atmosphere, and that the gas would part with its heat in the labor of operating the machine and after having done its work would become reliquefied and be ready again by the aid of the heat in the atmosphere to generate more gas, and again start upon a second round of effort the same as the first. In other words he was within one step of perpetual motion, the lacking step being the wearing out of the machine.

"Numerous members of the Senate and engineers of the army were on hand to see Gamgee's ammonia engine operated. Right here Gamgee struck a snag. He was able to generate so great a pressure from the ammonia gas that the ordinary cast iron would not contain it, and he set about making all sorts of alloys to strengthen the iron and to overcome its porosity. They all failed. The object of the enterprise and the whole manner of conducting the experiments were so novel to me that I spent several weeks with Gamgee helping him in any way I could. After a series of experimental failures he one day said to me, 'Ritchie, did you ever notice the meteorites at the Smithsonian Institution? I want you to go with me and see them.' I told him that I had many times seen them and knew just how they looked. He said, 'Well, we have no metallic iron on earth produced by nature in that form, and these meteors have all fallen from the skies, or have come from some other world. They nearly all contain nickel and are the closest grained metal we have. To-morrow we will send over to Philadelphia and get some nickel and we will try this metal as an alloy with iron, and see if we can imitate nature in duplicating the meteorite, as we are trying to imitate nature in the production of artificial cold for the yellow fever patients.'

"We did send over and get some nickel and at once commenced our experiments by adding one-half of one per cent. of nickel to the molten iron in the crucible, and increasing each separate mixture by an additional one-half of one per cent. of nickel, until a limit of thirty-six per cent. of nickel as an alloy with the iron had been reached. We thus had some seventy-two separate pieces of iron and nickel alloys all carefully marked. When an alloy containing some eight per cent. of nickel had been made we tested it, as we really did all the other specimens, but I particularly recall that containing eight per cent. of nickel. It was so hard that neither the file nor the cold chisel would affect it. We put it upon the anvil, and with a ten-pound sledge I expected to be able to break it into pieces, but although I then had seventy-five pounds less flesh than I now have, and several times as much muscle, I could not even mark the alloy with the heaviest blow I could strike with this ten-pound sledge, not to talk about breaking it. After we had made many tests with the several different percentages of the alloys, Gamgee threw up his hands and shouted, 'Eureka! I have found at last an alloy strong enough and hard enough to resist anything and close enough in texture to resist the escape of any form of gas.' The members of the Senate committee were again brought back to the Navy Yard to see these specimens of nickel alloy. The way now seemed clear for Gamgee to secure his promised $250,000 and to proceed with the building of his refrigerator ship which would be used as a hospital ship for the cure of yellow fever patients.

"Gamgee, like most abnormally developed geniuses, had no place in his make-up for such humdrum routine efforts as financial operations. In short, he had no other financial abilty than the abilty to get into debt without any ability to get out of debt, He never even took out any patents upon these alloys of nickel and iron and steel. He failed to agree with the Senate committee on the cost and management of his proposed ship, and thus failed to secure the $250,000 appropriation. In the language of diplomacy, the incident was closed, and I lost sight of Gamgee, and all the interesting experiments and experience passed out of my mind.

"All this was seven years before I had ever seen Canada.

Opening the Sudbury Field

"In 1882 I became interested in building the Central Ontario Railway to open up and develop the iron fields of North Hastings. When the road was built it was found that these iron ores contained so much sulphur as to be unmarketable, and I commenced a systematic search for other mineral deposits, which, under the terms of the charter of the railway, the railway could own and operate and by such conveyance of property I might support and protect the securities of the railway.

"In this effort to secure something for the railway I had a considerable search of the country made by the local inhabitants and others from Nova Scotia to Port Arthur. I went to the Geological Museum at Ottawa and examined specimens of every kind of ores from every part of the country. Among the many specimens examined at this museum I found some copper ores taken from a cut in the Algoma Branch of the Canadian Pacific Railway at what is now Worthington Station, and other specimens taken from a cut in the main line of the Canadian Pacific Railway at what is now known as the Murray mine, about three miles west of Sudbury. These samples I had analyzed and found them very rich in copper.

"I at once proceeded to have these deposits located. While so doing I found that W. B. McAllister and J. H. Metcalf of Pembroke, Ontario, had located and taken up a number of these deposits in this Sudbury mineral belt. Among these was what is known as the Copper Cliff mine, the Stobie mine, the Lady Macdonald mine, the McArthur mine and the Creighton mine, the latter not at that time yet deeded to them, and several other deposits not named. With the exception of a small mine, known as the Evans mine, and a little ore taken from what is known as the Frood mine, which I purchased shortly after the purchase made from McAllister and Metcalf, these mines thus purchased from McAllister and Metcalf in the summer of 1885 have furnished all the ore mined by the Canadian Copper Company from 1886 to this day, and are still their sole source of supply.

"Immediately after the purchase of these mines, or rather deposits, from McAllister and Metcalf, in 1885, and some other properties from individuals, in 1886, including some purchased from Rinaldo McConnell, James Stobie and R. J. Tough, I made application to the Ontario Government, through J. D. Evans, the engineer of the Central Ontario Railway, for large additional locations. Under this application Mr. Evans located 97,000 acres; however, those who were afterwards associated with me did not agree with me in keeping this area of land, but wished it to lapse, which it was allowed to do.

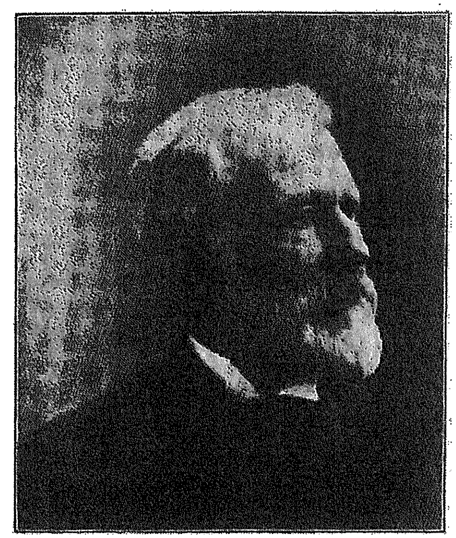
"In January 1886, I organised at Cleveland, Ohio, under Ohio charters, two corporations, one known as the Canadian Copper Company with a capital of $2,000,000, later increased to $2,500,000, and the other known as the Anglo-American Iron Company with a capital of $5,000,000.

"To the Canadian Copper Company my wife and self deeded the lands purchased from McAllister and Metcalf, Rinaldo McConnell and others, and to the Anglo American Iron Company the late James McLaren, the late H. B. Payne of Cleveland and my wife and self deeded the 85,000 acres of land along the line of the Central Ontario Railway, and for the opening up and development of which the Central Ontario Railway was built. The interest of the late William Coe of Madoc in these Hastings county lands was conveyed to the Anglo-American Iron Company at a little later date.

Discovering the Nickel

"In 1886 some work was done upon the property of the Canadian Copper Company at Copper Cliff, and in 1887 a shipment of some 1,200 tons of this ore was made to the works of the Orford Copper Company at Constable Hook, New Jersey, in the harbor of New York. While the chemist of the Orford Company was making his analysis of the product of the furnaces from these ores he found a metal with which he was not familiar, and after numerous tests he found this substance to be nickel I happened to be in the laboratory when this discovery was made. Robert M. Thompson, the president and owner of these works, was also there. The discovery of this nickel in these ores by the chemist of the Orford Copper Company was alike unexpected news to both Thompson and myself. We had no suspicion that they were anything but copper ores. This discovery changed the whole situation. We found we had a great nickel deposit, instead of a great copper deposit, or, to be more correct, we had a great nickel and copper deposit. As the world's annual consumption of nickel was then only about 1,000 tons, the question was what was to be done with all the nickel which these deposits could produce I at once recalled the experience I had with John Gamgee at the Navy Yard at Washington, ten years previous to this time, and it occurred to me that nickel could be used with success in the manufacture of guns and for many other purposes as an alloy with iron and steel. I wrote to the famous gun maker, Krupp, at Essen, Germany, telling him of the Washington experiments, and asking him about his use of it in the guns which he made. I received an answer from him through his New York agents treating the matter lightly, and refusing to believe that there was any sufficient quantity of nickel in the world to warrant experiments looking to any extended use of the metal. The question of these alloys was, however, brought by Krupp, or someone representing him, to the attention of the Iron and Steel Institute of Great Britain, and that Institute appointed one of its members, James Riley, the manager of the Steel Company of Glasgow, to conduct a series of experiments with this alloy, and report at the next meeting of the Institute. This he did with great care and exactness, and embodied his experiments in a report dated in May, 1889. This report I showed to General Tracy, then Secretary of the United States Navy, in the summer of 1889, just as I was leaving for Europe. He read

the report and grasped its far reaching importance within an hour or two after receiving it, and said that the Navy Department wished to send an expert representative of the Government with me to any and to all places which I might visit in Europe in the interest of this nickel-steel alloy.[102] As I was going to Europe for that purpose, Lieutenant B. H. Buckingham of the U. S. Navy, then connected with the office of the U. S. Ambassador at London, was appointed to accompany us wherever we might go in Europe in this interest. Sir Charles Tupper, then the Canadian High Commissioner in London, was also designated by Sir John A. Macdonald to accompany us in the interest of Canada in this enterprise to find out whatever might be learned in Europe about the uses and the alloys of nickel with steel. Sir Charles Tupper and Lieutenant B. H. Buckingham of the U. S. Navy did go with us to visit the works of Krupp in Germany and the principal establishments of Great Britain and France, and the famous Rio Tinto mines of Spain. Sir Charles made a report to Sir John A. Macdonald, and Lieutenant Buckingham made a report to the Secretary of the United States Navy of what we had been able to see and find out. We spent two days in the works of Krupp at Essen, and were shown every possible courtesy. Upon our return Secretary Tracy



Genl. B. F. Tracy, who introduced nickel-steel armor plate into the United States Navy.

ordered a nickel-steel armor plate made at the famous Creusot works in France, and also a plain steel plate made at the same works, and a plain steel plate made at the works of Cammel & Company at Sheffield, England, such as was then used on British vessels of war. These plates were brought to the Government proving grounds at Annapolis, Maryland, and set up side by side and fired at, at short range, by eight-inch guns.

"The victory of the French nickel-steel plate was so complete over both the French and English plain steel plates that the trial and tests were heralded by telegraph and cables all over the civilized world.

102 A synopsis of Mr. Riley's paper entitled "Alloys of Nickel and Steel," was published in the Report of the Royal Commission on the Mineral Resources of Ontario (1890), pp. 383-387.

"Tracy, by this Government test, sent all the common steel armor plates to the junk heap, and completely revolutionized the offensive and defensive efficiency of the navies of the world. Scarcely had the sound of the guns at Annapolis died away before Congress in an hour, at the request of the Secretary of the Navy, General Tracy, voted an appropriation of $1,000,000 to purchase nickel matte at Sudbury to be used in the manufacture of nickel-steel armor plate for the U. S. Navy. This million dollar appropriation by the U. S. Government and the use of nickel in steel advertised the Sudbury mines over all the commercial world. It saved the Canadian Copper Company from the expense of making any tests of nickel alloys, for they were all made by the Government. In short, the Government's action through the Secretary of the Navy put a new enterprise upon its feet. The Government changed the then existing contracts with the Bethlehem Steel Company from plain steel plates to nickel-steel plates. It entered into contracts with the Carnegie Steel Company for the manufacture of nickel-steel plates under which contracts millions of dollars were expended in building the famous Homestead works. The small experiments in the Washington Navy Yard in 1876 have grown to the proportions of covering every first-class war ship in the navies of the world.

The International Nickel Company

"On December 7th, 1901, an optional contract was entered into between four of the directors of the Canadian Copper Company and the Anglo-American Iron Company and Robert M. Thompson on behalf of himself and associates, the associates being Captain DeLamar, E. C. Converse and Charles M. Schwab, under which contract the directors of the Copper and Iron Co's undertook to sell, and Thompson and his associates undertook to buy, a controlling interest in the stocks of these two companies. It was a part of this contract, that Thompson and his associates should form a company under the laws of New Jersey to be known as the International Nickel Company, and that this company should receive from the purchasing syndicate the stocks of the Canadian Copper Company and the Anglo-American Iron Company purchased under this optional contract of Dec. 7, 1901, which optional contract was accepted by Thompson and his associates on February 28, 1902. The stocks of these corporations turned over by the purchasing syndicate were deposited with the New York Security and Trust Company as a basis for the issuance of the bonds of the International Nickel Company. I should perhaps have said that in carrying out this contract of Dec. 7, 1901, the International Nickel Company, under a New Jersey charter, was organised under date of April 1st 1902, with a share capital of $24,000,000, and a bonding privilege of $12,000,000.

"A mortgage was executed by the International Company under date of April 1st, 1902, securing the bonds of the company upon the stocks of the constituent companies deposited with the New York Security and Trust Company, who were the trustees for the bondholders of the International Company. The Nickel Syndicate also purchased the stocks of the Nickel Corporation of London, a New Caledonia concern, and one of Whitaker Wright's enterprises, and also the stock of another small French company, known as the Societe Minière Caledonienne. The aggregate of all the stocks, Canadian and New Caledonian, with the stocks of the Orford Copper Company, and the stock of Joseph Wharton's small plant at Camden, near Philadelphia, amounting to about $10,000,000, were deposited with the New York Security & Trust Company, and $10,300,000 of the authorized $12,000,000 of bonds and $18,000,000 of the authorized $24,000,000 of stock of the International Nickel Company were issued against these stocks thus deposited with the Trust Company. The stocks of all the constituent companies belong to the International Nickel Company. The New Caledonia companies are not and have not been operated by the International Nickel Company. No report is made of them in the reports of that Company.

The Canadian Copper Company now owns some 16,000 acres of land and the Anglo-American Iron Co. some 85,000 acres. The International Company operates in Canada wholly through the constituent companies.

"Neither Gamgee nor any other man invented nickel-steel. It is a discovery, not an invention, and it is probably the only instance in this world where any form of manufacture is carried on after a formula coming from the heavens or some other world other than our own.

"There is a very beautiful specimen of nickel-iron meteorite in the Geological Museum at Ottawa, weighing about 400 lbs. It contains something over six per cent. of nickel, and was found on a farm in Hastings county, and for years was used by some untidy farmer to hold his barn-door closed. It never occurred to this farmer that this lump of metal was a manufacture of the skies. I have several times offered $500 for this meteorite, but of course the Museum would not sell it. Perhaps I ought to add that as soon as Riley's report had been read by Secretary Tracy in 1889 and I had given him a report of the experiments at the Navy Yard in 1876, he put the whole machinery of the Department at work over the United States and Europe to find Gamgee. I, myself, while in Europe, had the directories of all the principal cities of Great Britain examined, but neither the Navy Department nor myself could find him. About a year later I was in the second-hand bookstore at Washington, owned by H. W. Lowdermilk, a place where Gamgee formerly spent much time, and I told the proprietor of the efforts of the Navy Department and myself to find Gamgee, and that we had concluded that he must be dead. He said he was not dead, and gave me his address in London which was within half a block of the office of the Canadian High Commissioner. I then wrote to him and received two or three letters from him. He was still in the field of invention, experiment and discovery. If there had been earlier laboratory tests or experiments with nickel and steel than those of the Washington Navy Yard in 1876, neither Gamgee nor myself knew anything about them. We followed the meteorite and there is not the shadow of a doubt that the reconstruction of the American navy, clad with nickel-steel armor plates, was the direct result of these Washington Navy Yard experiments following the formula of the meteorite, although the experiments were farther carried out by the Iron and Steel Institute of Great Britain under the direction of James Riley ten or twelve years later. Gamgee is now dead, but General Tracy is alive and well, and I have no doubt would fully confirm every statement here made.

"Whatever might have been the ultimate development and outcome of the Sudbury nickel-copper deposits in other hands, and by other parties, one thing is very certain, that had it not been for the development of sulphur in the Hastings county iron ores, which made them unsaleable, thus depriving the Central Ontario Railway of the principal tonnage which it was built to carry, there never would have been any Canadian Copper Company or any Anglo-American Iron Company, or any International Nickel Company, and as the Washington Navy Yard experiments with nickel, iron and steel following the formula of the meteorite had already passed out of mind before the discovery of nickel in the Sudbury ores, there would, in all human probability, have to-day been no nickel-steel clad American navy, and this would mean that there would have been no nickel-steel clad navy in the world. From the sulphur in iron ores in Hastings county, Ontario, aided by the composition of the meteorite, has grown all the nickel and nickel-steel industry of this hemisphere as well as very much of like industries in the old world."

Mr. Gamgee's Recollections

A letter from Mr. Gamgee to Mr. Ritchie in reply to a communication from the latter gives some further details regarding the early experiments carried on in the Navy Yard at Washington. It is dated London, March, 1893:

"S. J. Ritchie, Esq., Dear Sir: I have to thank you for your kind letter of the 28th of February, which duly reached me this morning. I have, of course, noticed with interest the progress made in utilizing the iron and nickel alloy.

"The difficulties we encountered in the castings for the ammonia engines and pumps at the Washington Navy Yard, in spite of the skilled workmen in the foundry, led to various devices to overcome the porosity of the metal, and one day I was much surprised at seeing pure tin run into some large blow holes. The loss incurred from having to discard cylinders on which much work had been expended suggested to me that some more rational and scientific method of providing a sound metal should be attempted. Suddenly the compactness and solidity of meteoric iron struck me, and I determined on trying very small proportions of nickel, beginning with one per cent. up to three per cent. Large quantities rendered the metal too hard for the tools, and we resorted to the process of annealing, in some cases. With the advantage of testing machines of the Navy Yard we soon determined that we could double the tensile strength of the best cast iron, and perhaps you know how how we had to secure uniformity of the alloy. We attempted to melt the nickel in lumps in the melted iron as it ran from the cupola, and the resultant casting was of unequaled hardness, tools being broken when striking against a knob of the nickel that had not been melted. We therefore first melted the nickel in a crucible and I shall never forget the effect as seen in our first trial of dropping the small proportion of melted nickel into the ladle. The surface of the melted mass became covered with particles of dirt or dross, which was skimmed off, leaving a perfectly pure mass, which we ran into moulds, and yielded castings that readily resisted, on testing, very heavy hydraulic pressure. I regret that I had no opportunity of introducing the metal for other purposes, but the experiments were so public and excited so much interest in the Navy Yard that I am not altogether surprised to find that at least some one turns up to give me credit for the suggestion.

"We rolled some plates, and many experiments were made with various quantities of nickel to obtain a metal that would not rust. I regret that I lost my original notes, but it is somewhat strange that the fact of the first experiments having been conducted by me in the Washington Navy Yard has never before been noticed, as there should be records by the officers who had charge of the Ordnance Department and testing machines.

"I have used the metal from time to time since, and one firm of ammonia machine makers in America have continued to make nickel-iron castings since I first introduced them in my methods in 1880. I am now deeply engaged with the final results of 15 years' labor in reaching the automatic condensation of all vapors. By this means I can run ice machines without using condensing water, and dispensing almost entirely with fuel. I am building a low temperature engine which will demonstrate the soundness of the views I entertained in the days when you remember me working in the States, and which were derided except by that most able of chief engineers, Mr. Isherwood, and a few other choice spirits. I am running steam engines working steam at 212° Fahrenheit, as stated in the circular, and I would give almost anything for more help and intelligent co-operation in the States and Canada. I sadly need help. My experiments have been costly and protracted, and whilst there is abundant ground for hope now at a good turn in affairs, yet I can assure that it is not easy to overcome the prejudices of the engineers anywhere. Might I ask in what position you are in the Navy Yard, and how you came to know so much of my wandering? I shall be glad to hear from you again at your earliest convenience, and remain, yours faithfully, JOHN GAMGEE."

"[NOTE.—The Gamgee experiments at the Navy Yard were not carried on under any inspection or oversight on the part of the government, and therefore the Navy Department kept no records of them, as the superintendent of the yard informed me, when I went to hunt up the records of these experiments and tests, in 1887.—S. J. R."]

Sir Charles Tupper's Report

The report of Sir Charles Tupper, referred to by Mr. Ritchie, giving the results of his investigations into the use of and probable demand for nickel in Great Britain and continental Europe, is interesting enough to warrant its being published in full. Sir John A. Macdonald's letter introducing Mr. Ritchie, which is also given, shows

that even at this early stage he recognized the importance both to Canada and the empire at large of the Sudbury nickel deposits. Unfortunately his hopes of interesting the Imperial authorities in the matter were not destined to be realized. Sir John's letter to Sir Charles is dated 11th July 1889:

"MY DEAR SIR CHARLES TUPPER: Our friend S. J. Ritchie, of Akron, Ohio, whom you know, is about to proceed to England for the purpose of calling the attention of the British public to our mineral wealth in Canada. He desires especially to submit to Her Majesty's Government the important fact that in Canada, especially in the region of Sudbury, is the largest deposit of nickel in the world. This metal is wanted particularly as an alloy to make an important gun metal, and its extended use will be of great advantage to the Dominion. Will you kindly put Mr. Ritchie in communication with the Secretary, both of the Army and Navy, as well as, if necessary, with Lord Salisbury. It is said that the use of nickel will tend to revolutionize the art of gun-making, and that experiments, both in England and Germany have proved this to be the fact, so you see the importance of the matter. I hope you will give Mr. Ritchie all the aid and countenance in your power. Believe me, yours very truly, JOHN A. MACDONALD."

Following is Sir Charles' report, dated London, November 1889:

"TO SIR JOHN A. MACDONALD, PREMIER, OTTAWA. My Dear Sir: On the 20th of August last Mr. S. J. Ritchie brought a letter from you to me requesting me to aid him in bringing to the notice of the British War and Navy officers the importance of the recent discovery in metallurgy consisting of an alloy of nickel and steel said to have very valuable properties for the manufacture of guns and armor-plates for warships. He also had letters from the Secretary of the Navy at Washington addressed to the American Minister here requesting his good offices in the same direction. He likewise had letters from the Commodore of the United States Navy directing the naval attache of the American legation here to accompany him to all places he might visit in Europe and to investigate the progress and results thus far obtained from the use of this metal. He asked me to accompany him and to see for myself the importance not only of this metal but of the whole iron, steel, copper and nickel interests, and to see the mines and the ores from which they are manufactured, as he said they would visit the largest mines and manufactures of the world.

"In compliance with this request I left London on the 24th of August in company with Mr. Cornell, Mr. Oviatt, Mr. Ritchie and Captain Buckingham, the representative of the United States Navy. We proceeded to Paris, which is the headquarters of the New Caledonia Nickel Company. This company has up to the present time produced nearly all the nickel consumed in the market of the world, and of course has entirely regulated the market for this article. The Society, as it is called in France, is known as 'Le Nickel.' It is a corporation with $12,500,000 capital. They employ 1,450 men, they reduce the ores upon the ground to a matte. They are then shipped to Havre in France, to Birmingham in England, to Glasgow in Scotland, and to Iserlohn in Westphalia, Germany, at each of which places the company have refining furnaces for the treatment of these mattes and converting them into fine nickel. The ores contain no other valuable mineral than nickel. The company produce cobalt, but this is principally obtained from ores containing but little nickel, the ores are not easily reduced or refined, and it is said that the cost of producing fine nickel to them is forty cents per pound. We called upon this company at their office in Paris and found them quite unwilling to believe that there were any nickel deposits in the world outside of their own of any importance. They, however, wanted the Canadian Copper Company to agree to let them have the control of their entire product. These mines belong almost wholly to the Rothschilds. A Frenchman of the name of H. Marbeau is the patentee of the alloy known as ferro-nickel. It is a composition varying from one to twenty per cent. of nickel with steel or iron; usually about three per cent. of nickel is used.

"A company has been formed in Paris under the name of the 'Ferro-Nickel Company' for the manufacture of this material. The patentee Marbeau is its president. The real owners are probably the Creusot works located at Creusot in France, and owned by Schneider & Company. This establishment is to France what Krupp is to Germany. They are a great establishment, employing over 15,000 men. We also called upon the Ferro-Nickel Society at their office and saw their product at their salesrooms. We found the president enthusiastic over his discovery, and the wonderful results he has been able to produce. He was much elated over the discovery of a new and large body of nickeliferous ore and pressed the members of the Canadian Copper Company who were there, in the strongest possible manner, to give their company sole control of their product; said that they could use it to any extent to which it might be produced as an alloy with steel. The Canadian Company, however, declined in either case to make any contracts with either the Nickel or Ferro-Nickel Companies.

"From Paris we went to Hamburg in Germany to which point the Sudbury Company had shipped some of their product. Parties from Vienna, who are largely engaged in the manufacture of nickel came to this place to meet us in connection with the Hamburg people. They wanted to contract with the Sudbury people for a period of ten years for the delivery of a large amount each year. They offered to buy the matte as now produced at Sudbury and to erect refining works at Hamburg for the refining of the nickel and copper contained in them. They pressed the matter very earnestly. These people own the largest manufactory of German silver-ware there is in Europe, their works are located at Berndorf. Both the Hamburg and Vienna people offered to send a Mr. Krupp, who is one of their firm, and a nephew of the great gun-maker, to see the property, and learn if some arrangements could not be made by which they could become identified in the ownership of these properties. It is likely this visit will be made in the spring.

"From Hamburg we all went to Berlin. The nickel works at that place were a small affair and we saw little of their working owing to the secrecy which is everywhere observed in the refining of this metal.

"From Berlin we went to Essen where are located the great works of Friedrich Krupp. These are the largest iron works in the world and are under the sole control and ownership of one man—Friedrich Krupp. These works were started by his father, who died a year or two ago, in a very small way with only three or four men. The present owner now employs in the various departments of his great works, and in the coal and iron mines connected with them, 22,000 men, and one of the superintendents of the works informed us that these employees represented a population of more than 106,000 persons. He remarked that they were very rich in children. These works are not only the largest gun manufactory in the world, but are also extensive manufacturers of steel rails, steel tires for locomotives and car wheels; the best wheels used by the Canadian Pacific Railway and by the Pullman Company are made here. It would cover many pages to describe these great works. They are generally regarded as very difficult of access. In fact, very few people are able to get inside the works at all. We, however, found no trouble. Two superintendents of different parts of the works met us at the hotel and gave up two days showing us over as much of the great plant as we were able to travel in that time. The managers were somewhat reserved as to the manner in which they cast the great steel ingots from which the heavy cannons were made. In everything else they were quite willing to answer every question asked of them.

"From Essen I returned to London and the other members of the party after visiting other points returned to Paris and after a few days returned again to London. We then called upon the firm of Tennant & Sons, to whom the Sudbury people had been making shipments of matte. Sir Charles Tennant is president of the Steel Works of Scotland, of which Mr. James Riley is manager. He is the man who made the report

and the experiments with nickel and steel herewith enclosed. This firm told us they were ready to at once convert their steel works into a ferro-nickel plant if they could only obtain a supply of nickel, and were very anxious to obtain sole control of the output of the Sudbury mines. They said they had an order for 4,000 tons of ferro-nickel plates for a transatlantic steamship, but had no nickel with which to make them. This is the trouble with all these works, there is no nickel on the market to use in this alloy. Formerly the use of nickel has been very limited, the consumption of the world being only about one thousand tons per annum, nearly all of which has been used in the manufacture of German silver and coins, the new use in alloys makes

James Riley, Glasgow, Scotland, whose paper on Alloys of Nickel and Steel, read in May, 1889, before the Iron and Steel Institute of Great Britain, marked the beginning of the modern use of nickel as a constituent of high-class steel.

a great demand and finds the market without any supply. We were told in Paris that not ten tons of this metal could be had in the whole of Europe.

"Outside of Sudbury there is not at present produced more than 1,200 or 1,400 tons of nickel in the world and the French Government is using fully one-third of that amount in the manufacture of cartridge shells. If the Sudbury Company extend their works as purposed they will be producing ten times as much nickel as the other mines in the world. The utility of this alloy seems everywhere to be fully conceded and nothing seems to remain to bring it into important use but a sufficient supply of the material.

"From London we went to Swansea, which is the great copper, gold, silver and nickel smelting and refining centre of Europe. We stopped with Sir Hussy Vivian, who is the largest smelter in England and employs 3,000 men. He is treating a large amount of the Sudbury mattes and is so much pleased with them that he has purchased what is known as the Murray mine located upon the line of the Canadian Pacific Railway about three miles west of Sudbury, and is putting up a furnace at the mine to smelt the ores and ship the matte to his works at Swansea to be refined. He expressed the highest opinion of these properties and a desire to be connected with them.

"Coming back from London we called at the office of the Rio Tinto Copper Mines. These mines are located on the southern coast of Spain about 30 miles in a direct line from the town of Huelva. The directors of this company invited us to go and visit them and we did so. These are the largest copper mines in Europe. They have been worked more or less for two thousand years, successively by Phoenicians, Romans, Goths, Huns, Moors and Spaniards, and now by an English company. They are very large deposits of low grade ore averaging only 2½ per cent. copper. We were very kindly entertained by the company upon our arrival and were shown their whole process. They mine about one and a half millions of tons per annum. Part of this is shipped to the sulphuric acid makers in England, Scotland and the United States, and the balance is either reduced to matte by smelting in the furnace upon the ground and the mattes sent to the company's refining furnaces near Swansea, or the copper is leached out of the ore after first being roasted and then precipitated upon iron. The company employ at the mine and at the refining works 12,000 men. They have a share and a bonded capital of $35,000,000, and in 1888 they paid a dividend of 17 per cent. upon their stock. Any description of the great establishments and mines visited beyond the mere outline given would exceed the limits of a report.

"From all the data we could obtain I was convinced that Sudbury could compete with any place in the world in the production of copper and that it could produce nickel for about one-half the price at which the French company could produce it. The best evidence I could obtain of the real importance of the Sudbury mines was the manifest desire both in England and upon the continent of the largest smelters, and consumers of both copper and nickel to become the owners of the mines or to control their output. Mr. Ritchie has furnished me with the most minute details of the expense of producing their material, and by comparing these figures with those published by the larger companies in Europe, I cannot escape the conclusion that this enterprise is one of the most important in Canada. Taking the three companies together I believe there are only two others which are likely to exceed them in importance, and they are Canada's two principal railway systems.

"I intended that my report should stop here, but Mr. Ritchie asked me to go with him to Birmingham and Sheffield, and I did so. At Birmingham we called upon Messrs. Henry Wiggin & Co. They and Sir Hussey Vivian, of Swansea, are the two principal nickel refiners in England, outside of those owned by the French company. They expressed the strongest desire to become identified with the Sudbury company. They were the most frank and unreserved about the cost and manipulation of this metal in its refining processes of any people we had thus far met. They were also treating the Sudbury mattes while we were there. From Birmingham we went to Sheffield and visited the great crucible steel works of William Jessop & Sons. These works have been in operation for a hundred years and are probably the most famous for the high character of their steel of any works in the world. Their manager, M. J. F. Hall, has quietly for the last two years been experimenting with nickel as an alloy with steel, and has produced the most wonderful results. I was shown pieces of steel containing no more than five per cent. of nickel and only one inch square, which showed a tensile strength sufficient to lift and support two locomotives with their tenders. These are the most wonderful results ever obtained from steel in any form, so I am informed. A hundred pound gun is nearly completed by this firm for the British Government, and they told me they had orders for thousands of tons of this nickel steel but had no nickel with which to make it. The firm took much pains to show us everything connected with the process of producing this metal and answered unhesitatingly every question asked of them. Mr. Hall was not present when we were there but came to London the next day to see me, and he and Captain Buckingham, who represents the United States Navy, and Mr. Ritchie all met in my office. Mr. Hall brought the samples with him from which such wonderful results were obtained, and gave Captain Buckingham and myself the fullest information regarding all his processes and results. The Captain declared that the success of such experiments would revolutionize the whole art of gun-making and the manufacture of armor plates. Mr. Hall said their whole operations were at a stand-still for want of nickel; but he had orders for many thousands of tons of this steel and could do nothing with them for lack of the nickel; that he could furnish any amount both to the Government and to individuals.

"Such being the conditions of the market for this metal, and Canada owning the governing supply of the world, I have asked myself, 'Why cannot Canada herself make this steel?'

"There is not a doubt that the best people in England would readily join in the enterprise. In answering this question the item of fuel at once comes up, and I learn upon inquiry that Chicago has the largest steel and rail mills in the United States. She hauls all her coke with which she reduces her ores and melts her pig iron, from Connellsville in Pennsylvania, a distance of over 500 miles. She also hauls her ores to her mills and furnaces from the mines in Michigan, a distance of over 400 miles. Canada can obtain coke from Pennsylvania at a haul of not more than 400 miles to the ores of Hastings county. A steel works located in this neighborhood would have the ores immediately at the place where they would be reduced. Why then should not Canada utilize these iron ores and these nickel ores and make this ferro-nickel upon her own territory? Why should she not go farther and make this nickel-steel and this armor-plate upon her own territory? If the Government takes the proper action there is no doubt that the best skill and the strongest financial backing in England could be had to carry it on, and it really looks as if it were possible for Canada to control the character and efficiency of the guns and the navies of the world. I am led to say this much from the statements of every expert with whom I have talked.

"The condition of the iron market here is unusually favorable for enlisting the necessary capital for an enterprise of this kind. The curious state of affairs is now presented here of iron being higher in England than in the United States. I enclose you slips from the papers showing the conditon of the market. Everywhere I have been on the Continent the same condition of the trade is found. I cannot but feel that it is Canada's golden opportunity to move and produce her own iron and steel as well as nickel steel for other countries. (Sgd.) CHARLES TUPPER."

LONDON, November, 1889.

Cost of Producing Matte in 1889

For use while in Europe, Mr. Ritchie had armed himself with analyses of the Sudbury ore and figures showing the cost of producing matte, etc. Among the statements was one dated September 1889, from Mr. H. P. McIntosh, secretary of the Canadian Copper Company, which is of interest as showing the cost of converting the nickel ore into matte at that time. Mr. McIntosh's letter reads:

"S. J. RITCHIE, ESQ., Care Morton Rose & Co., London, Eng. Dear Sir: In compliance with your telegram of this morning we enclose herewith assay report as follows: Mr. Hoffman's reports of March 16th and Oct. 1st 1885; Prof. Chapman's of Sept. 24th 1885; Orford Copper Co's reports, Dec. 1st, 2nd and 5th 1885; Sperry's certs. Nos. 2, 3 and 4, October 28th, 1885, and Nos. 7, 8 and 9, Nov. 9th, 1885; and his certs. Nov. 12th 1887. showing results of silver assay, samples of fifteen cars shipped to Nickel's Laurel Hill Works and complete analysis of copper ore. I have preserved no copy of the foregoing, and as they are the only record of the same, kindly preserve or have copies made.

"I also enclose a copy of the report of the Orford shipment, also reports of monthly assays for the Copper Cliff, Evans and Stobie up to the last inst.

"The itemized cost of matte is as follows:

Mining per ton	$2.79
Transporting	.255
Crushing and loading	.386
Cost of ore per ton at the roast heap	$3.431
Roasting per ton	.17
Delivering from R. H. to smelter	.28
Smelting per ton	1.76
This includes all fuel, labor, etc.	
Cost of one ton of ore in matte	$5.641

"The above figures are based on reports from the 1st of last Feb. to the 1st of last month, that is, six months, during which time the average run of the furnace was 6.87 tons of ore into one ton of matte.

"Multiplying $5.641 by 6.87 equals $38.75 per ton of matte. This cost is based on the working of one furnace to which all the fixed charges of smelting are charged; and now that we have got the two furnaces going the cost will probably be reduced to at least $35 per ton, and a greater number of furnaces will reduce it still lower than this, for there many of the fixed charges that will not be increased by the increase of the number of the furnaces, therefore the proportion of these charged to each ton of matte will decrease as the number of furnaces increase.

"The above remarks will also apply to the cost of producing the ore, for this cost includes many items of construction which will have to be duplicated, and besides as the production increases the fixed charges will not, therefore the amount of these per ton will decrease. We have calculated all of our figures against ourselves so as to have our factor of safety sufficiently large. Very respectfully, H. P. McIntosh, Sec'y."

"Frt. rate on shipment just leaving for Swansea: $9.13 Sudbury to Swansea; $7.51 Sudbury to Liverpool."

Mr. McArthur's Estimate of Costs

The possiblity of utilising the ores of the northern nickel range has been considered by various parties ever since the range was brought to light, fifteen years ago, among others by Mr. Ritchie himself, who in 1903 carried on correspondence with Mr. James McArthur, formerly for many years general manager of the Canadian Copper Company, and superintendent of that company's works at Copper Cliff, on the probable cost of producing nickel-copper matte from the ore bodies of that range, based on his experience in the Sudbury region. Mr. Ritchie propounded a series of questions designed to cover the ground in a letter to Mr. McArthur dated 14th December, 1903, to which the latter made reply as follows:

"S. J. Ritchie, Esq., Dear Sir: I have carefully noted your favor of the 14th inst. with names, estimated extent of ore bodies, and analyses of the several properties therein mentioned, which taking the rough average of the 19 assays as shown, would give an average value 3.5 nickel and 1.5 copper. This is a better value than the Canadian Copper Co. could show if they bunched all their properties together for an average sampling and assaying, which would probably range round 2.5 nickel and 2.1 copper.

"Commencing with the mining costs, I herewith submit approximate cost for the mining and treatment of 600 tons ore per day, with a furnace concentration of seven into one, product 35 per cent. matte.

APPROXIMATE MINING COSTS

Men			
1	mine captain	$8 00	$ 8 00
200	miners, helpers, trammers, etc., average rate	1 80	360 00
20	rock house helpers, average rate	1 40	28 00
1	rock house foreman	2 00	2 00
1	clerk (time-keeper)	1 60	1 60
2	hoisting engineers	2 00	4 00
2	firemen	1 75	3 50
2	firemen helpers	1 40	2 80
229	men at an average rate	1 78	409 90
	or an average of 68 cents per ton of ore for labor.		
	Coal consumption, 15 tons at $5.50 (a high price)		82 50
	400 lbs. dynamite at 11c.		44 00
	Total cost for mining 600 tons ore		$536 40
	or total mining expense 89.4 cents per ton.		

MINING AND ROCK HOUSE PLANT

Estimated cost for an output of 600 tons daily.

1	rock house	$3,500 00	
1	crusher and engine	2,200 00	
2	mine skips	500 00	
12	mine machine drills	2,700 00	
12	mine hand cars one ton capacity	900 00	
1	mine blacksmith shop and tools	200 00	
1	boiler and compressor house	1,500 00	
3	100-h.p. boilers	9,000 00	
35,000	brick at $8.00 per M.	280 00	
	Mason work and mortar at $6.00 per M.	210 00	
1	compressor	4,000 00	
1	mine hoist	4,000 00	
15	log houses at $250.00 each	3,700 00	
1	log boarding house	2,000 00	
	Sundries, such as pumps, trunnels, sorting tables, wire ropes, etc.	2,000 00	
	Rough estimate for mining plant	$36,690 00	
	Carried mining costs		$536 40

ROAST YARD EXPENSE FOR ROASTING 600 TONS DAILY

Men			
32	at $1.40 unloading ore from cars, wheeling and building same on heaps for roasting		$44 80
7	at $1.40 laying out cordwood into the different beds and roasting the same		9 80
50	at $1.40 loading roasted ore on cars, blasting the same		70 00
1	foreman		2 00
90.	Labor item being 21c. per ton or		$126 60
	Roasting fuel for 600 tons ore, 15 cords wood at $2.00 per cord	$30 00	
	Blasting, 120 lbs. dynamite, 11c. per lb.	13 20	
			43 20

Fuel and dynamite being 7 1-5 cents per ton.	
Grand total for roasting, being 28 1-5 cents per ton, or in all	$169 80
Dwellings, 5 log houses at $250.00 each	1,250 00

COST OF SMELTING 600 TONS DAILY

Men		
4	feeders at $2.00	$ 8 00
18	charge wheelers, $1.75	31 50
18	pot wheelers, $1.75	31 50
2	toppers, $2.00	4 00
8	slag elevator men, $1.75	14 00
2	foremen, $2.25	4 50
4	inside laborers, $1.40	5 60
2	boiler firemen, $1.75	3 50
2	boiler firemen help, $1.50	3 00
2	engineers, $2.00	4 00
6	load, weigh and ship matte, $1.40	8 40
5	unloading foreign coke cars, $1.40	7 20
1	unloading foreign coal cars, $1.40	1 40
1	watchman	1 40
75.	Total smelting labor 21¼ cents per ton ore per day	128 00

FUEL COST

84 tons coke at $7.00 per ton	$588 00
17 tons coal at $5.50 per ton	93 50
Total cost of fuel per ton ore smelted $1.13, or daily	$681 50
Grand total for labor and fuel in smelting, $1.35 per ton ore	$809 50
Carried working costs:	
Mining	$536 40
Roasting	169 80
Smelting	809 50
	$1,515 70

Or total cost of all departments, being $2 55 per ton ore smelted.
Add for incidentals .... 20 " "

Giving a grand total of .... $2 75 " "

SMELTER MACHINERY

1	furnace building and bins	$5,000 00
1	600-ton furnace with equipments	10,000 00
1	No. 8 Connorsville blower	4,000 00
1	elevated water tank	1,600 00
1	granulating slag equipment	2,000 00
1	office and store house	300 00
1	laboratory	1,000 00
100,000	brick for chimney and dust chambers, at $8.00 per M.	800 00
	Mason and mortar work at $6.00 per M.	600 00

1	boiler blowing engine house	1,500 00
3	100-h.p. boilers	9,000 00
1	pump, 1,000 gallons capacity	2,000 00
10	log houses at $250.00 each	2,500 00
1	boarding house	2,000 00
	Approximate cost smelting plant	$41,300 00
	Approximate cost mining plant	36,690 00
	Approximate cost of total plant	$77,990 00

"For modern plant see J. P. Channing, 11 Broadway, New York, who arranged and built the Tennessee Smelter, Tenn. JAS. MCARTHUR."

The cost of labor and possibly also of machinery and supplies has advanced since the date of Mr. McArthur's estimate, for which due allowance would have to be made in applying his figures to conditions at the present time.

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